UNCLASSIFIED

PROGRESS REPORT NO. 11
PROJECT NO. 157-3596

CONTRACT NO. NOBAR 49063

31 MARCH 1952
PROGRESS REPORT NO. 11
PROJECT NO. 157-9546

CONTRACT NO. NOber 49063

31 MARCH 1952
ABSTRACT

Progress of work during February and March, 1952, under Contract NObsr 49063, on the problem of shipborne radar detection of targets in sea clutter is reviewed briefly.

Work during this period has consisted mainly of continued construction and testing of the component parts of an experimental radar system and data recording and analysis equipment.

I. INTRODUCTION

The ultimate objective of the program of research under Contract NOB 49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The overall contract program is divided into three phases as follows:

Phase 1: Theoretical and Analytical Phase

(a) Analysis and evaluation of existing data on radar echoes from the sea and from small and medium sized surface targets for small grazing angles of incidence.

(b) Investigation of the potentialities of new statistical methods of analysis as a means of discriminating between radar echoes from targets and the adjoining sea.

Phase 2: Experimental Phase

(a) Design of special devices for rapid shifts of polarization (horizontal to vertical to circular) in experimental studies of radar echoes.

(b) Experimental studies of radar echoes from the sea and from small-to-medium surface targets at frequencies of 6,300 mc and 35,000 mc.

(c) Analysis of the results of the measurements and establishment of differences between sea echoes and target echoes.

Phase 3: Developmental Phase

(a) Modification of existing surface search radar, or construction of breadboard equipment operating at 6,300 mc and 35,000 mc for the
detection and location of small and medium targets in sea return (Beaufort Scale 1 to 5 inclusive) at any range from 0.25 to 7.0 miles, without penalizing range and other performance characteristics of the radar from 0.25 to 20 miles.
II. BRIEF SUMMARY OF PROGRESS DURING FEBRUARY AND MARCH 1952

A. Theory and Planning

Technical Report No. 3, "Clutter Crosscorrelation in a Dual Frequency System", was submitted to the Contracting Officer during February.

A comparison study has been made of the properties of the correlation functions obtained when the system response is linear, square-law, and logarithmic. It was found that appreciable differences exist between the various correlation functions. It was concluded that a linear system is necessary.

A study is being made to determine the effect of adding a constant signal to the random signal (fixed target in sea echo) to determine if the effect of the added constant signal can be detected.

Work is continuing on the design of experiments to test the correlator and the specification of data collection and analysis procedures.

B. Equipment Design and Construction

Brief statements of progress made by the groups working on the correlator and analysis equipment, the microwave equipment, and the radar display and control equipment are presented in the following paragraphs.

1. Correlator and Analysis Equipment

During this period, final construction of some of the correlator units was started. The timer unit and the tape control unit were completed. Work has also continued on testing and modifying, in a minor way, the various breadboard units of the correlator.

Some progress has been made in the construction of the mechanical tape transport units. The transport unit is presently capable of pulling short loops of magnetic tape for the purpose of testing the recording head drive amplifiers and the playback amplifiers and clippers. Some experimental work was done on a tape bin, similar to one constructed
by the National Bureau of Standards, for handling long loops of tape.

Construction of the breadboard units of the W₁ unit was started during this period. Some photographic tests were made to determine methods of recording the pulse count displayed by this unit.

2. Microwave Components, Receivers, and Modulators

a. Microwave Components

The polarization transition has been redesigned so that tuning is not necessary in either arm. The isolation is greater than 40 db. The entire plumbing system has been fabricated with the exception of the signal generator outlets and the antenna systems. Final tests have not been conducted.

b. Signal Generator

The design and construction of the breadboard model of the 35,000 mc signal generator is approximately 50% complete. A breadboard model of the modulator unit of the signal generator has been tested.

c. Receivers

A prototype balanced mixer and adding amplifier, which is used between the mixer crystals and the IF chain, has been tested and operates satisfactorily. Twenty-two SKL chain amplifiers have been modified for use as IF amplifiers.

An AFC unit has been tested and is being redesigned for greater bandwidth and gain.

d. Modulator

Pulse forming networks for the 0.05 and 0.25 μsec pulses have been constructed. The 0.05 μsec network performs properly, but additional work is required to eliminate ripple on the pulse produced by the 0.25 μsec network. Design of a high-level pulse transformer for use in the modulator is progressing satisfactorily.
3. Radar Indicators and Controls

a. Displays

A prototype master display is about 90% complete and further work has been suspended until core material for the sweep transformer is received from Arnold Engineering Corp. The final model of the transmitted pulse monitor display has been constructed and tested.

b. Timer

This unit is being constructed on three separate chassis. One chassis is completed and is being tested. The other two chassis are approximately 80% complete. Upon completion and testing of all chassis, they will be integrated into a single timer assembly.

c. Sampler

The breadboard construction of this unit has been completed and tested. Design and layout of the final model has started.

C. Travel

Messrs. Boyd and Widerquist made a survey of the Florida East Coast between Miami and Palm Beach for the purpose of selecting a field site. This trip resulted in the location of a suitable site and negotiations are presently underway to lease this property.


Mr. Flynt attended a conference given by Franklin Institute on correlation theory and techniques and a symposium on MTI devices.
D. Personnel

The following individuals have been assigned to the activities of this project as indicated. Full time is indicated by FT while part time is PT.

**Electronics Group**

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Boland, C. E.</td>
<td>FT</td>
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<tr>
<td>Culbreth, L. F.</td>
<td>FT</td>
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<tr>
<td>Jones, C. E.</td>
<td>PT</td>
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<tr>
<td>Mauldin, H. W.</td>
<td>PT</td>
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<tr>
<td>Prince, M. D.</td>
<td>PT</td>
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<tr>
<td>Robertson, D. W.</td>
<td>PT</td>
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<tr>
<td>Tyson, A. L.</td>
<td>FT</td>
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<tr>
<td>Walsh, J. R.</td>
<td>FT</td>
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<tr>
<td></td>
<td>Technician</td>
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<td></td>
<td>Research Assistant</td>
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<td>Research Assistant</td>
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<td>Secretary</td>
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**Microwave Group**

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<tr>
<td>Butterworth, J. C.</td>
<td>PT</td>
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<tr>
<td>Harris, M. D.</td>
<td>PT</td>
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<td>Hollis, J. S.</td>
<td>PT</td>
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<tr>
<td>McClendon, L.</td>
<td>PT</td>
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<td>Schaufelberger, A. H.</td>
<td>PT</td>
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<td>Wren, A. W.</td>
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<td>Youngblood, R. P.</td>
<td>PT</td>
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<td>Research Assistant</td>
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<td></td>
<td>Administrative Assistant to R. E. Honer</td>
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<td></td>
<td>Research Engineer</td>
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<td>Secretary</td>
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<td>Research Assistant</td>
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Submitted:

J. E. Boyd
Project Director

Approved:

Gerald A. Roselot, Director
State Engineering Experiment Station
PROGRESS REPORT NO. 21
PROJECT NO. 157-96
BUSHIPS CONTRACT NO. NObsr-49063
SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER
1 DECEMBER 1953
ENGRG EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Ga.

PROGRESS REPORT NO. 21

PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NOber-49063

SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

1 DECEMBER 1953
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This Report Contains 2 Pages.
I. INTRODUCTION

The ultimate objective of the program of research under Contract NObsr-49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase, and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and is directed toward the objective of performing thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 mc and 35,000 mc. These experimental studies are to be concerned with both the statistical properties and the polarization properties of the radar echoes.

During this report period the project efforts were directed toward the completion of the present field operation, the initiation of a period of equipment modification and study to overcome equipment difficulties revealed during the field operation.

II. OPERATIONS

Data were recorded on 1 October for the purpose of obtaining information about the difficulties associated with the parts of the radar system involved in calibration operations.

On 5 October recordings were made of the echo from a fixed land target (cabbage palmetto) which produced a fluctuating echo. From visual observation of the radar displays, the echo from this target appeared to have a frequency spectrum considerably narrower than sea echo, that is, the upper frequency limit of the echo was much lower than sea echo. The recordings of this fixed echo were made simultaneously on both the correlator (at 30 inches per second) and the low-speed recorder (at 3 inches per second). This data will be used to compare the results obtained when data are recorded at a low speed and analyzed at a high speed with those obtained when the recording and analysis are at a high speed.

These two recording sessions concluded the program for this field operation. The equipment was prepared for shipment and transported to Atlanta.
on 20 October. The remainder of this report period was used in setting up the radar system and data analysis equipment at the Engineering Experiment Station so that modifications and further studies of the equipment could be made.

All the control circuits and part of the signal circuits of the 6,300-mc r-f unit, which is essentially complete, have received satisfactory operational checks. The 2-1/4 degree 6,300-mc antenna is the major item associated with this r-f unit which is incomplete.

III. PROGRAM FOR NEXT REPORT PERIOD

Work during the next report period will be directed toward the solution of specific equipment problems which were revealed during the field operation. No attempt at data reduction will be attempted until certain accuracy and stability difficulties in the analysis equipment are solved.

Respectfully submitted:

V. R. Widerquist
Project Director

Approved:

J. E. Boyd, Head
Physics Division

Herschel H. Cudd, Director
Engineering Experiment Station
PROGRESS REPORT NO. 22
PROJECT NO. 157-96
BUSHIPS CONTRACT NO. NOber-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 FEBRUARY 1954
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

PROGRESS REPORT NO. 22
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. N00014-69-0063

SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

1 FEBRUARY 1954
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This Report Contains 5 Pages
The ultimate objective of the program of research under Contract NObr-49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase, and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and is directed toward the objective of performing thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 mc and 35,000 mc. These experimental studies are to be concerned with both the statistical properties and the polarization properties of the radar echoes.

II. PROGRESS

The work during this period has been directed toward equipment modifications and improvement which were indicated as necessary by field experience. Details of the work performed on the various equipments are given below:

1. Correlator. Work on the correlator was concerned with improvements of the accuracy and stability of the various units. Minor modifications were made in the modulator units to reduce hum pickup. The demodulator unit was modified to reduce the output impedance. Tests were made on a chopper-stabilized d-c amplifier for use in reducing drift in the integrator. Design and preliminary tests were completed on a plug-in type of operational d-c amplifier for use throughout the system to replace the present amplifiers used for such operations as integration, multiplication, summing, level changing, and impedance changing.

2. Average-Value Recorder. The present commercial type of amplifiers in the average-value recorder has been found unsatisfactory because the necessary calibration procedure is too laborious and time-consuming. Preliminary studies were made in the design of an amplifier that would be more stable and more readily calibrated. This study was related to the development of the operational amplifiers mentioned.
previously, with a view toward the possible use of this same type of plug-
in amplifiers in the average-value recorder.

3. \( W_1 \) Machine. It was discovered that each of the intervals was
receiving a varying number of spurious counts, regardless of what the
interval count should have been. A slight modification of the camera
control circuit reduced these spurious counts to a negligible number.

The "internal signal" circuit was modified to have a much greater
stability, which allows the interval width and the interval overlap to
be more accurately adjusted.

A chi-squared test on twenty consecutive computations of the same
data by the \( W_1 \) machine indicated, at an extremely high level of con-
fidence, that the twenty distributions were not alike. A rather exhaust-
tive circuit check of the \( W_1 \) machine was instigated. Computations of
distributions of sine wave and sawtooth signals were made in an effort
to help locate the cause of the nonreproducibility. No reduction in this
factor has been obtained. Further tests will be made.

4. 35,000-Mc R-F Unit. Work on the 35,000-mc unit has been
directed towards eliminating certain difficulties encountered in the
past field test. Some of the difficulties encountered and the correc-
tive action taken are discussed in this section.

The adjustment of the phase shifters and attenuators in the polar-
ization equipment associated with the receivers was found to be too
course and to contain excessive backlash. These components, three
phase shifters and four attenuators, have been redesigned to use a
differential screw as the actuating mechanism. The new components have
been completed and seem to work very satisfactorily.

Considerable difficulty was encountered in adjusting the r-f sig-
nal generator to operate satisfactorily in both cw and pulsed condition.
This difficulty has been eliminated by incorporating direct coupling be-
tween the final pulse amplifier and the klystron repeller.

A unit consisting of a discriminator pulse amplifier, pulse
stretcher, and d-c amplifier has been constructed to provide an
indication at the console for AFC "lock in" during remote operation.

The local oscillator has been enclosed to reduce drift due to wind cooling when the front panel is off.

The signal-generator coupling block has been changed from 20 db to 10 db to increase the useful calibration range of the signal generator.

The phone circuit outlet has been relocated in a more convenient place.

5. 6,300-Mc R-F Unit. At the beginning of this report period the 6,300-mc unit was essentially completed and preliminary testing had begun. These tests have been continued with the following results:

a. Control Circuits: The control circuits operate satisfactorily in both local and remote positions.

b. Polarization Circuits: A method has been devised for testing the receiver polarization circuits in the laboratory. The preliminary test on these circuits indicate the desirability, if not the necessity, of some method of reducing reflections from the receiver mixers.

c. Signal Generator: The signal generator operates satisfactorily.

d. Modulator: The modulator is not operating satisfactorily. The magnetron power output is low and the tube seems to misfire at least a third of the time. Tests are being conducted to determine the cause of this trouble.

e. AFC: The coupling device between the magnetron output and the AFC has not been completed. This circuit will be tested when the coupling device is
completed and the modulator difficulties have been eliminated.

f. Power Supplies: The high-voltage transformer in
the modulator power supply failed while the modu-
lator was being tested and has been replaced by
a spare. All supplies are now operating satisfac-
torily.

6. Radar IF, Video, and Indicators. A study of the amplitude-
response characteristics of the video amplifiers in the indicators
was initiated. This examination was performed for the purpose of
obtaining an adjustment procedure which would produce a uniform am-
plitude-response characteristic in all four receiving channels. At
the present a tube specification has been established and acceptable
tubes selected and pre-aged. Further work on this study has been
prevented due to a component failure in the radar power supply.

III. PERSONNEL

The following individuals are permanently assigned to this pro-
ject. Part-time personnel are indicated by an asterisk.

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. R. Widerquist</td>
<td>Assoc. Prof.</td>
<td>Project Director</td>
</tr>
<tr>
<td>W. S. Foster</td>
<td>Tech. Asst.</td>
<td></td>
</tr>
<tr>
<td>D. S. Holmes</td>
<td>Asst. Prof.</td>
<td>Theory and Analysis</td>
</tr>
<tr>
<td>H. D. Ivey</td>
<td>Res. Phys.</td>
<td>Theory and Analysis</td>
</tr>
<tr>
<td>S. P. Lenoir</td>
<td>Asst. Prof.</td>
<td>Analysis Equipment</td>
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<td>G. C. McKoy *</td>
<td>Res. Phys.</td>
<td>Microwave Equipment</td>
</tr>
<tr>
<td>A. B. Rhoades</td>
<td>Secretary</td>
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<tr>
<td>A. W. Wren</td>
<td>Res. Phys.</td>
<td>Microwave Equipment</td>
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<tr>
<td>J. R. Walsh</td>
<td>Res. Ass.</td>
<td>Radar Indicators and</td>
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<pre><code>                           |                         | Control                  |
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IV. PROGRAM FOR NEXT REPORT PERIOD

The present work and additional items of equipment improvement will constitute the activities for the coming period.

Respectfully submitted,

V. R. Widerquist
Project Director

Approved:

J. E. Boyd, Head
Physics Division

P. K. Calaway, Acting Director
Engineering Experiment Station
PROGRESS REPORT NO. 23
PROJECT NO. 157-96
BUSHIPS CONTRACT NO. NOber-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 APRIL 1954

UNCLASSIFIED
PROGRESS REPORT NO. 23

PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NOber-49063

SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

1 APRIL 1954
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This Report Contains 11 Pages
I. INTRODUCTION

The ultimate objective of the program of research under Contract NOber-49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase, and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and is directed toward the objective of performing thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 mc and 35,000 mc. These experimental studies are to be concerned with both the statistical properties and the polarization properties of the radar echoes.

II. PROGRESS

The work during this period has been directed toward equipment modifications and improvements as given below:

1. Correlator. A tentative design was adopted for the plug-in d-c operational amplifiers. Eight such units were built for testing in the various parts of the system. A new multiplier-integrator unit for the correlator was designed, making use of a number of these plug-in amplifiers and taking advantage of a higher signal level to reduce integrator drift. Construction was started on a breadboard model of this new multiplier-integrator unit.

2. Average-Value Recorder. A breadboard model of a driving amplifier for the average-value recorder was constructed, making use of the plug-in d-c operational amplifiers. The model is ready for testing, to determine its stability and ease of calibration.

3. W₁ Machine. During this period, further tests were made attempting to determine the cause of the nonreproducibility of results from the W₁ machine. After each of several minor changes, as many as 900 consecutive observations were made of the count at a given window level for the same loop of tape. Each such test indicated a definite lack of random behavior. All efforts to locate the source of this
fluctuation were of no avail, and it was decided to check the distributions again. Several tests were run and only one such test approached the limit that would need to be exceeded before nonreproducibility would be indicated. This implies that the mean-value shifts found above are not significant as far as the shape of the distribution is concerned but more information is required to bear this out. The mean-value shifts will cause wider limits to be established than could be the case if these shifts could be eliminated or reduced. The variance of the counts in a window is apparently proportional to the count in the window, but the proportionality may not be the same for every type distribution being studied. Further tests will be made along these lines.

4. 35,000-Mc R-F Unit. The only work connected with the 35,000-mc r-f unit has been the construction of an auxiliary wave-guide system to be used in testing the receiver polarization circuits. The auxiliary wave-guide system has been completed, but testing of the receiver polarization circuits has not started.

5. 6,300-Mc R-F Unit. Work during this report period has been concentrated on the modulator. The modulator, as previously reported, is not operating satisfactorily. To determine the difficulty the following tests have been made:

High-Voltage Test. A peak-reading voltmeter has been constructed and used in voltage measurements on the modulator. These measurements have failed to reveal the trouble.

