Project Title: Assistance on AN/F Radar Tests
Project No.: A-1055
Project Director: R. C. Johnson
Sponsor: Office of Naval Research
Effective: 1 July 1967
Estimated to run until: 30 June 1968
Type Agreement: Contract No. N00015-67-A-0050 Amount: $15,000

Report: Letter form progress reports, in quadruplicate, at least semiannually to Scientific Officer.
Other technical reports as requested. Distribution of reports to be made in accordance with a list approved by the Scientific Officer.

Contact Person:
Scientific Officer:
R. M. Division, Electronics
Naval Research Lab
Washington, D. C. 20390

Contracting Officer:
Mr. C. W. Hunter
Htd. of the Navy
Office of Naval Research
Washington, D. C. 20390

Assigned to: Electronics Division

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August 15, 1967
PROJECT TERMINATION

Date: February 1, 1979

PROJECT TITLE: Assistance on AGI Radar Tests
PROJECT NO: A-1036
PROJECT DIRECTOR: F. D. Dyk
SPONSOR: Office of Naval Research
TERMINATION EFFECTIVE: December 31, 1969

CHARGES SHOULD CLEAR ACCOUNTING BY: December 31, 1969

Contract Close-out Items Remaining:
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Mr. Paul Thiebaud  
Naval Research Laboratory  
Washington, D. C. 20390

Attention: Code 5315
Title: ASW Radar Tests
Subject: Monthly Progress Report 1

Dear Mr. Thiebaud:

A summary of progress for the period 1 July through 31 July on the referenced contract is contained herein.

Prosecution of the project has been designated Engineering Experiment Station Project A-1036. The project is under the general supervision of Dr. M. W. Long, Chief of the Electronics Division, and Dr. R. C. Johnson, Head of the Radar Branch and Project Director. It is anticipated that the following personnel will participate in the project:

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. M. Cherry</td>
<td>Assistant Research Engineer</td>
</tr>
<tr>
<td>F. B. Dyer</td>
<td>Senior Research Physicist</td>
</tr>
<tr>
<td>H. A. Cozrher</td>
<td>Principal Research Engineer</td>
</tr>
<tr>
<td>H. A. Ecker</td>
<td>Senior Research Engineer</td>
</tr>
<tr>
<td>R. C. Johnson</td>
<td>Principal Research Physicist</td>
</tr>
<tr>
<td>M. W. Long</td>
<td>Principal Research Physicist</td>
</tr>
<tr>
<td>T. M. Miller</td>
<td>Research Engineer</td>
</tr>
</tbody>
</table>

Initial efforts have been devoted to advice on test plans and to observation of the activities at Fisher's Island, New York.

On 6 July, R. C. Johnson and B. M. Cherry attended a meeting at NRL to discuss the test program for the ASW radars. Other attendees were Ike Fuller and Paul Thiebaud of NRL and Charles Quinnam and Milt Johnson of NAVSEC.
On 11 July, B. M. Cherry and F. B. Dyer visited Fisher's Island for a briefing on the ASW radars. T. M. Miller was an observer from 17 through 31 July, and B. M. Cherry was an observer on 31 July. F. B. Dyer visited Fisher's Island on 26 and 27 July to gather information of a technical nature.

It is anticipated that the month of August will be devoted to a continuation of efforts initiated during July.

Very truly yours,

R. C. Johnson
Head, Radar Branch
Project Director

RCJ:jan
Dear Mr. Thiebaud:

A summary of progress for the period 1 through 31 August on the referenced contract is contained herein.

Efforts have been devoted to advice on test plans and to observation of the activities at Fisher's Island, New York.

On 9 August, a meeting was held at Georgia Tech to discuss matters relating to the readiness of the radars for sea tests and to the scheduling of sea tests. Visiting attendees were Paul Thiebaud of NRL and Charles Quinnam of NAVSEC. Georgia Tech attendees were R. C. Johnson, M. W. Long, E. R. Flynt, H. A. Corriher, Jr., H. A. Ecker, F. B. Dyer, B. M. Cherry, W. S. Foster, and T. M. Miller.