Low-Voltage Test. Low-voltage test of the pulse-forming networks and the pulse transformer indicated no difficulties with impedance match or transformer step-up ratio.

Spectrum Test. At half power the spectrum was good but indicated an occasional misfire. At full power, misfiring was very bad.
It was concluded from these tests that the trouble was either marginal magnetrons or incompatibility of the modulator and the Type 4J59 magnetron.

It was decided at this point that a visit to the magnetron manufacturer was desirable. Accordingly, representatives of this organization visited Raytheon and Sylvania in Boston, Mass. Both manufacturers think our difficulty is too fast a rise time on the modulating pulse. In addition to this, they suggested several improvements that could be made in our measuring techniques.

In view of and with due regard to this information, work has been resumed on the modulator. At this date, however, there are no results to report.

The modulator high-voltage transformer failed again during the modulator test. Reappraisal of the transformer design indicated too small a power-handling capacity. To eliminate this difficulty a new transformer has been designed and constructed. Tests indicate sufficient power capacity in the new transformer.

In addition to the modulator work, the following items have been completed or modified.

1. AFC coupling device completed.
2. Local oscillator shielded to prevent pick-up.
3. Transmitter polarization switch modified to permit easier adjustment of stops.

6. 6,300-Mc Antenna. The adjustment and testing of the six-foot paraboloid has been started. The preliminary results indicate an excessive amount of cross polarization from the back-feed. A solid splash plate and a dielectric insert for the feed are being built. Although the new feed gives improper illumination of the paraboloid, tests with the feed should establish an upper bound for isolation. If the isolation obtained with the solid splash plate is less than 30 db, the back-feed will be abandoned in favor of the type of feed used on the four-foot, 35,000-mc paraboloid.
7. Radar System Indicators. No work on this part of the system was performed since the replacement for a bad component was not received until the end of March.

8. Unidirectional Lines. Reflections from the mixers in the receiver polarization circuits have made polarization tuning on both the 35,000 mc and 6,300 mc very difficult. It appears that the use of unidirectional lines in the polarization equipment will greatly simplify this problem by increasing the isolation between the various receivers. Since suitable commercial lines are not available in the desired frequency ranges, an attempt is being made to develop unidirectional lines on both bands.

A brief literature survey has been made, and experiments have been started at 6,300 mc. Several ferrites are being tested to determine which type is most suitable. Present results are encouraging, and it is felt that a successful unidirectional line can be developed.

Respectfully submitted:

V. R. Widerquist
Project Director

Approved:

F. E. BoyH, Head
Physics Division

P. K. Calaway, Acting Director
Engineering Experiment Station
UNCLASSIFIED
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

PROGRESS REPORT NO. 24
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

1 JUNE 1954
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This Report Contains 3 Pages
The ultimate objective of the program of research under Contract NObsr-49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase, and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and is directed toward the objective of performing thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 mc and 35,000 mc. These experimental studies are to be concerned with both the statistical properties and the polarization properties of the radar echoes.

II. PROGRESS

The work during this period has been directed toward equipment modifications and improvements as given below:

1. Correlator. The breadboard model of an improved multiplier-integrator unit was completed and tested. Drift in the output of the unit was reduced by an estimated factor of ten, from the previous unit through the use of larger signal amplitude and more stable d-c operational amplifiers. Since these tests were made, a further improvement in operational amplifiers has been realized. The new amplifiers have been incorporated into the circuit, but the system has not yet been tested with them. An additional source of error has been discovered in the excessive impedance of the multiplier gate. This gate circuit has been altered to reduce the impedance, but tests have not been made since the modification was completed.

2. Average-Value Recorder. The breadboard model of this unit has been tested and found to operate satisfactorily. The final models are under construction.

3. W_1 Machine. Additional tests on the W_1 machine indicated a high correlation between the power-supply voltages for this equipment and the running count average obtained when a specific group of data
was used for test purposes. From these tests, it was estimated that the
use of more stable power supplies would decrease the variance of the
counts in one window by approximately 40 per cent. Extremely well-regu-
lated power supplies (Kay-Lab Absolute Power Supplies) were ordered and
were received recently. Preliminary examinations reveal a decrease in
the variance of at least 40 per cent with considerable evidence to indi-
cate that further improvements will be obtained by modification of the
correlator demodulators.

4. 35,000-Mc R-F Unit. The pulse modulator for the Signal Gener-
ator has been modified to materially reduce frequency and amplitude modu-
lation of the R-F output when the Signal Generator is pulsed. Performance
of the unit is now satisfactory.

Modifications of the receiver AFC amplifier and discriminator have
been made to produce a unit suitable for field conditions. Tests on the
modified unit indicate satisfactory performance. A remote AFC indicator
(for the control console) is being added to permit remote tuning and AFC
monitoring.

5. 6,300-Mc R-F Unit. As previously reported, the 6,300-mc trans-
mitter has been misfiring, thus giving a very poor spectrum and low-average
power. The magnetron manufacturer suggested that our difficulty might be
too fast a rise time on the modulating pulse. Accordingly, an attempt was
made to slow down the rise time. After some experimenting, it was found
that a R-C circuit, with suitable values of R and C, inserted between the
magnetron cathode and ground reduced misfiring in the 0.25-μsec positions
to a minimum. With this circuit installed, the modulator was thoroughly
tested with each of the four spare magnetrons. In all cases, the spec-
trum at full power was very good. No work has been done on the 0.05-μsec
pulse.

6. 6,300-Mc Antenna. At the end of the previous report period,
tests were being conducted on the backfeed to determine its maximum iso-
lation. These tests have been completed. Since the best isolation ob-
tained was only slightly over 20 db, the backfeed has been abandoned.
A feed similar to the one used on the four-foot 35,000-mc antenna has been constructed and installed. Preliminary tests indicate the possibility of obtaining very good isolation (i.e., in excess of 30 db).

III. PROGRAM FOR NEXT PERIOD

The program for the next period will consist of a continuation of equipment improvement. It is anticipated that analysis of the data collected during the field operation will be started about July 1st. Also, preparations will be made, under another contract, to use the radar systems for a preliminary study of ground clutter and land targets.

Respectfully submitted:

[Signature]

Project Director

Approved:

[Signature]

J. H. Johnson, Head
Physics Division

F. K. Calaway, Acting Director
Engineering Experiment Station
PROGRESS REPORT NO. 25

PROJECT NO. 157-96

SHIPBOARDS CONTRACT NO. NOab-49063

SHIPBORE RADAR DETECTION OF TARGETS IN SEA CLUTTER

I AUGUST 1954

UNCLASSIFIED

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PROGRESS REPORT NO. 25
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 AUGUST 1954
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The ultimate objective of the program of research under Contract NOBSR-49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase, and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and is directed toward the objective of performing thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 mc and 35,000 mc. These experimental studies are to be concerned with both the statistical properties and the polarization properties of the radar echoes.

II. PROGRESS

Preparations were made, under another contract, to move the radar system and a part of the data-recording equipment to a field site at the Atlanta General Depot. The site and the equipment are ready to make the move during the first week in August. Operation at that site is intended as a shakedown test of the equipment and a training period for the operating crew, while the equipment is being used for preliminary studies of ground clutter and land targets.

The remainder of the work during this period has been directed toward equipment modifications and improvements as follows:

1. Correlator. Tests were completed on the breadboard model of the new multiplier-integrator. The unit was rebuilt in its final form and tested. Modifications were made in the demodulator unit to improve stability and in the power control unit to supply the additional voltages required. Tests were begun to determine the over-all stability of the complete correlator as modified.

2. Average-Value Recorder. The final amplifier and the power distribution panels have been constructed and tested. The results were as good as expected.

Each of the four channels has a variable gain from 1/3 to about 15, and several choices of integrating time constants ranging from zero up
to 20 seconds. Signals with mean values from zero to +150 volts can be accepted without overdriving the amplifiers. A calibrating voltage can be applied to any of the four channels; this voltage is variable from zero to +150 volts with an accuracy of 0.1 per cent. After an initial warm-up period of about two hours, the drift in any channel is not greater than 1.0 per cent of full scale per hour, at maximum gain. The drift is considerably improved at lower gain settings.

3. $W_1$ Machine. Tests undertaken during this period indicate that the $W_1$ machine can now be considered stable in that repeated analyses of the same loop of data yield distributions which do not differ significantly from the mean value.

Use of $\chi^2$ to test whether a sample has been drawn from a population with specified probability distribution requires, for maximum information, that the number of observations in each class be equal. Thus, if there are $N$ observations and $K$ classes, there should be $N$ observations $\frac{N}{K}$ per class. This requirement makes necessary windows of unequal width. Since it may be necessary for this project to make such tests occasionally, an investigation of the optimum number and width of windows has been started.

4. Control and Indicator Console. A remote indicator for the local oscillator automatic frequency control has been constructed for the 35,000-mc unit, and the 6,300-mc unit has been modified so that a remote meter may be used in series with the pedestal AFC meter. The 35,000-mc unit required an additional amplifier and detector, because the AFC unit on the pedestal operates at the klystron repeller potential, and the console unit must be at ground potential. The remote unit has been checked and works as intended.

Tests have been made on the samplers in the main console, and it was found that they are linear over a range adequate for the output of the preceding video amplifiers. Tests of the video-inverting amplifiers show that they saturate at an output voltage of approximately 11 volts, which is therefore the maximum sampler input voltage.
5. **6,300-Mc Antenna.** The six-foot, 6,300-mc antenna was completed and tested during this report period. The only remaining work is the mounting of the antenna and wave guide. This work cannot be done until the 6,300-mc pedestal is located on the platform.

6. **6,300-Mc R-F Unit.** Preliminary test of this unit was completed. Several minor troubles which developed during the test were corrected. Two replacement power transformers for the 6,300-mc modulator have been constructed.

7. **35,000-Mc R-F Unit.** Preliminary testing and tuning were started. The tuning was interrupted when the high-voltage transformer in the remote signal generator burned out. A replacement transformer has been re-designed and constructed. The other preliminary tests were completed. Several minor troubles which developed during the test were corrected.

8. **Unidirectional Lines.** Several ferrite materials were tested during this report period. The General Ceramics Ferramic R-1 looks promising. Directivity of 18 to 20 db has been obtained over the desired band of operation. Insertion loss is less than 3 db. The only possible difficulty lies in the rather high magnetic field required. Work is continuing as time permits.

9. **Remote Tuning Equipment.** A new horn and rotary stand for use with the 35,000-mc unit have been completed.

Respectfully submitted:

E. H. Hynt
Associate Project Director

Approved

J. E. Boyd
Head
Physics Division

P. K. Calaway, Acting Director
Engineering Experiment Station
UNCLASSIFIED

PROGRESS REPORT NO. 26

PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

1 OCTOBER 1954
PROGRESS REPORT NO. 26
PROJECT NO. 157-96

-0-0-0-0-0-

BUSHIPS CONTRACT NO. NOber-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

-0-0-0-0-0-

1 OCTOBER 1954
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This report contains 3 pages
I. INTRODUCTION

The ultimate objective of the program of research under Contract NObsr-49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase, and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and is directed toward the objective of performing thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 mc and 35,000 mc. These experimental studies are to be concerned with both the statistical properties and the polarization properties of the radar echoes.

II. PROGRESS

The 35,000-mc radar system, the average-value recorder, and the low-speed tape recorder were moved early in August to a field site at the Atlanta General Depot. This has provided an opportunity to check out the equipment under field operating conditions while remaining within commuting range of the laboratories. Work since the move has been devoted to making linearity, stability, and noise tests on individual components of the system, correcting circuit faults as they are discovered, and developing standardized procedures for operation and calibration. Data recordings of ground clutter have been made and returned to the laboratories for use in checking the performance of the correlator and the $W_1$ machine.

1. Correlator. Tests made during this period indicated that the modifications made in the correlator were satisfactory. Studies were started,
using data recorded during the 1953 field operation, to determine an optimum length of data sample. Studies were also started, using current data from the Atlanta General Depot operation, to evaluate the effects of radar receiver saturation on the correlation functions and to determine a method of receiver adjustment to minimize errors due to nonlinearity.

2. \( W_1 \) Machine. The determination of the mean count and the variance of the count in a given window, with the pulse heights Rayleigh distributed and the noise normally distributed, are being evaluated in order to complete the investigation of the optimum number of windows for the \( W_1 \) machine. The mean window count has been completed, and the study of the variance has been started.

A sampling trigger chassis was constructed. This allows the sampling trigger to be obtained from a constant-frequency waveform recorded on the same magnetic tape with the data signal. This procedure has resulted in improved repeatability of the \( W_1 \) machine count.

During this period, all schematic diagrams of the \( W_1 \) machine circuits have been given a final check, and the preparation of an instruction manual has been started.

3. Average-Value Recorder. Several minor modifications were made in the average value recorder; otherwise, this unit has been operated successfully during this period.

4. Radar System. Throughout this report period the 35,000-mc radar system has been used in the performance of a preliminary investigation of the polarization reflecting properties of military vehicles and ground clutter
under Contract No. DA 36-039-sc-56761 (Project A-158). This measurement program has revealed various equipment difficulties, which have been corrected or have been neutralized by operating technique.

III. PROGRAM FOR NEXT PERIOD

During the next period the 6,300-mc radar system will be used for measurements of ground targets, and analysis of data previously collected will continue under Project A-158.

Analysis of data collected during the 1953 field operation will continue. The project will prepare for a move about December 1st to the Atlantic Coast Field Site, Boca Raton, Florida, for an extended field operation. Preparation of reports and instruction manuals for the radar system and analysis equipment will continue.

Respectfully submitted:

E. R. Flynt
Associate Project Director

Approved:

J. E. Boyd, Head
Physics Division

P. K. Calaway, Acting Director
Engineering Experiment Station
PROGRESS REPORT NO. 28
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-l9063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 FEBRUARY 1955

UNCLASSIFIED
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

PROGRESS REPORT NO. 28
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 FEBRUARY 1955
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During this report period, the project efforts were directed towards the initiation of the present field operation which started on 1 December.

II. PROGRESS DURING DECEMBER '54 AND JANUARY '55

The radar system and part of the recording and analysis equipment were transported to the Boca Raton Field Site on 1 and 2 December and unloaded on 3 December. The field site was found to be in good condition except for corrosion damage to the radar-elevating-platform tilting mechanism. The only damage observed in the radar system's interconnecting cables, which were left installed, was the corrosion of some connectors on the exterior of the building.

Installation of the equipment started on 6 December and was essentially completed by 31 December. The month of January was used to adjust the two r-f units of the radar system, to check system performance, and to study the problem of standard targets which could be used for polarization tuning and system calibration.

Computation of correlation functions of data recorded during the fall of 1953 was started on 3 January 1955. This examination was intended to be used as a source of information on the recording interval to be used when taking data. However, a problem of tape fouling, which appears to be recurrent, developed and prevented an orderly completion of the study.
one-minute tape loop has been computed to obtain correlation functions for loop lengths from 60 seconds down to 5 seconds. These computations were stopped on 26 January.

Visual comparison of sea echo for 6,300 and 35,000 mc reveals that the signal received for 6,300 mc is much larger than the 35,000-mc signal. The great difference in signal strengths indicates that the initial measurements should be made primarily with the 6,300-mc portion of the radar system. A tape recording of 6,300-mc sea echo was made on 21 January, and computation of correlation functions was started on 27 January. The results of these computations will be considered when a recording interval for the tape recorders is selected.

Respectfully submitted:

Associate Director

for V. R. Widerquist
Project Director

Approved:

J. E. Boyd, Head
Physics Division

P. K. Galaway, Acting Director
Engineering Experiment Station
PROGRESS REPORT NO. 29
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NOBSR-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 APRIL 1955

UNCLASSIFIED
PROGRESS REPORT NO. 29
PROJECT NO. 157-96

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

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During this report period, the project has been occupied with a continuation of the field measurements program. The efforts have been directed towards checking system performance, working out a calibration method, making indicated system modifications, recording data, and partially analyzing the data to determine some of the obviously pertinent properties of 6,300-mc sea echo. This report is divided into an "Operations" section, which deals with data collection and pertinent analyses, and an "Exploratory Work and Equipment Modification" section, in which the compatibility of the equipment and sea echo is considered and equipment problems and modifications are described.
II. OPERATIONS

The present field operations are being conducted primarily to obtain data for future analysis; however, certain specific analyses must be performed during the course of the measurements to insure that the radar and recording systems adequately record the data, that the equipment is operated in an effective manner, and that a suitable monitor is maintained on system and personnel performance.

Consequently, correlation functions have been computed for the purpose of determining a suitable recording interval and obtaining gross information on the properties of 6,300-mc sea echo. Problems of system calibration and operating techniques have been examined, and a suitable recording procedure devised. Data have been recorded, and the average radar cross section of sea echo $\sigma^0$, has been computed to estimate the usefulness of the data. The determination of $\sigma^0$ appears to be a very suitable check on the value of the data since it can be performed rapidly and requires the analyst to examine, if casually, all the paper recorded data. There is an indication that operation of the system to give satisfactory $\sigma^0$ results will insure that the data collected will be suitable for other forms of processing.

Some of the results of the operational work performed during the last two months are presented in the following paragraphs.

A. Computation of Correlation Functions

Run 1, 21 January 1955, was recorded to obtain data on 6,300-mc sea echo which could be analyzed to determine a recording duration which would adequately represent all frequency components of the sea echo. The original plan was to take a 10-minute recording of the horizontal and vertical echo components and to compute the autocorrelation functions, $\mathcal{P}_{ii}(T)$, for the integration time, $T$. Subsequently, the tape was to be divided into two 5-minute loops and $\mathcal{P}_{ii}(T)$ computed for each loop. Further halving was to be continued until the minimum loop length of the correlator ($T = 5$ seconds) was reached.

It was hoped that comparison of the resulting $\mathcal{P}_{ii}(T)$ would yield information about the minimum integration time required to produce a confident
result for a given value of maximum $\tau$, or, conversely, the maximum $\tau$ for which a confident $\bar{c}_{ii}(\tau)$ could be obtained with a given $T$. This study was not carried to a satisfactory conclusion because of tape-fouling difficulties; however, the results that were obtained are interesting.

A typical curve is presented in Figure 1 showing the autocorrelation function, $\bar{\xi}^{\text{HH}}(\tau)$, computed from the 10-minute recording ($T = 580$ seconds) of the horizontal receiver output. The nature of the curve is such that its properties are best displayed by using three different time scales. The short-time scale (0 – 0.07 second) shows the shape of the curve near $\tau = 0$ and it demonstrates the asymptotic nature of the short decorrelation time components to the longer time components. The middle-time scale yields essentially the same information as the short-time scale, while the long-time scale (0 – 7 seconds) reveals a second asymptotic characteristic of a band of medium decorrelation time components to very long time components and might produce a suspicion that a periodicity exists in these very long time components. An alternate method of displaying this same autocorrelation function is given in Figure 2 using a logarithmic $\tau$ scale.

Four correlation functions of various integration times for the horizontal echo component were complete enough to permit a comparison of the effect of shortening the integration time. The first operation was to determine the asymptote that the short decorrelation time components approached, to subtract this asymptote to obtain the short-time components only, and then to renormalize the short-time components. The results of the above-mentioned process are shown in Figure 3. The agreement of these curves is well within the computing error of the correlator so it appears that the short decorrelation time components are adequately sampled with a recording time of one minute. However, a correlation function computed with a 5-second integration time differed appreciably (from the above-mentioned results) in the character of its short decorrelation time components. From various observations it is concluded that an integration time of 5 seconds is likely to produce nontypical results unless the data analyst is careful when selecting the data to be processed.
RUN 1 - 21 JAN 55
VERTICAL TRANSMISSION
HORIZONTAL RECEPTION
LOW-SPEED RECORDING
INTEGRATION TIME = 580 SEC.

Figure 1. Autocorrelation Function for 6,300-Mc Sea Echo.
Figure 2. Autocorrelation Function for 6,300-Mc Sea Echo.
Figure 3. Comparison of Short-Time Components of Autocorrelation Functions Computed for Various Integration Times.
The next operation is to subtract the short-time components from the correlation function and to renormalize the remainder, in this case the medium and long decorrelation time components. The results of this process are shown in Figures 4 and 5. In Figure 4, it is seen that there is considerable variation among the curves but no definite relationship between integration time and curve shape. However, the integration time to \( \tau \) ratio is becoming small enough to give a curve to curve variation. The curves in Figure 5 are distinctly different since \( 50^\circ_{HH}(\tau) \) approaches zero in an erratic fashion, while \( 580^\circ_{HH}(\tau) \) appears to approach an asymptote well removed from zero. It appears that an integration time of 50 seconds is definitely too short for \( T_{\text{max}} \) \# 8 seconds with 6,300-mc sea echo, and a 580-second integration time has not been demonstrated to be sufficient.

For various reasons, including recording and analysis convenience, a recording period of 10 minutes has been tentatively selected as standard.

B. Data Recording

An uncommon weather condition developed on 3 February 1955 and continued until 5 February 1955. The results were steady gale winds, 6-foot seas, many whitecaps, stable sea condition and strong sea echo. The sea state was about as rough as normally occurs in this area (except for hurricanes). Although an acceptable method for referring system calibration to a standard target had not been devised, it was decided that data recordings from such seas would be useful as a source of correlation information since the computation of normalized autocorrelation functions requires neither absolute nor relative calibration. Consequently, data were recorded on 4 February 1955 until an equipment failure forced a cessation of activities. After repairs were accomplished, additional recordings were made on 5 February 1955 and an attempt was made to provide relative calibration of the data. This calibration effort revealed serious inadequacies in the method when used with the low-speed recorder because of the time required for each calibration. Therefore, a different method for calibrating low-speed recordings has been devised and is quite satisfactory.

The remainder of February was devoted to selecting and verifying an operational method for referring all data to a corner reflector used as a
RUN 1 - 21 JAN 55
VERTICAL TRANSMISSION
HORIZONTAL RECEPTION
LOW-SPEED RECORDING
INTEGRATION TIME,
T, AS SHOWN

Figure 4. Comparison of Medium-Time Components of Autocorrelation Functions Computed for Various Integration Times.
Figure 5. Comparison of Long-Time Components of Autocorrelation Functions Computed for Two Integration Times.
standard target. Since the standard target is, of necessity, located in the interference region, considerable care must be exercised when using such a target for calibration purposes. By measuring interference patterns and computing the surface reflectivity, it has been possible to obtain fair agreement within 1.5 db between the corner cross section computed from corner geometry and the cross section measured with the radar system.

Since the tape recorders were being used for other purposes, the major portion of the measurements made during March were recorded with the Average Value Recorder (AVR). The data recording results obtained to date are presented in Table I. A satisfactory method of corner calibration was introduced on 10 March 1955, and data recorded since then have been referred to a standard target. One of the more discouraging realities associated with data recording is the time required to obtain a significant amount of data. For examples, the recordings on 10 March required 2-1/2 hours, on 22 March, 1-1/2 hours, on 25 March, 1-1/2 hours, and on 28 March, 7 hours. This time is in addition to prerecording checks and adjustments which require about 1-1/2 to 2 hours. Under typical conditions it will require about 2-1/2 hours to record the values of $\sigma^o$ as a function of arrival angle, $\alpha$, for one transmission polarization using only the Average Value Recorder. If the tape recorders are used, the time will be greater. If the $\sigma^o(\alpha)$ which is obtained is to be significant, the wind and sea conditions cannot change during the recording period. Stable sea and wind conditions for a 2- to 4-hour period are not particularly common.

From the viewpoint of the data-collection theory, the work of adequate data collection could be accomplished at a much greater rate if all of the system parameters could be adequately measured. It appears unlikely that this approach can be utilized since a satisfactory measure of the sea surface has not been demonstrated.

To cover adequately all the variables permitted by the radar system and field site will require a considerable amount of recording time.

C. Preliminary Values of $\sigma^o_{6300}$

Reduction of the data to obtain curves showing the dependence of $\sigma^o_{6300}$ on the arrival angle has been accomplished in two cases. The
TABLE I

COMPILATION OF DATA RECORDING FROM
1 FEBRUARY TO 31 MARCH, 1955

<table>
<thead>
<tr>
<th>Date</th>
<th>Run Nos.</th>
<th>Wave Vel.</th>
<th>Wind Vel.</th>
<th>Min</th>
<th>Min</th>
<th>R</th>
<th>Q</th>
<th>Range of Variables and Remarks.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Feb</td>
<td>3-16</td>
<td>6</td>
<td>40/47</td>
<td>100</td>
<td>60</td>
<td>No</td>
<td>X</td>
<td>H₂V Pol., at 2.3°, 2.0°, 1.2°, 0.8°; No Calibration</td>
</tr>
<tr>
<td>5 Feb</td>
<td>18-23</td>
<td>6</td>
<td>35</td>
<td>No</td>
<td>60</td>
<td>Yes</td>
<td>X</td>
<td>H₂V Pol., at 2.4°, 1.60°, 0.8°; Calibration Attempted</td>
</tr>
<tr>
<td>17 Feb</td>
<td>24</td>
<td>-</td>
<td>15/20</td>
<td>No</td>
<td>10</td>
<td>No</td>
<td>X</td>
<td>Special Run for Saturation Tests</td>
</tr>
<tr>
<td>1 Mar</td>
<td>25-27</td>
<td>1/2</td>
<td>0</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>X</td>
<td>H₂V at 2.3°; No Calibration</td>
</tr>
<tr>
<td>4 Mar</td>
<td>29-32</td>
<td>1-1/2</td>
<td>10/14</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>X</td>
<td>H₂V at 2.4°; No Corner Calibration</td>
</tr>
<tr>
<td>10 Mar</td>
<td>33-41</td>
<td>1</td>
<td>10</td>
<td>No</td>
<td>No</td>
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<td>X</td>
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resulting curves are shown in Figures 6 and 7. The curves have an identifying system in which the first letter indicates the transmission polarization and the second letter the reception polarization.

The curves of Figure 6 indicate that $\sigma^0$ increases rapidly with $\alpha$, passes through a maximum, and then decreases with increasing $\alpha$. The validity of this latter characteristic is subject to some doubt. The data were recorded with the antenna starting at the top of the tower and moving down. The first point ($\alpha = 2.3$ degrees) was recorded at 0930 hours. The wind speed usually increases during the morning so this falling off at larger $\alpha$ may actually be a demonstration of the effect of increasing wind speed.

The curves of Figure 7 appear to have been produced by more stable sea and wind conditions. It will be noted that three of the points for horizontal transmission are missing. This is due to a difficulty in measuring $\sigma^0$ for horizontal polarization at small angles because of receiver saturation limitations on the operation of the equipment.

Determination of $\sigma^0_{6300}$ for the data of 22 March 1955 was of primary interest because measurements were taken looking into the waves and across the waves. When the aspect was changed from 0 (into the waves) to 90 degrees (across the waves), the value of $\sigma^0_{VV}$ decreased about 5 db, the values of both $\sigma^0_{VH}$ and $\sigma^0_{HV}$ decreased about 12 db, and the value of $\sigma^0_{HH}$ decreased about 20 db. The magnitude of the latter two values appear large and should be viewed with skepticism.

D. Subjective Impressions of Sea Echo

For slight winds and calm seas there is a marked difference in the magnitude and character of echoes produced by horizontal and vertical transmission. As has been previously reported by other observers, the $\sigma^0_{HH}$ is much smaller than $\sigma^0_{VV}$ for calm seas, but as the wind and seas increase $\sigma^0_{HH}$ increases more rapidly than $\sigma^0_{VV}$ becoming approximately equal to $\sigma^0_{VV}$ for moderate seas. The character of the echo fluctuations is quite different for $\sigma_{HH}(t)$ and $\sigma_{VV}(t)$ where the fluctuations are considered as functions of time. In calm seas, $\sigma_{VV}(t)$ exhibits an area extensive property and varies over a rather limited dynamic range of about 10 to 15 db.
Figure 6. Average Radar Cross Section for 6,300-Mc.
RUNS 82-100 - 28 MAR 55
WAVES: 2 1/2 TO 3 FT
WIND: 15 MPH
MANY WHITE CAPS

Figure 7. Average Radar Cross Section for 6,300-Mc.
On the other hand, $\sigma_{HH}(t)$ varies over such a large dynamic range (25 db or more) that when the receiver gain is set to minimize echo saturation, the echo becomes discrete and spiky. This spikiness cannot be directly correlated with any obvious wave effect such as shadowing.

As the seas and winds increase, $\sigma_{VV}(t)$ begins to look more like $\sigma_{HH}(t)$ until 6-foot waves produce a series of rapidly fluctuating echo spikes moving with the waves. Although the amplitudes of the spikes fluctuate violently, the spikes last for several seconds and have an appreciable average value (short-time average). Evidently, this phenomenon is due to failure of the sea echo to be area extensive for the radar system which has been operated to give an illuminated area about 100 feet square.

The cross-polarized components of the echo appear to behave like the associated direct component, that is, $\sigma_{HV}(t)$ like $\sigma_{HH}(t)$ and $\sigma_{VH}(t)$ like $\sigma_{VV}(t)$. When the average values are computed to get $\sigma_{HV}^0$ and $\sigma_{VH}^0$, it is not unusual to find that $\sigma_{HV}^0$ and $\sigma_{VH}^0$ are markedly different. This observation has not been accepted as representing a property of the data, but it has not been explained as a equipment or personnel error.
III. EXPLORATORY WORK AND EQUIPMENT MODIFICATION

A. Estimate of 6300-Mc Sea-Echo Spectrum

At the conclusion of the data-recording session on 5 February 1955, a special tape was recorded during which an attempt was made to have an echo in the sampler gate at all times by tracking the large echo spikes. Since the sea conditions were about as rough as normally occur, except for hurricanes, it was believed that this data would have an autocorrelation function representative of the minimum decorrelation time which might be encountered during the recording of 6300-mc echoes. Vertical polarization was used for transmission. The autocorrelation functions of the horizontal and vertical components and the crosscorrelation between these two components are shown in Figure 8. Since the purpose of this experiment was to determine the minimum decorrelation time in order to properly select a recording bandwidth, the asymptotic level that the correlation function approaches has been subtracted and the curve renormalized to one. The original function is shown in Figure 9 for the horizontal autocorrelation function.

Since the decorrelation time of random noise recorded with the low-speed recorder is about three $\tau$-units, the correlation functions shown in Figures 8 and 9 represent the properties of sea echo and not the recording system. It appears that decorrelation to $1/\sqrt{2}$ of the original amplitude will not be less than four $\tau$-units for the 6300-mc echo.

B. Effect of Signal Saturation on the Autocorrelation Function

On 17 February 1955, a recording was made to evaluate experimentally the effect of receiver saturation on the correlation function of sea echo. The radar system was connected so that all four i-f channels were fed from the output of the horizontal receiver preamplifier. The various gains of the i-f channels were adjusted to provide various degrees of amplification of the same signal. Hence, the gain of channel 1 was set at a value which provided the maximum unsaturated echo. By using the signal generator as a reference, the gains of channels 3, 2, and 1 were set to values 3, 6, and 9 db greater, respectively, than channel 4. A 10-minute recording of all four channels was made with the low-speed recorder (3 ips). During the
Figure 8. Autocorrelation Functions of High-Frequency Components of 6,300-Mc Sea Echo.
Figure 9. Autocorrelation Function of 6,300-Mc Sea Echo.
recording period, channel 1 did not saturate, channel 2 saturated occasionally, channel 3 saturated moderately, and channel 4 saturated frequently.

This 10-minute recording was formed into a 1-minute loop for computation on the correlator (tape speed of 30 ips), a procedure which requires the use of a tape bin. Since difficulty with tape fouling had occurred in previous uses of the bin, the autocorrelation functions of the four-channel outputs were computed in a manner intended to yield the most complete results before the inevitable tape fouling started occurring. The results are shown in Figure 10. Only one curve, \( \Phi_{11} \) was completed and \( \Phi_{22} \) was never started. Further computation was prevented by rapid and complete destruction of the tape loop by fouling.

It is interesting to note that the curves for the two lowest gain settings, \( \Phi_{33} \) and \( \Phi_{44} \), are essentially identical and that the primary result of saturation appears to be an increase in the ratio of short decorrelation time components to long decorrelation time components.

C. Tape-Bin Redesign

It became obvious in the above-mentioned computations that the various palliatives, both mechanical and operational, which had been used to relieve tape fouling were not effective enough to permit computations of the length required. Since certain questions need to be answered prior to satisfactory data taking, it was considered necessary to solve this problem immediately. After considerable "trial and error" modifications were made in the bin, a design was developed which appeared to be operationally satisfactory although it did not eliminate the basic cause of the tape fouling. The prototype of this new design prevented tape fouling for a period of processing considerably longer than had been previously realized when further testing was halted and construction sketches prepared and sent to Atlanta about 10 March 1955. Whether or not the new bin will be a satisfactory solution remains to be determined.

D. Frequency Response of the Tape Recorders

When the recording system parameters were originally selected, the anticipated data bandwidth requirement of 1 kc caused the selection of a
Figure 10. Signal-Saturation Effect on Autocorrelation Function.
recording tape speed of 30 inches per second. Since the same tape pulling unit is used for the correlator playback, the playback speed is 30 ips. At that time, there was no strong indication that the low-frequency components of sea echo would be so pronounced or that low-frequency periodicities might be so obvious and, consequently, no recording equipment was developed specifically for the purpose of investigating the properties of sea echo in the region of fractions of a cycle per second.

As part of the projected oceanographic instrumentation, a tape recorder was constructed which covered the frequency range from about 100 cps to d.c. The recording speed is 3 ips, and the unit is compatible with the 30-ips high-speed unit, that is, recordings made at 3 ips may be played back and correlated. When computed on the correlator, a low-speed recording undergoes time compression by a factor of 10 and the effective $\tau$ delay of the correlator is increased 10 times. Thus, a 10-minute recording of low-speed data can be played back in 1-minute, and the maximum time delay, $\tau$, of the correlation function is 9.1 seconds. It is evident that the use of the low-speed recorder is advantageous since it decreases tape consumption and computation time by a factor of 10 times and increases the time delay sufficiently to reveal data periodicities at frequencies as low as $1/10$ cps.

Since one computation of a 6300-mc autocorrelation function indicated that the minimum decorrelation time to be expected at these frequencies is approximately 3.32 ms, the low-speed recorder will probably be adequate for all the 6300-mc recordings. Furthermore, it appears that the low-speed recorder would be useful for determining the low-frequency properties of 35,000-mc sea echo, if suitable filtering of the high-frequency components were obtained. In view of the anticipated extensive use of the low-speed recorder, the use of the low- and high-speed recorders in a time compression process, and the desirability of having the frequency response of the two recorders geometrically similar, it was decided that the bandwidth characteristics of the two systems should be checked in order to determine what modifications were indicated to permit similar interpretations to be placed on all computed correlation functions regardless of recording speed.
When the receiver noise was used as a signal source for the samplers, when the resulting random signal was recorded with both high- and low-speed recorders, and when the autocorrelation functions were computed from the recordings, it was found that the autocorrelation function computed from the high-speed recording took 3 τ units to decrease to 1/ε of the τ = 0 value, whereas the autocorrelation computed from the low-speed recording decreased to this value in 1-1/2 τ units. From these observations it is evident that the bandwidth of the two recorders did not scale like the tape speed. It was also noticed that the signal amplitude from the low-speed recording was much less than that from the high-speed recording. Measurement of the record-playback bandpass characteristics revealed an appreciable difference between the high- and the low-speed recorders and a tendency for certain signal components, having frequencies higher than the recorder maximum frequency, to produce spurious signals when played back. In order to eliminate the above-mentioned difficulties and to make the two recording units geometrically similar in frequency, low pass filters of appropriate cut-off frequency were added to the modulators of both recorders. The resulting over-all record and playback frequency response was geometrically similar for both the high- and low-speed recorders.

The following experiment was performed to check the recording system's behavior to random functions. Receiver noise was recorded for 17 seconds on the high-speed recorder and for 1700 seconds on the low-speed recorder. The low-speed recording of 1700 seconds was played back on the correlator (taking 170 seconds) and re-recorded on the low-speed recorder to give a low-low-speed recording of 170 seconds' duration at 3 ips. Then, the first 170 seconds of the 1700-second low-speed recording was removed and formed into a loop. Loops were also formed from the high-speed and low-low-speed recordings. This procedure produced three tape loops of the same physical length but representing 17 (HS), 170 (LS), and 1700 (LLS) seconds of random noise recordings with nominal bandwidths of 1500, 150, and 15 cps, respectively. Autocorrelation functions were then computed for each of the three speeds, and the results are shown in Figure 11. The autocorrelation function computed from the LLS recording possessed an asymptote which was essentially constant to a τ delay of 83 seconds. This asymptote probably represents
Figure 11. Autocorrelation of Noise Voltage for Various Recording Speeds.
the contribution to the correlation function produced by sampler drift, radar drift, power-line fluctuations, etc. The asymptote was subtracted out and the resultant renormalized to obtain the curve shown in Figure 11.

Ideally, the correlation functions for all three recordings would be identical in the display shown in Figure 11. However, since there is no assurance that the noise source used was "white," the autocorrelation functions for the HS, LS, and LLS recordings are in good agreement, especially in view of the fact that the sampling process modifies the frequency spectrum of noise. The record-playback characteristics will be assumed to be geometrically similar for random functions for all three types of recording.

By using the present recorders and copying when necessary, time compression of 1, 10, and 100 can be obtained, thus permitting a detailed examination of the frequency characteristics of sea echo from 2/3 cycle per minute up to 1000 cycles per second. It is evident from the asymptotic characteristic of the correlation function for the 28-minute (1700 second) recording that radar system and other extraneous extremely low-frequency fluctuations will become annoying in the LLS recordings. It is concluded from the magnitude of the extraneous noise that further time compression is not advisable. Furthermore, it is necessary to record data that will yield information about the system noise at extremely low frequencies.

Although further tests and checks of the tape recorders are anticipated, these units can be considered as operationally satisfactory and ready for extensive routine recording.

E. Average Value Recorder

The measurements of the average value of sea echo which have been attempted during the past two months have indicated the advisability of changing the time constants available for weighted integration in the average value recorder. In order to satisfy the dual purposes of direct recording from the radar and playback recording from tape, the following time constants have been selected and installed in the 4 integrators of the average value recorder: 0.02, 0.06, 0.2, 0.6, 2, 6, and 20 seconds. Check measurements of the time constants reveal an anomaly which is being examined, namely,
the measured recorded time constant for a positive step voltage is different from the measured recorded time constant for a negative step voltage. This phenomenon varies from channel to channel (of which there are 4) and between time constants. It is suspected that the phenomenon is a property of the recording meter movements.

F. Sampler Modifications

The samplers have been considered by the operating personnel to be the weakest link in the entire radar and recording system. Previously, during the ground return measurements taken for the Signal Corps, it was found that the output level drifts in a random manner after the warmup period, that the magnitude of the random drift often reached ±5 per cent of full scale output, and that the drifting characteristics of a given sampler channel (of which there are 4) were not predictable. In practice, it is necessary to check the drifting characteristics each time the samplers are turned on since partial failures appear to occur when power is applied. A serious failure can be readily recognized, but a partial failure or increase in drift magnitude has to be determined by long-time Sanborn recordings. No way has been found to eliminate this drifting characteristic (short of complete redesign), but operational methods helping to minimize the drift or discover its presence have been adopted.

Another difficulty, which has probably existed all along, was finally recognized as a potential source of data modification. When the sampler is subjected to a large step function, the output exhibits damped sinusoidal oscillations of about 3 cps. This was traced to improper damping of a feedback amplifier. The damping was improved within allowable practical limits with the result that this oscillatory response to transients has been effectively minimized. At the same time, a modification was made to improve the rise-time response of the sampler to enable it to follow full-range changes in input signal occurring at one-half the sampling rate.

During the course of the above-mentioned investigation, it was observed that the zero level of a sampler channel would change when the sampler was switched from OPERATE to CALIBRATE and back. This zero shift is neither constant nor predictable as to magnitude or direction nor have any results
been attained in trying to locate the cause or effect a cure. However, it has been fairly well established that this shift usually occurs only when the OPERATE-CALIBRATE switch is used. By modifying the recording procedure, it is possible to minimize this difficulty.

Although the operating personnel are not satisfied with the performance of the samplers, their vagaries are understood enough to permit the taking of effective and reasonably accurate data. It appears that the only effective way to improve the performance of the samplers materially is by a complete redesign, probably including a different circuit philosophy.

Respectfully submitted:

Associate Director

for V. R. Widerquist
Project Director

Approved:

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Physics Division

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Engineering Experiment Station
UNCLASSIFIED

PROGRESS REPORT NO. 30
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 JUNE 1955
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SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 JUNE 1955
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I. INTRODUCTION

The ultimate objective of the program of research under Contract N09063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and involves thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 and 35,000 mc. These experimental studies are concerned with both the statistical properties and the polarization properties of the radar echoes.

During this report period, the project has been occupied with a continuation of the field measurements program and partial data reduction.
II. SEA-ECHO MEASUREMENTS

A. Operations

During this report period, a total of 50 hours of recording time has produced 10-1/2 hours of magnetic tape recordings and 1/4-3/4 hours of average value recordings. All the significant periods of data recording are listed in Table I. It is evident that the major portion of the recording periods was used in collecting data from moderately rough seas; however, the last three efforts started out as examinations of the echo from a sea surface having very little fine (micro) structure and, in two cases, practically no waves or swells.

Observations made during the recording of sea echo and the results of the data analysis have led to the conclusion that some time should be spent in studying echo from calm seas. When the data are considered in their entirety, it appears that the instrumentation is sufficient to permit the sea and wind conditions to be used as the primary variables.

B. Correlation Functions for 35,000-Mc Sea Echo

During January, a group of correlation functions were computed from 35,000-mc sea-echo data recorded during September 1953. Using these data, curves have been plotted and examined for the purpose of estimating the frequency response of the recording system and the recording interval required to produce consistent computed correlation functions. Since these curves were obtained from sea echo collected during rough seas and moderate gale winds, the bandwidth of the power-frequency spectrum of this echo is probably typical of the maximum bandwidth to be expected.

The longest integration time for which a correlation function was computed, out to the maximum machine time delay (0.83 second), was the value of 26 seconds obtained for curve No. 1h. A plot of this correlation function is shown in Figure 1 where the significant characteristics are emphasized by using two time scales. It is evident that the correlation function has at least one asymptote and that the short decorrelation time component crosses zero into the negative region, back to the positive region.
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DATA FROM RUN 19, 23 SEPTEMBER 53
VERTICALLY POLARIZED TRANS.
35000 Mc
5- TO 6- FT WAVES
35-MPH WIND
CURVE NO. 14, 26 SEC
INTEGRATION TIME.

Figure 1. Autocorrelation Function of 35000-Mc Sea Echo.
and then approaches the asymptote. It is suspected that this negative overshoot may be produced by saturation of the signal in the radar receiving system prior to recording on the tape.

A plot of three curves having different integration times (referred to as loop lengths in the figures), but computed from overlapping portions of the same recording, is presented in Figure 2. It is seen that these curves have approximately the same shape and approach the same asymptotic value. It would appear that an integration time, and necessarily a recording time, of 20 to 30 seconds will produce a reproducible correlation function in the region of the short decorrelation time components and its asymptote.

A further decrease in the integration time was obtained by dividing the tape loop used for computing curve No. 18 into three 5-second loops. The initial values and the shapes of the asymptote differed appreciably in the three resulting curves (No. 19, 24 and 27). In each case the asymptote was subtracted and the resulting curve renormalized for curves No. 18, 19, 24 and 27. The resulting correlation functions for the short decorrelation time components of the sea echo are presented in Figure 3. Evidently a reasonably accurate autocorrelation function for the short-time component could be obtained from integration times of about 5 seconds. It appears that a recording interval of one minute should suffice if the maximum time delay, $\tau$, for the correlation function does not exceed 0.8 second. If larger maximum $\tau$ are required, the recording interval should be increased.

It is estimated that the upper half power frequency in the power-frequency spectrum is 200 cps. This requires the use of the high-speed recorder with a bandwidth of 1500 cps. Probably sea echo taken for wind speeds less than 12 miles per hour could be satisfactorily recorded on the low-speed recorder with a bandwidth of 150 cps.

C. Average Value of 6,300-Mc Sea Echo

The quantity of average value data is sufficient to indicate that the relationships among sea echo, wind speed and arrival angle are in qualitative agreement with previous work. There appears to be a direct relationship between the whitecap density and the average value of the sea echo.
DATA FROM RUN 19, 23, SEPTEMBER 53
VERTICALLY POLARIZED TRANS.
35000 Mc
5- TO 6- FT WAVES
35-MPH WIND
NO. 12 COMPUTED FROM 54-SEC LOOP OF DATA, NO. 14 COMPUTED FROM 26-SEC LOOP SALVAGED FROM THE 54-SEC LOOP. NO. 18 COMPUTED FROM 22-SEC LOOP SALVAGED FROM THE 26-SEC LOOP.

Figure 2. Comparison of Correlation Functions for Successively Shorter Integration Times.
Figure 3. Comparison of High-Frequency Components for Different Integration Times.

NORMALIZED AUTOCORRELATION FUNCTION, $\Phi_{HH}(\tau)$

-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100

TIME DELAY, $\tau$, IN MILLISECONDS

1
2
3
4
5
6
7

DATA FROM RUN 19, 23, SEPTEMBER 53

VERTICAL POLARIZATION

5, 10, 15, 20, 25, 30, 60, 120, 240 WIND WAVES

30° TO 45° INCIDENCE FROM 2-SEC. LOOPS OF DATA FROM 19, 23, AND 27, COMPUTED FROM 5-SEC. LOOPS CUT USED FOR NO. 18.
intensity. Typical results for all the average value data collected to date are presented in Figures 4, 5 and 6.

At the present time it is not considered advisable to interpret the results presented in Figure 4 as a positive demonstration that whitecaps are a major factor in producing sea echo. Figure 5 shows that there is a definite relationship between whitecap density and wind speed and that there appears to be a rapid transition in the number of whitecaps which occur at a wind speed of about 14 miles per hour. Consequently, it may well be that the whitecaps do not contribute appreciably to the echo intensity but are results of the action that causes this marked increase in the average echo intensity.

In Figure 5 the points for wind speeds less than 5 miles per hour are misleading. Wind speed was measured at the radar, while the wind speed at the target area was known to be different from that at the radar in many cases. Most of these points were obtained when making measurements for flat seas with areas of wind streaks and slicks (glossy surface denoting no appreciable air motion at the water surface). A difference of 15 db between $\sigma^0$ for a slick area and a wind streak is typical.

The functional relationship between $\sigma_{vv}^0$ and the arrival angle for various wind speed ranges is shown in Figure 6. The behavior for angles less than one degree becomes erratic, but this is the region below the critical angle and is also a region where measurements become difficult to make and inaccurate results are common. These data do reveal a limiting phenomenon in the increase of $\sigma^0$ with wind speed which appears to occur at wind speeds of about 14 miles per hour.

Attempts to correlate $\sigma^0$ with the sea state have not been satisfactory. It appears that $\sigma^0$ is much more sensitive to changes in wind speed than to sea state and there is a masking effect caused by the wind which covers the dependence upon sea state.
Figure 4. Dependence of $\sigma_{VV}^0$ on Arrival Angle for Various Sea States and Wind Speeds.
Figure 5. Dependence of $\sigma_{\text{HH}}^0$ on Wind Speed For Various Sea States and Arrival Angles.
Figure 6. Dependence of $\sigma_{VV}$ on Arrival Angle for Various Sea States and Wind Speeds.
III. EQUIPMENT

The study of equipment deficiencies has continued throughout this report period, and this work is being performed whenever a unit and its attendant personnel are not engaged in data recording or equipment repair.

A. Average Value Recorder

In a previous report mention was made of an anomaly in the integration time constants of the average value recorder. In a given channel the time constant measured from a recording may be different for positive and negative input signals. Thus, when the input signal is a positive step, the time constant measured from the paper recording usually differs from the time constant measured from the recording of a negative-step input. This anomaly is reproducible for a given channel and nominal time constant, but there appears to be no correlation between channels or, for a single channel, between nominal time constants.

By rotating the recorder meter movements among the meter driving amplifiers, this anomaly was demonstrated to be a property of the meter movement and not of the electronic integrator or driving amplifier. Further attempts at eliminating this condition were stopped and a record was made of the measured time constants (for both positive and negative inputs) corresponding to the nominal time constant for each of the four channels. No attempt has been made to evaluate the effect, if any, that this anomaly has on the recorded data.

B. Low-Speed Recorder

A recurrent difficulty with the tape drive mechanism was minimized by modifying the capstan-roller pressure mechanism to increase the force of the capstan rollers on the capstan.

C. Samplers

Further effort was expended to improve the performance of the samplers by modifying the sampling pulse generator. When the sampler is switched from "OPERATE" (sampling the radar echo) to "CALIBRATE" (sampling the signal-generator pulse) or vice versa, the zero level of the sampler output shifts
in an unpredictable manner. Consequently, it is necessary to record the zero level of the sampler before and after changing the position of this switch. This trouble is apparently due to a change in the deionization time of the thyratrons in the sampling pulse generator which produces a change in the voltage to which the pulse-forming networks charge. A triode charging circuit for the pulse-forming networks was breadboarded and tried, but no noticeable improvement was observed in the behavior of the samplers. The circuits were restored to their original configuration, and the work was suspended.

D. Video Amplifiers

Baseline overshoot following saturated sea echo extending for several microseconds in range has been observed under certain conditions of operation. As would be expected, this condition was traced to insufficient low-frequency response in the video chain amplifier stages. This overshoot was eliminated by changing screen bypassing and coupling capacitors and by redesigning the bias circuits for the video amplifiers.

E. 6,300-Mc R-F Unit

There has been indication in the past that the signal-generator pulse could not be attenuated to a level below receiver noise. Upon checking, it became obvious that there was signal leakthrough from the signal-generator oscillator to the receiver microwave plumbing which bypassed all the attenuators in the signal generator. This leakthrough was most sensitive to the position of objects in front of the panel supporting the microwave plumbing. Every attempt to eliminate the signal-generator leakthrough by shielding and filtering the signal generator and its connections failed to produce any appreciable effect. It was found that the leakthrough was eliminated when the signal generator was removed from its mounting in the r-f unit and placed on the outside of the r-f unit. This exterior location was made semipermanent.

F. Equipment Failures

The following equipment failures were suffered during this report period:

1. The recording-meter movement of the correlator burned out about 15 April and was replaced about 5 May. This failure
prevented the correlator from being used to compute correlation functions.

2. The capstan-roller linkage on the correlator progressively failed until it was removed from service on 9 May and sent to Atlanta for repairs. This item was repaired and replaced on 30 May.

3. The automatic-frequency control unit in the 6,300-mc r-f unit failed on 14 April and repairs were completed on 22 April.

4. A high-current, high-voltage, selenium rectifier unit in the 160-volt power supply for the radar system failed abruptly on 19 May. A replacement unit is on order and is presently overdue.

Respectfully submitted:

V. R. Widerquist
Project Director

Approved:

J.E. Boyd, Head
Physics Division

P.K. Calaway, Director
Engineering Experiment Station

-14-
UNCLASSIFIED

PROGRESS REPORT NO. 31
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

1 AUGUST 1955
PROGRESS REPORT NO. 31

PROJECT NO. 157-96

BUSHIPS CONTRACT NO. N08sr-139063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 AUGUST 1955
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This report contains 4 pages.
The ultimate objective of the program of research under Contract NObsr-49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase, and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and involves thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 mc and 35,000 mc. These experimental studies are concerned with both the statistical properties and the polarization properties of the radar echoes.
II. PROGRESS FOR JUNE AND JULY

A. Operations

During this report period a total of 40 hours of recording time has produced 2-1/2 hours of magnetic tape recordings and 9-1/3 hours of average value recordings. All significant periods of data recording are listed in Table I. Until recently, most of the measurements have been made with the 6,300-mc system; however, the work of the last two weeks has been directed toward the collection of data with the 35,000-mc system.

In the past, a sequence of runs was made when it was anticipated that the sea and wind conditions would be essentially constant throughout the sequence. Having satisfied this requirement, it was feasible to use the arrival angle as a variable, but the collection of data was dependent on weather conditions. Some of the run sequences listed in Table I depart from the previous pattern by fixing the arrival angle and spacing the successive runs in time to permit the wind and sea conditions to change.

B. Equipment

Further experience in measuring sea echo has emphasized the necessity for some method of measuring the sea conditions which will provide more information about wave structure than can be obtained from visual observation of a marked pole. The previous work on design and development of a sea state meter indicated that a sensitive and accurate instrument for measuring instantaneous water height should be fairly simple to construct. By using previously developed circuits containing several minor modifications, a breadboard unit was constructed and given a preliminary test, which indicated that the instrument should be sensitive to ripples a few millimeters in height. Further tests on the breadboard were considered unnecessary, therefore a "sea-going" prototype has been constructed. A reel of 1,800 feet of remote control cable has been ordered, and installation will be accomplished upon receipt of this cable. This sea state meter will be mounted on a piling located 1,350 feet from the beach in 25 feet of water. This piling will be installed by a group from NRL which will share the field-site facilities.
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<td>--</td>
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<td>47</td>
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<td>1-1/2-4</td>
<td>6-15</td>
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<td>66</td>
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<td>1/2-1-1/2</td>
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<td>11</td>
<td>----</td>
<td>15</td>
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</tbody>
</table>
C. Equipment Failures

The high-current rectifier for the radar system power supply was received on 11 June, and the system was restored to operating condition on 16 June. Equipment failures in the radar have been common but relatively minor since that date.

Respectfully submitted:

[Signature]
Associate Director

for V. R. Widerquist
Project Director

Approved:

[Signature]
J. E. Boyd
Assistant Director
PROGRESS REPORT NO. 32
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 OCTOBER 1955

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PROGRESS REPORT NO. 32
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. N00014-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 OCTOBER 1955
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This report contains 5 pages
I. INTRODUCTION

The ultimate objective of the program of research under Contract N0014-49-0063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase, and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and involves thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 mc and 35,000 mc. These experimental studies are concerned with both the statistical properties and the polarization properties of the radar echoes.
II. PROGRESS FOR AUGUST AND SEPTEMBER

A. Operations

The measurements performed during this period produced 251 runs, which represent about 37 hours of data recorded on both the average value recorder and the magnetic tape recorder. The pertinent information on these runs is presented in Table I.

Prior commitments to a group from the Naval Research Laboratory necessitated the removal of the 35,000-mc r-f unit from the radar elevator platform on 24 August. Consequently, the quantity of 35,000-mc recordings is limited to 77 runs containing 11-1/4 hours of data. Limited transmitter power, a high receiver noise figure, and relatively low sea states required that all the 35,000-mc measurements be made with the 1/2-degree antenna at target ranges between 350 and 500 yards.

With one exception, the remaining measurements were made with the 6,300-mc system using the 9-degree antenna. This group of runs used as independent variables the transmission polarization, arrival angle and, as nature permitted, the wind speed, wind aspect angle, and wave aspect angle. The aspect angle is defined as the angle between the azimuth of the radar target area and the direction of wind or wave motion. Operating conditions limited the target range to either 500 or 1000 yards. On 30 September, the 6,300-mc antenna was changed to 2-1/4 degrees in preparation for two submarine visits expected in early October.

Observations of the properties of sea echo and characteristics of the sea surface indicate that crosscorrelation of the echoes from the same area obtained by using two different transmission frequencies might yield significant information about the phenomena producing sea echo. The indicated experiments involve the transmission and reception of energy of the same polarization from systems having the same antenna characteristics and pulse duration but having considerably different transmission frequencies. Specifically, one would crosscorrelate the echoes obtained from the 6,300-mc system and the 35,000-mc system when both were
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<td>14-18</td>
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<td>2.3, 1.9, 1.5</td>
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simultaneously operated with 2-1/4-degree antenna and a 1/4-μsec pulse using either horizontal transmission-horizontal reception (HH) or vertical-vertical (VV). After being plagued with failures in the 35,000-mc r-f unit, an uncalibrated recording (run 403) was made for HH on both systems. A serious equipment failure following this run precluded the VV measurement. It is anticipated that analysis of run 403 will indicate the desirability of making additional measurements of this type.

B. Equipment

On 8 September, the rectifier in the 160-volt 12-amp power supply for the radar system failed. The system was restored to limited 2-channel operation by using available spare power supplies. The replacement rectifier was installed on 28 September.

Installation of the sea state meter was abandoned because of the unavailability of a suitable submarine cable. However, arrangements were made to record wave-height data from a Beach Erosion Board wave meter installed by the NRL group. This instrument quantizes the wave height in 0.2-foot increments but does provide a continuous recording of wave height as a function of time.

Since the correlators have demonstrated a continuing characteristic of destroying data tape loops during computation, it was decided that the original data recordings should be copied and the copies used for analysis computations. Work has been initiated to assemble a suitable copying system (utilizing existing equipment) and to develop and evaluate copying techniques. Other than the time required to perform the copying operation, there appears to be no inherent disadvantage.
to this operation and the advantage of preserving the original data is obvious.

Respectfully submitted:

V. R. Widerquist
Project Director

Approved:

J. E. Boyd, Associate Director
Engineering Experiment Station
UNCLASSIFIED

PROGRESS REPORT NO. 33
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 DECEMBER 1955

UNCLASSIFIED
PROGRESS REPORT NO. 33
PROJECT NO. 157-96

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BUSHIPS CONTRACT NO. NOber-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

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1 DECEMBER 1955

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CONFIDENTIAL

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This report contains 5 pages

CONFIDENTIAL
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I. INTRODUCTION

The ultimate objective of the program of research under Contract N00014-49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase, and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and involves thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6,300 mc and 35,000 mc. These experimental studies are concerned with both the statistical properties and the polarization properties of the radar echoes.
II. PROGRESS FOR OCTOBER AND NOVEMBER

A. Operations

The measurements taken during October and November produced 145 runs which included 17 hours of sea echo data recorded on both the average value recorder and magnetic tape, a limited amount of data on submarines, and photographs demonstrating a marked difference between echo characteristics for horizontal and vertical transmission. The data collected are presented in Table I.

All measurements were made with the 6,300-mc system using a 2-1/2-degree antenna. Variables for the sea echo data include polarization, arrival angle, range, wind and sea aspect angles, and wind speed. The submarine measurements were on periscope return for SS 285 and snorkel return for SS 382. The periscope data cover ranges from 3300 to 6400 yards. It is strongly suspected, however, that the submarine was operated with considerably more of the periscope exposed than would be permitted under tactical conditions. The snorkel data cover ranges from 3900 to 9100 yards in moderate seas with a snorkel exposure estimated to be slightly greater than that used under tactical conditions. Calibrated data were recorded for the average value recordings of periscope and snorkel echoes, but operating conditions limited the tape recordings to uncalibrated data suitable for correlation analysis only.

A-scope photographs were made which demonstrate the marked difference observed for low sea state in the characteristics of sea echo for horizontal and vertical polarization.

Operations were suspended on 3 November and certain items of equipment returned to Atlanta. The complete radar system, most test equipment, and the average value recorder were left at the field site in operating condition. Personnel returned to Atlanta the week of 7 November.
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<th>Run No.</th>
<th>Wave Height (feet)</th>
<th>Wind Speed (knots)</th>
<th>Arrival Angle or Remarks</th>
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</thead>
<tbody>
<tr>
<td>3 Oct</td>
<td>574-577</td>
<td>2</td>
<td>3-7</td>
<td>2.3 and 1.5</td>
</tr>
<tr>
<td>4 Oct</td>
<td>580-588</td>
<td>$1 \frac{1}{2}$ to 2</td>
<td>6-10</td>
<td>2.3 and 1.9</td>
</tr>
<tr>
<td>5 Oct</td>
<td>591-592</td>
<td>$2 \frac{1}{2}$ to 3</td>
<td>Variable</td>
<td>2.3</td>
</tr>
<tr>
<td>5 Oct</td>
<td>593-597</td>
<td>2</td>
<td>10-13</td>
<td>BALAO (SS 285)</td>
</tr>
<tr>
<td>6 Oct</td>
<td>600-601</td>
<td>2</td>
<td>12</td>
<td>0.7</td>
</tr>
<tr>
<td>7 Oct</td>
<td>604-608</td>
<td>4</td>
<td>17</td>
<td>PICUDA (SS 382)</td>
</tr>
<tr>
<td>7 Oct</td>
<td>609-618</td>
<td>3 to 5</td>
<td>13-20</td>
<td>0.7, 1.1, 1.5, 1.9, 2.3</td>
</tr>
<tr>
<td>10 Oct</td>
<td>621-624</td>
<td>1</td>
<td>12-14</td>
<td>2.3</td>
</tr>
<tr>
<td>11 Oct</td>
<td>627-628</td>
<td>1</td>
<td>13</td>
<td>1.5</td>
</tr>
<tr>
<td>24 Oct</td>
<td>632-641</td>
<td>3</td>
<td>12-14</td>
<td>Various ranges</td>
</tr>
<tr>
<td>26 Oct</td>
<td>642-656</td>
<td>$\frac{1}{2}$ to 1</td>
<td>4-8</td>
<td>Photographs</td>
</tr>
<tr>
<td>27 Oct</td>
<td>659-666</td>
<td>1 to 1 $\frac{1}{4}$</td>
<td>10</td>
<td>2.3 and 1.9</td>
</tr>
<tr>
<td>28 Oct</td>
<td>669-671</td>
<td>$1 \frac{1}{2}$ to 2</td>
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<td>0.7, 1.1, 1.5, 1.9</td>
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<tr>
<td>31 Oct</td>
<td>687-698</td>
<td>2</td>
<td>13-15</td>
<td>2.3 and 1.5</td>
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<tr>
<td>1 Nov</td>
<td>701-704</td>
<td>1 to 1 $\frac{1}{2}$</td>
<td>11</td>
<td>2.3</td>
</tr>
<tr>
<td>2 Nov</td>
<td>707-716</td>
<td>1 to 1 $\frac{1}{2}$</td>
<td>8-11</td>
<td>2.3, 1.9, 1.5, 1.1, 0.7</td>
</tr>
<tr>
<td>2 Nov</td>
<td>717-718</td>
<td>1 to 1 $\frac{1}{2}$</td>
<td>8-11</td>
<td>Photographs</td>
</tr>
</tbody>
</table>
B. Data Reduction

The data-reduction equipment, consisting of two correlators, a \( W_1 \) unit, and a low-speed recorder, has been assembled in a flexible system to permit magnetic tape copying either with or without time contraction (a process of rerecording tape in order to shorten the real time duration of the data), to compute first probability distributions, and to compute correlation functions. Suitable operators have been employed and trained to perform the unrewarding task of running the reduction equipment, and routines for equipment operation and tape copying have been established. The data-reduction equipment and its operators are being studied at the present time to establish an over-all reliability estimate. As soon as this reliability study is completed, routine reduction of the tape data into first probability distributions and correlation functions will be started.

C. Staff

Upon completion of the field operation, certain personnel were relieved from assignment to this project. The present staff and their duties are listed below:

V. R. Widerquist               Professor               Project Director and Analysis
D. S. Holmes                 Asst. Prof.               Asst. Proj. Dir. and Analysis
S. P. Lenoir, Jr.            Asst. Prof.               Data Reduction and Analysis
J. R. Kelly                  Technician               Equipment Maintenance
Avis Rhoades                  Secretary
Anne Mintz                    Technical Asst.          Correlator Operator
Sue McLemore                  Technical Asst.          Correlator Operator
D. Program for December and January

The work scheduled for this period will be directed toward two objectives-first, an evaluation of the totality of data runs to determine if the quantity of information is adequate for the number of independent variables involved and to locate any significant omissions within the range of these variables and, second, completion of the study of the reliability of the data-reduction equipment and techniques.

Respectfully submitted:

V. R. Widauquist
Project Director

Approved:

[Signature]
Project Director
Engineering Experiment Station
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

PROGRESS REPORT NO. 34
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

1 FEBRUARY 1956

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PROGRESS REPORT NO. 34

PROJECT NO. 157-96

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BUships CONTRACT NO. NObar-49063

SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

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1 FEBRUARY 1956

CONFIDENTIAL
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<td>III. PROGRAM FOR FEBRUARY AND MARCH</td>
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The ultimate objective of the program of research under Contract NObsr-49063 is the development of means for the detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The over-all program is divided into three phases, namely (1) the theoretical and analytical phase, (2) the experimental phase and (3) the developmental phase. At the present time, the work being performed is part of the experimental phase and involves thorough experimental studies of radar echoes from the sea and from small surface targets at frequencies of 6300 and 35,000 mc. These experimental studies are concerned with both the statistical properties and the polarization properties of the radar echoes. The present work is directed toward preliminary reduction of data recorded during a recent field operation.
II. PROGRESS FOR DECEMBER AND JANUARY

The data recorded on the run sheets, which include all information except that contained in the average value recordings and the tape recordings, have been transferred to IBM cards. Four variables, namely, wind speed, wind aspect angle, wave height, and arrival angle (actually the angle of sight of the radar antenna with respect to the plane of the reflecting surface) appear to be of primary importance for evaluating completeness of the measurements. The range and the uniformity of distribution of these four variables has been determined for each of the radar frequencies with the following results.

For 6300 mc recordings a uniform distribution of wind speed was obtained for winds up to 24 knots. Although dominated by lower heights, a fair representation was obtained for wave heights up to 6 feet. For arrival angle, a uniform distribution was obtained for values between 0.6 and 2.3 degrees, with a few values occurring between 2.4 and 4.5 degrees. Adequate density of the wind aspect angle distribution is restricted to angles less than 60 degrees.

For 35,000 mc recordings, wind speed, wind aspect angle and wave height had approximately the same range as for 6300 mc, but since there were only about one-fifth as many runs at 35,000 mc, the distribution density of the variables could only be considered as fair. The arrival angle is generally restricted to values between 1.8 and 4.2 degrees.

In view of the prevailing wind conditions which exist at the field site and the fact that the field site is a shore-based installation, it appears that it would not be profitable to make further measurements exclusively at 6300 mc; however, simultaneous measurements at both 6300 mc and 35,000 mc are definitely needed. Additional data taken exclusively at 35,000 mc also appears desirable.

The study of the reliability of the data-reduction procedures was suspended when an unanticipated tape problem developed. In the fall of 1952, a supply of magnetic tape was acquired and has been used with varying
degrees of success. Problems such as tape fouling and tearing were attributed, primarily, to the tape-transport mechanism and to the operating requirements of the correlator and not to the mechanical properties of the tape. Since the original tape supply was nearly exhausted, a re-order was executed and received late in November. When placed in use, it was found that the new tape would not function satisfactorily because of rapid build up, within a few minutes operation, of a large quantity of oxide coating on the magnetic-recording heads. Since it initially requires about 15 minutes to adjust the correlator and about 3 hours to compute a correlation function, this difficulty makes it impossible to use the correlator with the new tape.

Discussion of this problem with representatives of the tape manufacturer has, so far, produced no results. There is indication that a change was made in the manufacturing process for the two lots of tape.
III. PROGRAM FOR FEBRUARY AND MARCH

For obvious reasons, a solution to the tape problem must be found. This work will be continued until proper operation has been obtained.

Analysis of the data on the average value of sea echo will be initiated.

Respectfully submitted:

V. R. Widcrquist
Project Director

Approved:

J. E. Boyd, Associate Director
Engineering Experiment Station
PROGRESS REPORT NO. 35
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. N0ber-49063
SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

1 APRIL 1956
PROGRESS REPORT NO. 35
PROJECT NO. 157-96

BUSHIPS CONTRACT NO. N0891-49063
SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

1 APRIL 1956
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This report contains 3 pages
I. INTRODUCTION

The ultimate objective of the original program of research under Contract NObsr-4963 was the development of means for detection, by shipborne radar, of small surface targets in the presence of severe sea clutter. The overall program was divided into three phases, namely, (1) the theoretical and analytical phase, (2) the experimental phase and (3) the developmental phase. This program has been recently modified to limit the work to a conclusion of the experimental phase. The revised program is concerned with completion of an experimental study of the statistical and polarization properties of sea echo and analysis of these experimental results. The present work is directed towards reduction of data recorded during the recent field operation.
II. PROGRESS FOR FEBRUARY AND MARCH

During a recent conference with the Contracting Officer's Technical Representative it was mutually agreed that no attempt should be made to develop a prototype operational radar equipment under this contract. Consequently the scope of future work will be limited to the reduction and analysis of data collected during the recent field operation for the purpose of contributing to knowledge about the statistical and polarization properties of sea echo and relationships of these properties with various parameters describing the radar systems, wind conditions, and sea conditions.

In the last progress report difficulty with a new supply of magnetic tape was discussed. Inquiries have indicated that this difficulty, a shedding of oxide coating, is not an uncommon occurrence. Consultation with representatives of the manufacturer failed to provide any explanation for the phenomenon or any suggestions for possible solution to the problem; however, after considerable experimentation it was concluded that the difficulty must be due to a change in the type of binding material used and possibly the method of application of the oxide coating to the cellulosed-backed tape. Finally, the manufacturer supplied an experimental, mylar-backed, high output, high temperature instrumentation tape (not yet commercially available) which was found to function satisfactorily. It was also found that another brand of instrumentation mylar-backed tape would perform satisfactorily. As soon as a sufficient quantity of either of these tapes is obtained, computation of first probability distributions and correlation functions with the analog computing equipment will begin.

Training of an analyst to read and interpret Sanborn chart recordings, which display the data on the average value of sea echo, has been completed and the consolidation in tabular form of the information contained on these recordings is in progress.
III. PROGRAM FOR APRIL AND MAY

Reading and interpretation of the data on the average values of sea echo will be continued and analysis of these data will be initiated when a sufficient quantity of tabulated data has been prepared.

Computation of first probability distributions and correlation functions for selected runs taken from the totality of data will be started.

Respectfully submitted:

V. R. Widerquist
Project Director

Approved

J. E. Boyd, Associate Director
Engineering Experiment Station
PROGRESS REPORT NO. 36
PROJECT NO. 157-96

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SHIPS CONTRACT NO. N00014-49063

SHIPBORNE RADAR DETECTION OF
TARGETS IN SEA CLUTTER

- - - - - -

JUNE 1956
PROGRESS REPORT NO. 36

PROJECT NO. 157-96

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BUSHIPS CONTRACT NO. NObsr-49063

SHIPBORNE RADAR DETECTION OF TARGETS IN SEA CLUTTER

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<td>III. PROGRAM FOR JUNE AND JULY</td>
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<tr>
<td>IV. PERSONNEL</td>
<td>6</td>
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I. INTRODUCTION

The objective of the program of research under Contract NObsr-49063 is a study of the statistical and polarization properties of sea echo. The work is presently concerned with an experimental examination of sea echo and directed toward reduction of data collected during a recent field operation.
II. PROGRESS FOR APRIL AND MAY

The major effective effort of this period was expended in reading all of the Sanborn recordings from which are derived values (expressed in decibels) for the average radar cross-section per unit area, \( \sigma^0 \), of sea echo. This information was then transferred to IBM cards for analysis. The analysis of these data was started before all of the reading was completed so that anomalies might be discovered and eliminated. The results of these preliminary studies are discussed below. A complete analysis of the average value data should be completed during the next report period. The calculations performed during the preliminary analysis were done with desk calculators. Computations for the complete analysis will be done on an IBM 650 Electronic Digital Computer.

The lack of useable magnetic tape prevented computation of the first probability distributions and the correlation functions with the analog computing equipment. Samples of tape furnished by two manufacturers during this period were given long trials and both proved satisfactory. Ten 2400-ft reels were ordered from each manufacturer on the basis of these results.

The "Irish" tape (manufactured by Orradio Industries) was received and proved to be unsatisfactory. Samples of the trial tape and the delivered tape were returned to their laboratory for comparison. A small difference was found in the hardness of the finish of the two, and a new sample reel is now being prepared at their laboratory.

The "Scotch" tape (manufactured by Minnesota Mining and Manufacturing Company) is expected about the middle of June.

The preliminary studies were made on 6300-mc data composed of 191 sets of simultaneous observations of \( \sigma^0 \) (in decibel notation), wind speed, wave height, arrival angle, wind aspect angle and wave aspect angle. A multiple regression type analysis was selected to describe the dependence of \( \sigma^0 \) on the other variables mentioned above. A linear equation which can be used to predict \( \sigma^0 \) from observed values of wind speed, \( X_1 \), wave height, \( X_2 \),
arrival angle, \( X_3 \), wind aspect angle, \( X_4 \), and wave aspect angle, \( X_5 \), was set up as follows:

\[
\sigma^o = A + \sum_{k=1}^{5} B_k X_k
\]

where \( A \) and \( B_k \) are constants evaluated from the data such that the sum of squares of the differences between \( \sigma^o \) observed, \( \sigma^o_{\text{obs}} \), and \( \sigma^o \) calculated, \( \sigma^o_{\text{cal}} \), from the prediction equation is a minimum ("least squares" fit). Two prediction equations were set up for \( \sigma^o \): one for horizontal polarization on transmission and reception, \( \sigma^o_{HH} \), and the other for vertical polarization on transmission and reception, \( \sigma^o_{VV} \).

A root mean square of the difference between the observed values and those calculated using a prediction equation is being used as an indication of how well we may expect a selected prediction equation to estimate \( \sigma^o \) for a given set of \( X_1, X_2, \ldots, X_5 \). This root mean square is called the standard error of estimate, \( S_{\sigma^o} \), and is defined as

\[
S_{\sigma^o} = \sqrt{\frac{\sum_{i=1}^{N} \left( \sigma^o_{\text{obs}} - \sigma^o_{\text{cal}} \right)^2}{N-K}}
\]

where \( N \) is the total number of observations and \( K \) is the number of independent variables used in the prediction equation.

If there were no prediction equation available the best estimate of \( \sigma^o \) would be the average value, \( \bar{\sigma}^o \), as observed over the set of data. The standard deviation of the set of \( \sigma^o \)'s is a measure of the error that would be made if the average value of \( \sigma^o \) were to be predicted regardless of the value of the variables \( X_1, X_2, \ldots, X_5 \) since the standard deviation \( s_{\sigma^o} \) is defined as

\[
s_{\sigma^o} = \sqrt{\frac{\sum_{i=1}^{N} \left( \sigma^o_i - \bar{\sigma}^o \right)^2}{N-1}}
\]
The multiple correlation coefficient, $R$, is defined as

$$R = \sqrt{\frac{s^2 \sigma^2 - S^2 \sigma^2}{s^2 \sigma^2}}$$

which is a measure of the error improvement using the linear prediction equation rather than the average value of $\sigma^0$ to estimate $\sigma^0$.

The table below is a summary of the preliminary studies. The reductions in error of estimation of $\sigma^0$ are significant and should be repeatable under further experimentation.

<table>
<thead>
<tr>
<th>Polarization</th>
<th>$s_\sigma^0$</th>
<th>$S_\sigma^0$</th>
<th>$\sigma^0$</th>
<th>N</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>5.8 db</td>
<td>3.5 db</td>
<td>-41.4 db</td>
<td>86</td>
<td>0.62</td>
</tr>
<tr>
<td>Vertical</td>
<td>4.3 db</td>
<td>1.06 db</td>
<td>-39.4 db</td>
<td>105</td>
<td>0.88</td>
</tr>
</tbody>
</table>


III. PROGRAM FOR JUNE AND JULY

Analysis of the data on average values of sea return will be continued.

Some of the experimental data will be recorded on magnetic tape and correlation functions for these data will be calculated.
**IV. PERSONNEL**

Effective 1 July 1956, personnel devoting considerable effort to this investigation will be as follows:

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. G. Boring</td>
<td>Research Assistant</td>
</tr>
<tr>
<td>E. R. Flynt</td>
<td>Special Research Engineer</td>
</tr>
<tr>
<td>D. S. Holmes</td>
<td>Assistant Project Director</td>
</tr>
<tr>
<td>J. R. Kelly, Jr.</td>
<td>Technician</td>
</tr>
<tr>
<td>C. A. Krohn</td>
<td>Assistant Research Engineer</td>
</tr>
<tr>
<td>H. P. Lenoir, Jr.</td>
<td>Special Research Engineer</td>
</tr>
<tr>
<td>M. W. Long</td>
<td>Project Director</td>
</tr>
<tr>
<td>A. S. McLemore</td>
<td>Technical Assistant</td>
</tr>
<tr>
<td>A. B. Mintz</td>
<td>Technical Assistant</td>
</tr>
<tr>
<td>A. B. Rhoades</td>
<td>Secretary</td>
</tr>
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Respectfully submitted:

V. R. Widequist
Project Director

Approved:

E. E. Boyd, Associate Director
Engineering Experiment Station
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

PROGRESS REPORT NO. 38
PROJECT NO. 157-96
SEA RETURN STUDY
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BUSHIPS CONTRACT NO. NObr-49063
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1 AUGUST TO 1 OCTOBER 1956
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

PROGRESS REPORT NO. 38
PROJECT NO. 157-96
SEA RETURN STUDY
Prepared By
J. G. BORING, E. R. FLYNT, and M. W. LONG
- o - o - o - o -
NUSMIPS CONTRACT NO. NObsr-49063
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1 AUGUST TO 1 OCTOBER 1956
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I. INTRODUCTION

The objective of the research under this contract is the accumulation of information on sea return which will be useful in detecting, by means of shipborne radar, small surface targets in the presence of severe sea clutter. Present effort is being directed toward processing and analyzing experimental data to determine statistical and polarization properties of sea return. These data were collected at Boca Raton, Florida, during the period January to November, 1955.

The experimental data consist of amplitude recordings of the output of a 6300-mc multiple polarization radar having horizontal beamwidths of 2-1/4° and 9°, and of a multiple polarization 35,000-mc radar having beamwidths of 5/8° and 2-1/2°. The data were collected with angles between the line-of-sight and horizontal of 0.7° to 4.2° and with ranges not exceeding 3000 yards.

In the equipment used, the output of each receiver is processed in a sampler to produce a voltage which represents the instantaneous echo amplitude at a predetermined range. The frequency characteristics of the sampler are such that the output waveform can contain intelligence frequencies as high as 1 kc. Consequently, a voltage time-function, the sampler output, is produced which is equivalent to the instantaneous radar cross section of a particular target area. The sampler outputs, one for each receiver, could be recorded by two methods: magnetic tape for electronic processing and paper graph for average value data. The magnetic tape unit, as normally operated, has a frequency pass-band from direct current to 100 cps.
II. PROGRESS

This report presents some of the results for the period 1 August to 1 October, 1956, of a program which is investigating the statistical and polarization characteristics of experimental sea return data. The work during this period has been primarily devoted to calculating autocorrelation functions and first probability distributions of sea echo. Future plans include the continuation of calculations and analyses of these data and of calculation of correlation coefficients between vertically and horizontally polarized echoes during transmission of either horizontally or vertically polarized waves.

A. First Probability Distributions

Seventy first probability distributions have been computed, of which 25 have been plotted for purposes of comparison. Figures 1 through 6 are curves chosen from this group to illustrate typical shapes. Pertinent parameters for these runs are listed in Figure 7.

To compute these distributions, the range of power over which the received signal fluctuated was divided into 14 equal intervals, and the fraction of the observation time during which the received power was within each of these intervals was measured. The total range of power actually used was from zero to a level exceeded during one percent of the observation time, since according to theory there is at least a small probability that the echo intensity will exceed any value of intensity, however large. The calibration process included in the computation provides compensation for receiver nonlinearities, so that the 14 power levels represent equal increments of received r-f power. The observation time for each curve is approximately 10 minutes.
The model most frequently used in describing the mechanism of sea return fluctuation is that of a number of independent randomly moving scatterers, such that the received echo is the vector sum of the echoes from the individual scatterers adding in random phase. Under the assumptions that the number of independently moving scatterers is sufficiently large and that the average amplitude of the component echoes from individual scatterers is constant, the first probability distribution has been shown to be

\[ W_1(P) \ dx = e^{\frac{-P}{P_0}} \frac{dx}{P_0} \]

where \( P_0 \) is the average intensity. It is seen that such a distribution is exponential in form, and may be represented on semilogarithmic graph paper as a straight line with a slope dependent on the average intensity, \( P_0 \).

It is generally agreed that the random scatterers referred to above are not individual ocean waves, but that the dimensions of the scatterers are small compared to the dimensions of ocean waves. It appears reasonable that when large waves are present, the echo fluctuation will be altered somewhat from that predicted by the above model, as successive waves pass through the illuminated area. This has been observed to be the case. As described in the last progress report, the autocorrelation function of sea return reveals a rapid component of fluctuation attributed to the doppler beats between the echoes from the random scatterers, a fluctuation component on a somewhat longer time scale attributed to the effects of ocean waves, and a variation on a much longer time scale attributed to gradual changes in the sea surface conditions during the ten-minute observation periods. It is to be expected that the fluctuation components attributed
to ocean waves and to gradual changes in surface conditions will cause the first probability distribution of echo intensity to be somewhat different from the exponential distribution predicted on the basis of the independent random scatterers alone. For example, if the effect of the periodic passing of ocean waves through the radar beam were approximated by assuming the addition of a sine-wave component to the echo intensity, the result would be to raise each end of the first probability distribution curve. The shape of the curve would be changed most noticeably on the lower end, where the logarithmic plot is most sensitive to small changes. This could provide a qualitative explanation for the extended "tail" of the distribution curve that has been reported by a number of observers. Representation of the component of echo fluctuation due to ocean waves by a function other than a sine wave would also have a similar effect on the distribution, provided that the probability distribution of the ocean-wave component has less slope on the end than the component due to small random scatterers.

An additional component of the radar data is receiver noise. Since the noise bandwidth is much greater than the bandwidth of the data recording system, the effect is to integrate the noise, causing a constant intensity approximately equal to the average noise intensity to be added to all measurements of sea echo. As a result, the most probable value of power is no longer zero, but is more nearly the mean value of the noise power. This is shown in some of the histograms of first probability distribution, in which the maximum height of the curve does not occur in the block representing the lowest power level. It is most noticeable in
Figures 5 and 6, representing the probability distributions of cross-polarized echoes, since the signal-to-noise ratio of the cross-polarized component is considerably lower than that of the direct-polarized component. The small portion of the noise spectrum falling within the bandwidth of the data recording equipment is reproduced as a fluctuation inseparably added to the sea echo fluctuation, but is considered to be small enough to be of no great consequence.

Figure 1 is a plot of the first probability distribution of sea echo, using vertically polarized transmission and reception. The histogram can be quite closely approximated by a single straight line on the semilogarithmic plot, indicating a very nearly exponential distribution. Figure 2 is the distribution of another data run using vertically polarized transmission and reception. This plot can also be approximated with a single straight line, with the exception of the first block in the histogram. Receiver noise is offered as a possible explanation of the lower block on the left end of the plot, as described above. Figures 1 and 2 are considered to be representative of all distributions plotted to date for vertical transmission and reception.

Figures 3 and 4 are distributions of sea echo, using horizontally polarized transmission and reception. It should be observed that the right-hand ends of both of these distributions are higher than they should be for best approximation by a single straight line. This situation has been found typical for horizontal polarization in that all distributions plotted to date for horizontal polarization have higher "tails" than any distribution plotted for vertical polarization. The qualitative explanation offered above for this "extended tail" phenomenon involved the effects of
individual ocean waves passing through the area illuminated by the radar. It is significant that observation of the radar A-scope display for horizontal polarization reveals the presence of a number of tall spikes, apparently related to individual large waves, and moving across the display in range at a rate commensurate with the rate of travel of the ocean waves. Such spikes related to individual waves are very much less in evidence on the A-scope display for vertical polarization. It also appears, in auto-correlation functions of sea echo, that the portion of the curves indicating fluctuations on a time scale comparable to the period of the ocean waves shows considerably greater amplitude for horizontal polarization than for vertical polarization.

Figures 5 and 6 show first probability distributions of cross-polarized sea return. Figure 5 is the distribution of data taken from a horizontally-polarized receiver during vertical transmission, recorded simultaneously with the data for Figure 2. Figure 6 is the distribution of data taken from a vertically-polarized receiver during horizontal transmission, recorded simultaneously with the data for Figure 4. The most significant characteristic of Figures 5 and 6, and of all distributions that have been computed from cross-polarized echoes, is the displacement of the peaks of the curves toward the right; expressed in other terms, it is the lower probability of power occurring in the very low power levels. The explanation for this situation that was offered above involved the presence of integrated receiver noise. This explanation is rendered more plausible by the fact that signal-to-noise ratio is much lower for cross-polarized signals. The average signal levels for Figures 5 and 6 were approximately 10 db below the corresponding direct-polarized signal levels for Figures 2 and 4.
Figure 1. A First Probability Distribution of 6300-mc Sea Return Vertically Polarized Transmission and Reception.
Figure 2. A First Probability Distribution of 6300-mc Sea Return Vertically Polarized Transmission and Reception.
Figure 3. A First Probability Distribution of 6300-mc Sea Return Horizontally Polarized Transmission and Reception.
Figure 4. A First Probability Distribution of 6300-mc Sea Return Horizontally Polarized Transmission and Reception.
Figure 5. A First Probability Distribution of 6300-mc Sea Return Vertically Polarized Transmission, Horizontally Polarized Reception.
Figure 6. A First Probability Distribution of 6300-mc Sea Return Horizontally Polarized Transmission, Vertically Polarized Reception.
<table>
<thead>
<tr>
<th>Figure No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td>513</td>
<td>518</td>
<td>519</td>
<td>513</td>
<td>519</td>
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<tr>
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<td>6300</td>
<td>6300</td>
<td>6300</td>
<td>6300</td>
<td>6300</td>
<td>6300</td>
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<tr>
<td>Pulse Length (μsec)</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Range Gate (μsec)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
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<td>3035</td>
<td>3035</td>
<td>3035</td>
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<td>450</td>
<td>450</td>
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<td>Antenna Height (ft)</td>
<td>83</td>
<td>83</td>
<td>65.9</td>
<td>65.9</td>
<td>83</td>
<td>65.9</td>
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<td>Grazing Angle (degrees)</td>
<td>3.4</td>
<td>3.4</td>
<td>2.8</td>
<td>2.8</td>
<td>3.4</td>
<td>2.8</td>
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<tr>
<td>Horizontal Beamwidth (degrees)</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
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<tr>
<td>Wind Speed (mph)</td>
<td>10</td>
<td>7.5</td>
<td>7.5</td>
<td>7</td>
<td>7.5</td>
<td>7</td>
</tr>
<tr>
<td>Wave Height (ft)</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Observation Time (min)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Sea Surface</td>
<td>Short-crested waves, light to medium chop, occasional whitecaps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7. Pertinent Data for Figures 1 through 6
B. Correlation Functions

During this report period, the plotting of correlation functions has continued as the data are computed. The correlation functions have been normalized and each curve plotted on two different time scales as described in the last progress report. To date 47 autocorrelation functions for 35,000-mc echo have been computed, which is all of the data for that frequency. Several auto- and cross-correlation functions have been computed from 6300-mc data.

As discussed in the last progress report, the correlation functions may be considered as the sum of three components having short, medium, and long decorrelation times, respectively, and in some cases an additional periodic component with a period comparable to the decorrelation time of the medium-time component. Measurements of the amplitude and width of these components of the correlation curves are being made in an effort to determine their dependence on sea and wind conditions and on radar parameters. The values that are measured are illustrated by the letters A through G on Figure 8, and are defined as follows:

\[ A = \text{the amplitude of the short-decorrelation-time component, measured from the peak of the curve to the first sharp break in the downward slope}, \]

\[ B = \text{the amplitude of the medium-decorrelation-time component, measured from the lower end of A to the asymptote of the lower portion of the curve}, \]

\[ C = \text{the amplitude of the long-decorrelation-time component, measured from the lower end of B to the abscissa}, \]

\[ D = \text{the width of the short-time component, measured at the amplitude of } A/2, \]

\[ E = \text{the width of the medium-time component, measured at the amplitude of } B/2, \]
Figure 8. Illustration of the Characteristics Measured on Correlation Functions.
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\[ F = \text{the amplitude of any periodic component present, measured as the vertical distance between the first minimum and the succeeding maximum, and} \]

\[ G = \text{the half-period of any periodic component present, measured as the horizontal distance between the first minimum and the succeeding maximum.} \]

C. Average Value Data

As indicated in the last two progress reports, the multiple regression type of analysis on the average value 6300-mc data has been employed in connection with predicting the dependence of \( \sigma^0 \) on sea conditions. The forms of the prediction equations have been based primarily on simplicity rather than on a physical model, for use in gaining an insight into this type of mathematical analysis. Some knowledge of the dependence of \( \sigma^0 \) on sea conditions has been gained while acquiring experience in programming for this complex type of analysis. An effort to develop a prediction equation based on a physical model has been made concurrently with the data processing work. This effort has been devoted to determining the dependence of \( \sigma^0 \) on a single independent variable by selecting data for which other variables are essentially constant. To date this effort has not been markedly successful except that strong dependence of \( \sigma^0 \) on wind speed and arrival angle has been noted. Our data, however, do indicate that \( \sigma^0 \) is proportional to the square of wind speed as reported in the literature.

For the sake of completeness, the work on multiple regression analysis is repeated here. Desk calculators were used on 191 sets of simultaneous equations.

observations of $\sigma^0$ and sea conditions to determine the accuracy of a prediction equation of the form:

$$10 \log_{10} \sigma^0 = A + \sum_{k=1}^{5} B_k X_k$$

where $A$ and $B_k$ are constants evaluated from the data for a least squares fit between $\sigma^0$ calculated and $\sigma^0$ observed. The $X_k$'s represent wind speed, arrival angle, wave height, wind aspect angle and wave aspect angle, respectively. Two prediction equations were used: one for transmission and reception of horizontal polarization and the other for transmission and reception of vertical polarization.

When it became possible to perform this analysis on the IBM 650 Electronic Computer, instead of repeating the calculations already done, an equation of the following form was used:

$$10 \log_{10} \sigma^0 = a_0 + a_1 \log X_1 + a_2 \log X_2 + a_3 X_3 + a_4 X_4 + a_5 X_5 + a_6 \log X_1 \log X_2$$

The log transformations were used for wind speed and arrival angle because this appeared from graphs of $10 \log_{10} \sigma^0$ with wind speed (and arrival angle), with other variables held constant, to be a better relationship than a linear relationship. The cross product was inserted to take into account change of the form of dependence of $\sigma^0$ on wind speed for different arrival angles. This term cannot degrade the prediction equation since $a_6$ would automatically become zero if it produced no improvement. Results for the horizontal and vertical prediction equations follow.
### Progress Report No. 38, Project No. 157-96

<table>
<thead>
<tr>
<th>Polarization</th>
<th>$s_{\sigma}$</th>
<th>$S_{\sigma}$</th>
<th>$\text{av value of } 10 \log_{10} \sigma^2$</th>
<th>$N$</th>
<th>$R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>5.8 db</td>
<td>4.5 db</td>
<td>-61.6 db</td>
<td>82</td>
<td>0.64</td>
</tr>
<tr>
<td>Vertical</td>
<td>3.6 db</td>
<td>2.6 db</td>
<td>-38.9 db</td>
<td>74</td>
<td>0.71</td>
</tr>
</tbody>
</table>

In this table $S_{\sigma}$ is the standard error of estimate of the prediction equation for the observed set of data, $s_{\sigma}$ is the standard deviation of the set of observed $\sigma^2$ from the average ($\sigma^2$ expressed in decibels), $N$ is the number of sets of data and $R$ is the multiple correlation coefficient. These results indicate less success with the second prediction equation than with that using the simple linear equation obtained on the desk calculator, but they still indicate a high degree of correlation of $\sigma^2$ with the observed data.

The lower multiple correlation coefficients obtained with the more complex equation was not understood, and it was thought advisable to re-calculate the equations in the linear form with the aid of the electronic computer. There was some slight adjustment in the data. The results from this re-calculation showed the first calculations on the desk computer were in error.

The results obtained from use of the electronic computer are given as follows:
<table>
<thead>
<tr>
<th>Polarization</th>
<th>$s_1^o$</th>
<th>$S_1^o$</th>
<th>$10 \log_{10} \sigma^2$</th>
<th>N</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>5.8 db</td>
<td>3.2 db</td>
<td>-41.4 db</td>
<td>85</td>
<td>0.84</td>
</tr>
<tr>
<td>Vertical</td>
<td>6.8 db</td>
<td>6.0 db</td>
<td>-38.7 db</td>
<td>105</td>
<td>0.89</td>
</tr>
</tbody>
</table>

With $X_1$'s having the same representations as in the first equation, the regression equations for vertical and horizontal polarization, respectively, are:

\[ 10 \log_{10} \sigma^2 = -52.139 + 0.720 X_1 + 2.246 X_2 + 0.985 X_3 - 0.061 X_4 + 0.017 X_5 \]

\[ 10 \log_{10} \sigma^2 = -53.894 + 0.668 X_1 + 1.299 X_2 + 2.185 X_3 + 0.011 X_4 - 0.113 X_5 \]

Further work with multiple regression analysis will not be done until a prediction equation based on theory has been determined. It is hoped that this equation will be of such a form that can be used for a wider range of variables than is available with our data.
III. PROGRAM FOR OCTOBER AND NOVEMBER

Analysis to determine dependence of the average cross-section per unit area on sea conditions and radar parameters will be continued. Calculation and analysis of correlation functions and first probability distributions of sea echo will be continued, and the computation of correlation coefficients between vertically and horizontally polarized echoes during transmission of either horizontally or vertically polarized waves will be initiated.

Respectfully submitted:

M. W. Long
Project Director

Approved:

[Signatures]
J. E. Boyd, Associate Director
Engineering Experiment Station
PROGRESS REPORT NO. 39

PROJECT NO. 157-96

SEA RETURN STUDY

BUSHIPS CONTRACT NO. N0bsr-49063

1 OCTOBER TO 1 DECEMBER 1956
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

PROGRESS REPORT NO. 39
PROJECT NO. 157-96
SEA RETURN STUDY
Prepared by
J. G. BORING, E. R. FLINT, and M. W. LONG
BUSHIPS CONTRACT NO. NObsr-49063
1 OCTOBER TO 1 DECEMBER 1956
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</tbody>
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## FIGURE

1. Illustration of the Characteristics Measured on Correlation Functions | 3    |
I. INTRODUCTION

The objective of the research under this contract is the accumulation of information on sea return which will be useful in detecting, by means of shipborne radar, small surface targets in the presence of severe sea clutter. Present effort is being directed toward processing and analyzing experimental data to determine statistical and polarization properties of sea return. These data were collected at Boca Raton, Florida, during the period January to November, 1955.

The experimental data consist of amplitude recordings of the output of a 6300-mc multiple polarization radar having horizontal beamwidths of 2-1/4° and 9°, and of a multiple polarization 35,000-mc radar having beamwidths of 5/8° and 2-1/2°. The data were collected with angles between the line-of-sight and horizontal of 0.7° to 4.2° and with ranges not exceeding 3000 yards.

In the equipment used, the output of each receiver is processed in a sampler to produce a voltage which represents the instantaneous echo amplitude at a predetermined range. The frequency characteristics of the sampler are such that the output waveform can contain intelligence frequencies as high as 1 kc. Consequently, a voltage time-function, the sampler output, is produced which is equivalent to the instantaneous radar cross section of a particular target area. The sampler outputs, one for each receiver, could be recorded by two methods: magnetic tape for electronic processing and paper graph for average value data. The magnetic tape unit, as normally operated, has a frequency pass-band from direct current to 100 cps.
II. COMPUTATION AND ANALYSIS

This report presents some of the results for the period 1 October to 1 December, 1956, of a program which is investigating the statistical and polarization characteristics of experimental sea return data. The work during this period has been primarily devoted to the following:

1. calculation and analysis of correlation functions,
2. computation of correlation coefficients between vertically and horizontally polarized echoes and
3. initiation of analysis of average-value data for 35,000 mc.

A. Calculation and Analysis of Correlation Functions

Computation and plotting of autocorrelation and crosscorrelation functions, as described in the last progress report, have been continued during this report period. A partial analysis has been made of curves computed from 54 data runs at 35,000 mc and 85 data runs at 6,300 mc.

As previously discussed, each curve may be resolved into three components, apparently associated with three distinct random physical phenomena, and in some cases an additional component which is periodic. Figure 1 is a correlation curve repeated from the last progress report, to illustrate the measurements that are being made on each curve. In Figure 1, measurements A, B, and C are the amplitudes of the components having short, medium, and long decorrelation times, respectively. D is the width, at the half-amplitude point, of the short-time component, and E is the width of the medium-time component. F and G are the amplitude and half-period of the periodic component. Calculations are being made to relate variations in these measurements to changes in radar parameters and sea and wind conditions.
Figure 1. Illustration of the Characteristics Measured on Correlation Functions.
Measurement A, Figure I, is believed to be an approximate measure of power contained in rapid fluctuations caused by doppler beats between the echoes from a large number of small randomly-moving scatterers on the sea surface. Measurement B is believed to be an approximate measure of power contained in signal fluctuations associated with random echoes from individual ocean waves. The ratio B/A, irrespective of the normalizing process in plotting the curves, would then be an indication of the ratio of power contained in random fluctuations caused by ocean waves to power contained in fluctuations caused by the randomly moving small scatterers. Tabulated below is information concerning the ratio B/A.

<table>
<thead>
<tr>
<th>Frequency (mc)</th>
<th>Polarization</th>
<th>B/A Max.</th>
<th>B/A Min.</th>
<th>B/A Mean</th>
<th>No. of Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>35,000</td>
<td>V</td>
<td>0.56</td>
<td>0.05</td>
<td>0.21</td>
<td>29</td>
</tr>
<tr>
<td>35,000</td>
<td>H</td>
<td>3.09</td>
<td>1.04</td>
<td>1.91</td>
<td>24</td>
</tr>
<tr>
<td>6,300</td>
<td>V</td>
<td>0.28</td>
<td>0.00</td>
<td>0.05</td>
<td>37</td>
</tr>
<tr>
<td>6,300</td>
<td>H</td>
<td>1.72</td>
<td>0.08</td>
<td>0.69</td>
<td>37</td>
</tr>
</tbody>
</table>

Since, at each frequency, the ratio for horizontal polarization is notably greater than the ratio for vertical polarization, it is indicated that the contribution of individual ocean waves is significantly greater on horizontal than on vertical polarization. This conclusion is consistent with the visual appearance of clutter return from the two polarizations and with other statistical measurements.

The fact that the above values for B/A are consistently lower for 6,300-mc data than for 35,000-mc data should not be used to draw any conclusions as to the dependence of B/A on radar frequency. This group of data runs
was not made simultaneously on both frequencies, but rather all of the 6,300-
mc runs were made several weeks later than the 35,000-mc runs. A part of
the difference may be caused by a difference in sea and wind conditions. No
analysis has yet been made of the dependence of B/A on such factors as wave
height and wind speed. Furthermore, there is reason to believe that the
100-cycle bandwidth of the recording device used for these runs was adequate
for the 6,300-mc data but was less than the highest significant fluctuation
frequencies of the 35,000-mc data. It is possible that this recorder band-
width limitation results in an abnormally high value of B/A at 35,000 mc,
since the higher fluctuation frequencies associated with measurement A pos-
sibly were attenuated with respect to the lower frequencies associated with
measurement B.

Measurement C, Figure 1, is the residue of the correlation curve after
subtracting the component that decorrelates rapidly because of the small
randomly-moving scatterers and the component that decorrelates in a moderate
time because of random echoes from individual ocean waves. It is assumed
that this residue, C, would drop to zero after a sufficiently long time delay,
and that C represents very slow changes in the sea return caused by gradual
changes in wind and sea surface conditions. No further analysis of C is con-
templated beyond the recognition of its presence and underlying cause.

If it is assumed that measurement D, Figure 1, is related to fluctuation
frequency components due only to the doppler beats between independently
moving random scatterers, then D should be inversely proportional to radar
frequency. It has been found that D is consistently smaller for 35,000-mc
data than for 6,300-mc data. Because of the previously mentioned bandwidth limitation of the recording device, the value of D measured at 35,000 mc is greater than the true value. The exact relationship of D to radar frequency, therefore, cannot be properly determined from these data runs. A few runs were made with a recorder with adequate bandwidth, but they have not yet been analyzed to determine whether they give an accurate indication of the manner in which the echo fluctuation frequencies are related to radar frequency.

The recorder bandwidth appears to be adequate for all of the 6,300-mc data. Computations have been made from 6,300-mc data to relate variations of measurement D with wind and sea conditions. A significant relationship was found between D and wind speed. Plots of D versus wind speed, while indicating some scatter, appear to be approximately linear. Coefficients of linear correlation of D with wind speed were computed and are tabulated below.

<table>
<thead>
<tr>
<th>Transmitted Polarization</th>
<th>Received Polarization</th>
<th>Linear Cor. Coef.</th>
<th>Number of Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>V</td>
<td>-0.77</td>
<td>31</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>-0.72</td>
<td>37</td>
</tr>
<tr>
<td>V</td>
<td>H</td>
<td>-0.58</td>
<td>24</td>
</tr>
<tr>
<td>H</td>
<td>V</td>
<td>-0.62</td>
<td>13</td>
</tr>
</tbody>
</table>

The negative sign indicates that on the average D increases as wind speed decreases. A decrease in D implies an increase in the frequency components of echo fluctuation.

All of the above correlation coefficients are sufficiently large to indicate a significant relationship between D and wind speed. The observations
for cross-polarized echoes were for smaller ranges of wind speed than those for transmission and reception of like polarizations. This may account for the lower coefficients for the cross-polarized data.

B. Computation of Correlation Coefficients

Linear correlation coefficients between simultaneously received vertically and horizontally polarized echoes have been computed for 64 runs. These data are for 6,300 mc.

The following table includes information related to the correlation coefficients.

<table>
<thead>
<tr>
<th>Transmitted Polarization</th>
<th>Correlation Coefficient</th>
<th>Number of Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td>horizontal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.36</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>0.06 - 0.74</td>
<td></td>
</tr>
<tr>
<td>vertical</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.23</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>0.01 - 0.51</td>
<td></td>
</tr>
</tbody>
</table>

The following indicates that the mode of the correlation coefficients for each polarization is lower than the corresponding mean.

<table>
<thead>
<tr>
<th>Polarization</th>
<th>Correlation Coefficient</th>
<th>Number of Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>horizontal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.06</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.13</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.20 - 0.29</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>0.30 - 0.39</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0.40 - 0.49</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>0.50 - 0.59</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>0.60 - 0.64</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.74</td>
<td>1</td>
</tr>
<tr>
<td>vertical</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.01 - 0.09</td>
<td>3</td>
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</table>
It appears that the correlation of the received signals is higher when the transmitted polarization is horizontal than when it is vertical.

C. Analysis of Average Value Data

Initial analysis of 35,000-mc data began during this report period. There were only 49 data runs made on this band for average value data as compared with 198 for 6,300 mc. Due to this small amount of 35,000-mc data, which was measured under a wide range of conditions, the dependence of $\sigma^0$ (average radar cross section per unit area) on sea conditions has not yet been determined. Information pertinent to the 35,000-mc average value data is included in Chapter III.

Some comparisons have been made between values of $\sigma^0$ for 35,000 mc and those for 6,300 mc. For this purpose, all 35,000-mc data were used, but the 6,300-mc runs considered were only those for which the ranges of values of arrival angle, wind speed, and wave height were within the ranges encountered in the 35,000-mc runs. These ranges are:

arrival angle, 1.5 to 4.0°
wind speed, 4.0 to 20.0 knots
wave height, 0.3 to 3.1 ft.

The data were not sorted according to wind and wave directions in these comparisons. Although various wind and wave directions are involved, the waves and wind in the majority of runs tended to be moving toward the radar along the line-of-sight.
Values of $\sigma^0$ are listed in the following table for comparison.

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<th>Polarization</th>
<th>$\sigma^0$ (db)</th>
<th>Number of Observations</th>
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<tr>
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<tr>
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The data below are the results of simultaneous reception of both polarizations, i.e., the differences are based on differences occurring in individual data runs.

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<th>Difference between $\sigma^0$ for parallel-polarized reception and $\sigma^0$ for cross-polarized reception (db)</th>
<th>Number of Observations</th>
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III. AVERAGE VALUE DATA FOR 35,000 MC

Because of its interest to others in the field, pertinent data for the 35,000-mc runs are included here. Data are ordered according to angle of arrival.

35,000-mc Data
Horizontally-Polarized Transmission

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<th>C</th>
<th>D</th>
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<th>F</th>
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### Vertically-Polarized Transmission

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<th>B</th>
<th>C</th>
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</table>
Column A—Angle of arrival in degrees.

Column B—Wind speed in knots. The speed is an average measured during the recording period.

Column C—Wave height in feet. The wave height was estimated from a wave pole near the surf.

Column D—Wind aspect angle in degrees. The wind aspect is the angle between the wind direction (averaged over the run) and the target azimuth. Following this scheme, a wind aspect angle of 0° indicates that the radar is looking upwind, and for angles of 180° the radar is looking downwind.

Column E—Wave aspect angle in degrees. Wave aspect is defined similarly to wind aspect.

Column F—Average value of the cross section per unit area of sea return expressed in decibels. This value was obtained by averaging the return having a polarization parallel to that transmitted.

Column G—Average value of the cross section per unit area of sea return for cross-polarized echoes.

Column H—Column G subtracted from Column F.
IV. PROGRAM FOR DECEMBER AND JANUARY

Analysis to determine dependence of the average cross section per unit area on sea conditions and radar parameters will be continued. This analysis will be directed toward the cross section for back scattering which is polarized parallel and perpendicular to the transmitted polarization. Analysis of correlation functions will be continued.

Respectfully submitted:

[Signature]

Joye G. Boring

Approved:

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PROGRESS REPORT NO. 40
PROJECT NO. 157-96
SEA RETURN STUDY
--o--o--o--o--
BUSHIPS CONTRACT NO. NObsr-49063
--o--o--o--o--
1 DECEMBER 1956 TO 1 FEBRUARY 1957
ENGINEERING EXPERIMENT STATION
of the Georgia Institute of Technology
Atlanta, Georgia

PROGRESS REPORT NO. 40
PROJECT NO. 157-96
SEA RETURN STUDY
Prepared by
E. R. FLYNT and M. W. LONG

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BUSHIPS CONTRACT NO. NObar-49063

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1 DECEMBER 1956 TO 1 FEBRUARY 1957
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I. INTRODUCTION

The objective of the research under this contract is the accumulation of information on sea return which will be useful in detecting, by means of shipborne radar, small surface targets in the presence of severe sea clutter. Recent effort has been devoted toward processing and analyzing experimental data to determine statistical and polarization properties of sea return. Research on sea return will be terminated during May, 1957, at which time a final report will be submitted to the contracting agency.

The experimental data consist of amplitude recordings of the output of a 6300-mc multiple polarization radar having horizontal beamwidths of 2-1/4° and 9°, and of a multiple polarization 35,000-mc radar having beamwidths of 5/8° and 2-1/2°. The data were collected with angles between the line-of-sight and horizontal of 0.7° and 4.2° and with ranges not exceeding 3000 yards. These data were collected at Boca Raton, Florida, during the period January to November 1955.

In the equipment used, the output of each receiver is processed in a sampler to produce a voltage which represents the instantaneous echo amplitude at a predetermined range. The frequency characteristics of the sampler are such that the output waveform can contain intelligence frequencies as high as 1 kc. Consequently, a voltage time-function, the sampler output, is produced which is equivalent to the instantaneous radar cross section of a particular target area. The sampler outputs, one for each receiver, could be recorded by two methods: magnetic tape for electronic processing and paper graph for average value data. The magnetic tape unit, as normally operated, has a frequency pass-band from direct current to 100 cps.
II. PROGRESS

This report presents some results of work performed from 1 December 1957 to 1 February 1957, on a program which is investigating the statistical and polarization characteristics of experimental sea return data. The work during this period has been devoted to calculation and analysis of correlation functions and preparation of data in a form suitable for presentation in the final report.

A. Polarization Dependence of Echo Fine Structure

A short time after the measurement program was started the operating personnel noticed that under certain conditions there was a marked difference between the characteristics of echo produced by horizontal transmission and reception (HH) and that produced by vertical transmission and reception (VV). With continuing observation it became apparent that the degree of difference was affected by the sea state, with the greatest difference occurring during periods of dead calm or a calm sea with a rippled surface. These differences were observed with both the 6300-mc and the 35,000-mc systems. For brevity, only partial results of tests performed at 6300-mc are included in this report.


A difference between VV echo and HH echo is portrayed in the photographs of Figure 1. These were obtained by photographing an A-scope having a sweep repetition frequency of 3,000 per second with an exposure time of 0.1 seconds. Consequently, each photograph represents approximately 300 successive traces. Gains were adjusted so that "hard" saturation of the echo signals was uncommon.

The measurements were made with the 6300-mc system using the 2-1/4° antenna with an antenna height of approximately 52 feet, and a 0.19-microsecond transmitted pulse length. The antenna was pointing into the wind and waves with an
Figure 1. Photographs each containing 300 successive range traces:
(a) Vertical transmission and reception, photographs taken randomly.
(b) Horizontal transmission and reception, taken only when echo was visible.
elevation angle maximizing the signal at approximately midrange. The wind speed was constant at 8-1/2 knots. The sea was characterized by short crested waves approximately one foot high covered with light chop and a few small white caps.

The photographs of VV echo were taken at random intervals without observing the radar scope. On the other hand the photographs of HH echo were obtained by observing the radar display and making exposures when echoes were present. The photographs of VV echo are typical of what would be observed at any randomly selected observation time. A casual look at Figure 1 will give an entirely false impression about the rate of occurrence of pikes in the HH echo since much of the time the scope trace was unbroken or had a barely perceptible echo present. These photographs were obtained by continuously monitoring the display and making exposures only when echo was visible. From the photographs in Figure 1 it is evident that VV echo has no well defined characteristics. On the other hand the HH echo usually appears as a single well defined echo having the same shape as the transmitted pulse--thus appearing as if produced by a single reflector. The overshoot on the trailing edge of the echo is due to an equipment limitation. This pronounced difference between the echoes obtained for the two polarizations was commonly observed for low sea states.

2. Results From Fixed Range Sampling.

In the equipment used for fixed range sampling, the output of each receiver is processed in a sampler to produce a voltage which represents the instantaneous echo amplitude at a predetermined range. The pulse repetition frequency of the radar system was 3,035 pulses per second, a rate sufficiently high to insure that the instantaneous cross section of the sea surface would not change
by a measurable amount between successive pulses. The wave form, which represents the instantaneous cross section, was integrated in a simple r-c filter having a variable time constant, and the output of the integrator was plotted with a paper chart recorder.

A time plot of the results obtained by integrating the instantaneous VV echo from a fixed range, by use of a low pass filter having a time constant of 0.06 seconds, is presented in Figure 2. It is seen that the echo fluctuates in a random fashion even though the high-frequency components have been removed.

The results obtained when HH echo was processed in a similar manner are displayed in Figure 3. Here again the spiky echo produced when utilizing horizontal transmission is quite obvious and it is evident that a considerable portion of the time the signal is essentially zero. When comparing the amplitude of the fluctuations for the VV echo and the HH echo it is seen that the dynamic range of the VV echo is much smaller than that of the HH echo and at all times the echo amplitude remains well above zero. On the other hand the HH echo is essentially zero for a large portion of the time and actually reaches saturation on occasional large spikes. The dynamic range of the system and calibration of the recorder is approximately the same for the two echoes.


Paper chart recordings were also made of the cross-polarized component of echoes for vertical and horizontal transmissions. Some 6300-mc recordings are illustrated in Figures 4 and 5, for which calibration marks are given at 2-db intervals and a reference of $\sigma^0$ in db is shown. The equipment as operated for these measurements possessed sufficient isolation between polarizations in the
Figure 2. Typical $\sigma_{VV}^0$ at 6300 mc. Filter time constant 0.06 sec.

Figure 3. Typically spiky $\sigma_{HH}^0$ at 6300 mc. Filter time constant 0.06 sec.
Figure 4. $\sigma_{VV}^0$ (upper) and $\sigma_{VH}^0$ (lower) at 6,300 mc. Filter time constant 0.06 sec.

Figure 5. $\sigma_{HV}^0$ (upper) and $\sigma_{HH}^0$ (lower) at 6,300 mc. Filter time constant 0.06 sec.
antenna and the receiving equipment to insure that cross talk was more than 25 db below the signal level in the direct receiving channel.

The beamwidth was 9°, the arrival angle was 4°, the illuminated area was 72 feet wide by 100 feet in range, and the radar antenna was pointed into the waves. The wind velocity was quite variable with an average value of about 11 knots at an aspect angle of 35° from the line of sight of the radar antenna. In addition to the small waves covered with chop and a few small white caps, a well defined swell of approximately 3 feet in height had an aspect angle of 55°.

Examination of $\sigma_{HH}^0$ reveals the characteristic spiky echo associated with HH. From recordings for the cross-polarized components $\sigma_{HH}^0$ and $\sigma_{HV}^0$, it appears that the cross-polarized components are more spiky than $\sigma_{VV}^0$ but less spiky than $\sigma_{HH}^0$.

B. Correlation Functions

Computation and plotting of autocorrelation functions have been continued during this report period. An analysis has been made of curves computed from 54 data runs at 35,000-mc and 114 data runs at 6300-mc.

As previously discussed, each curve may be resolved into three components, apparently associated with three distinct random physical phenomena, and in some cases as additional component which is periodic. Figure 6 is an autocorrelation curve, repeated from previous reports to illustrate the measurements that are being made on each curve. In Figure 6, measurements A, B and C are the amplitudes of the components having short, medium and long decorrelation times, respectively. D is the width, at the half-amplitude point, of the short-time component, and E is the width of the medium-time component. F and G are the amplitude and half-period of the periodic component. Calculations are
Figure 6. Illustration of the Characteristics Measured on Correlation Functions.
being made to relate variations in these measurements to changes in radar parameters, and sea and wind conditions.

Measurement A, Figure 6, is an approximate measure of power contained in rapid signal fluctuations, believed to be caused by doppler beats between the echoes from a large number of small randomly-moving scatterers on the sea surface. Measurement B is an approximate measure of power contained in much slower signal fluctuations, believed to be associated with random effects of individual ocean waves. The ratio B/A, irrespective of the normalizing process in plotting the curves, would then be an indication of the ratio of power contained in random fluctuations caused by ocean waves, to power contained in fluctuations caused by the randomly-moving small scatterers. Figure 7 shows the mean value of B/A for a number of curves at each frequency and polarization.

In Figure 7, the ratio B/A for horizontally polarized transmission and reception is notably greater than the ratio for vertically polarized transmission and reception. The ratio B/A is approximately the same for horizontally polarized transmission and vertically polarized reception as for vertically polarized transmission and horizontally polarized reception, as might be expected. These ratios for cross-polarized return are greater than the ratio for vertically polarized transmission and reception. The above observations all lead to the conclusion that the contribution of individual ocean waves is significantly greater on horizontal than on vertical polarization. This conclusion is consistent with other statistical measurements, and with the visual appearance of the clutter return from the two polarizations.

With either transmission polarization, the value of B/A for the cross-correlation of horizontal and vertical returns is greater than B/A for the
<table>
<thead>
<tr>
<th>Frequency (mc)</th>
<th>Transmitted Polarization</th>
<th>Received Polarization</th>
<th>Curve Measured</th>
<th>Mean B/A</th>
<th>No. of Runs</th>
</tr>
</thead>
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<tr>
<td>6300</td>
<td>H</td>
<td>H</td>
<td>Autocorrelation</td>
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<td>50</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>V</td>
<td>V</td>
<td>Autocorrelation</td>
<td>0.21</td>
<td>29</td>
</tr>
</tbody>
</table>

Figure 7. Mean values of B/A computed from correlation curves.
autocorrelation of either horizontal or vertical return. This implies that the degree of coherence between the horizontally and vertically polarized components of the return is greater for the mechanism responsible for B than for the mechanism responsible for A. This is compatible with the belief that A is related to the doppler beats between echoes from many randomly-moving small scatterers and that B is related to individual ocean waves.

The fact that the values of B/A shown in Figure 7 for 35,000-mc are greater than the corresponding values for 6300-mc should not be used to draw any conclusions as to the dependence of B/A on radar frequency. There is reason to believe that the 100-cycle bandwidth of the recording device was adequate for the 6300-mc data but was less than the highest significant fluctuation frequencies of the 35,000-mc data. It is possible that this recorder bandwidth limitation results in an abnormally high value of B/A at 35,000 mc, since the higher fluctuation frequencies associated with measurement A possibly were attenuated with respect to the lower frequencies associated with measurement B.

The study of B/A ratios described above all relate to mean values of B/A taken from a large number of correlation curves. In addition, an attempt was made to relate variations in B/A from one curve to another, to variations in sea and wind conditions. The range of values was quite wide. For example, in the 50 curves of horizontally polarized transmission and reception at 6300-mc B/A ranged from a minimum of 0.08 to a maximum of 1.72, with a mean value of 0.70. Nevertheless, no significant correlation was found between the values of B/A and wave height, wind speed, or angle of incidence. Apparently B/A is related to some other conditions, such as shapes of the sea surface structure not adequately described by such gross measurements as wave height and wind speed.
Measurement C, Figure 6, is the residue of the correlation curve after subtracting the component that decorrelates rapidly because of the small randomly-moving scatterers and the component that decorrelates in a moderate time because of random echoes from individual ocean waves. Measurement C represents a component having a very long decorrelation time. Most of the curves do not reach the abscissa within the 6 seconds of time delay for which the curves have been computed. In a few instances points have been computed for much longer time delays, and these have demonstrated that the curves do eventually approach the abscissa. It appears that the component having very long decorrelation time is caused by slow changes in the condition of the sea surface, occurring within the 10-minute data recording interval, but extending over a time much longer than the 6-second time delay for which the curves are plotted. No further analysis of C has been made, beyond the recognition of its presence and underlying cause.

Measurement D, Figure 6, is the width, at the half-amplitude point, of the component having a short decorrelation time. If this component is due entirely to doppler beats between the echoes from many small randomly-moving scatters, then D should be inversely proportional to radar frequency. This has been found to be approximately true. In addition to the frequency dependence, D has been found to vary approximately inversely as wind speed. This wind speed dependence indicates an increasing relative velocity between individual scatterers with increasing wind speed. There appears to be no significant dependence of D on transmitted or received polarization. From a total of 149 autocorrelation curves at 6300-mc, the maximum value was 16.25 milliseconds, the minimum value was 0.33 milliseconds, and the mean was 6.75 milliseconds.
Measurement E, Figure 6, is the width, at the half-amplitude point of the component having medium decorrelation time. Although this value varies somewhat from one data run to another, no consistent relationship could be found between E and radar frequency, polarization, wave height, or wind speed. The fact that E is substantially independent of radar frequency implies that the fluctuations involved in this component are not caused by a doppler phenomenon. The independence of E and radar frequency is consistent with the belief that the component having medium decorrelation time is caused by individual ocean waves passing through the illuminated area. The mean value of E, from 128 autocorrelation curves, was 420 milliseconds. This value is commensurate with the time that individual ocean waves might be expected to remain within the range gate.

Measurements F and G, Figure 6, are the amplitude and half-period of a periodic component that appears on some of the correlation curves. The amplitude shown in the illustration is somewhat greater than average, and a large number of the curves show no measurable periodic component. The number of curves having a definite periodicity is too small to provide a significant statistical analysis of the relationship between radar parameters and the amplitude of the periodic component. Generally speaking, the periodic curves were associated with observations at relatively high wave height and wind speed. The period, 2G, is in the range from about 3 to 6 seconds, and can be accepted as representing the periodic passage of ocean waves through the illuminated area. During one data run, an observer counted the waves passing a fixed point during a timed interval, and the wave period was found to be equal to the period indicated...
on the autocorrelation curve for that run. Since the curves were ordinarily computed to 6 seconds of time delay, approximately one cycle of the periodic component appeared, as shown in Figure 6. For one data run having a rather large periodic component, the curve was computed for much longer values of time delay, revealing a long train of loops having substantially constant period and amplitude. This test indicates that, at least for that run, the ocean waves passed through the illuminated area in a truly periodic manner.

The portions of the correlation curves measured by amplitudes B and F have both been described as relating to individual ocean waves. The difference between the two is that B represents a random phenomenon, resulting in a single loop on the correlation curve, while F represents a periodically recurring event. The explanation offered is that the ocean waves occurred periodically in time but were randomly distributed in amplitude. Both the random and periodic fluctuations due to individual waves are, of course, superimposed on the much more rapid random fluctuation measured by A, caused by doppler beats between the echoes from small randomly movingscatterers on the sea surface.

C. Dual-Frequency Correlation

In one data run, recordings were made simultaneously on 6300 mc and 35,000 mc. The two radar systems had similar antenna beamwidths and transmitted pulse lengths, and the two antennas were directed toward the same spot on the sea surface. Both systems were adjusted for horizontally polarized transmission and reception. Figures 8 and 9 are the autocorrelation functions of the 6300-mc and 35,000-mc returns, respectively. Figure 10 is the cross-correlation function of the 6300-mc and 35,000-mc returns. In each of the three figures, the initial portion of the curve is shown on an expanded time scale by the broken-line curve.
Figure 8. Autocorrelation Function of 6,300-mc Sea Return. Run 403.
Figure 9. Autocorrelation Function of 35,000-mc Sea Return. Run 403.
Figure 10. Crosscorrelation Function of 6,300-mc and 35,000-mc Sea Return. Run 403.
The two autocorrelation curves, Figures 8 and 9, are both made up of three distinct random components, having short, medium and long decorrelation times. No significant periodic component is present in either of these curves. The crosscorrelation curve, Figure 10, is made up of two random components having medium and long decorrelation times, similar in shape to the corresponding components of the autocorrelation curves. The component with short decorrelation time is completely absent from the crosscorrelation curve. It is inferred that there is no correlation at all, between 6300-mc and 35,000-mc data, of the high-frequency components of fluctuation due to the relative motion of small randomly-moving scatterers. There is a very pronounced correlation, between data at the two frequencies, of the medium-frequency and low-frequency fluctuations due to individual ocean waves and gradual changes in surface structure. The correlation coefficient for the two frequencies is zero for the component having short decorrelation time, and 0.71 for the component having medium decorrelation time. When the curves are not resolved into separate components, the correlation coefficient for the total signal at the two frequencies is 0.51.

The width of the component of Figure 8 due to high-frequency fluctuations is greater than the width of the corresponding component of Figure 9, but the ratio is not inversely proportional to radar frequency. This is explained by the fact that the recording bandwidth was inadequate for the high-frequency fluctuations of the 35,000-mc data. For other runs recorded with greater bandwidth, the high-frequency component has resulted in a narrower loop on the 35,000-mc correlation curves. The remainder of Figure 9 and all of Figures 8 and 10 show no effects of bandwidth limitation. The component due to fluctuations attributed to individual ocean waves is approximately the same width for both frequencies.
III. PROGRAM UNTIL CONTRACT TERMINATION

Research on sea return at Georgia Tech will be terminated during May, 1957 because of a lack of funds. The program until then includes preparation of a final report in which the major subjects to be treated are:

1. Some properties of the polarization dependence of sea echo.
2. Dependence of the average value of sea echo on sea conditions and radar parameters.
3. Correlation functions and first probability distributions of sea echo.

Respectfully submitted:

/ M. W. Long /
Project Director

Approved:

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