Observers at Fisher's Island during August were the following:

<table>
<thead>
<tr>
<th>Name</th>
<th>Inclusive Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. M. Cherry</td>
<td>1-4, 21-25, 28-31</td>
</tr>
<tr>
<td>J. E. Ivey</td>
<td>28-31</td>
</tr>
<tr>
<td>T. M. Miller</td>
<td>1-4</td>
</tr>
<tr>
<td>R. G. Pearl</td>
<td>21-25</td>
</tr>
</tbody>
</table>

Other Georgia Tech visitors to Fisher's Island included M. W. Long on 22 August, and R. C. Johnson and E. R. Flynt on 23 August.

During the month of September it is anticipated that the shore-based tests will be completed and that planning will continue for the sea tests.

Very truly yours,

R. C. Johnson
Head, Radar Branch
Project Director

RCJ:jan
Dear Mr. Thiebaud:

A summary of progress for the period 1 through 30 September on the referenced contract is contained herein.

On 1 September, F. B. Dyer and B. M. Cherry met with Paul Thiebaud at NRL. The discussions concerned techniques for recording data during the shipboard tests and the preparation of a test plan.

On 14 September, F. B. Dyer and B. M. Cherry visited the Naval Base at Newport, Rhode Island, with Paul Thiebaud of NRL and C. J. Quinnam of NAVSEC. During the morning, they inspected the installation of Raytheon's equipment aboard the USS Wilkinson. During the afternoon, they met with Naval personnel, who will be participating in the sea tests, in the wardroom of the Commander Destroyer Development Group 2. On 15 and 16 September, F. B. Dyer and B. M. Cherry met with Paul Thiebaud at NRL to discuss the test plan and data-taking for the sea tests.

On 22 September, B. M. Cherry and T. M. Miller visited the Naval Base at Newport, Rhode Island, along with Paul Thiebaud of NRL. They visited the USS Witek and then attended a pre-sail conference with representatives of USS Wilkinson, USS Witek, USS Grouper, USL, GE, Westinghouse, and Raytheon.

On 21 September, F. B. Dyer was appointed Project Director of Georgia Tech's efforts under the referenced contract. Mr. Dyer has contributed to and is thoroughly familiar with the work to date on the project, and he is well qualified to assume the duties of Project Director.

Efforts during the month of October will be devoted to preparation for the sea tests.

Very truly yours.

RT.

C. Johnson
Head, Radar Branch

cc: F. B. Dyer
Project Director
Mr. Paul Thiebaud  
U. S. Naval Research Laboratory  
Washington, D. C.  20390

Attention:  Code 5315
Title:  ASW Radar Tests
Subject:  Monthly Progress Report

Dear Mr. Thiebaud:

A summary of progress for the period 1 through 31 October on the referenced contract is contained herein.

On 4 October, Paul Thiebaud visited the Georgia Tech facility at Boca Raton, Florida. The discussions concerned the interrelation of the various techniques which are being applied to the ASW radar problem. An exercise was scheduled for the Georgia Tech system during the period 4 through 7 October and thus Mr. Thiebaud was able to see the Georgia Tech technique in operation.

Paul Thiebaud and Bruce Cherry were scheduled to sail with the USS Wilkinson during the period of 5 October through 12 October to observe the operation of the Raytheon system. The decision was made to cancel the observers’ trip when it appeared that the probability of successful operation of the radar was small and target service would be essentially unavailable.

On 11 October, F. B. Dyer met with Paul Thiebaud at NRL. The discussions concerned procedures for conducting the shipboard tests and planning of schedules.

On 24 October, F. B. Dyer and B. M. Cherry boarded the USS Wilkinson at Newport, Rhode Island for a cruise to Norfolk, Virginia. The ship was to be drydocked at Norfolk for approximately one month. It was intended that the observers be aboard to observe the performance of the
Raytheon radar and to discuss the test plan with the ship personnel. Equipment malfunction prevented the observers from evaluating most of the modes of operation of the radar. F. B. Dyer and B. M. Cherry left the ship on 26 October at the Yorktown, Virginia facility.

Efforts during the month of November will be devoted to preparation for the sea tests.

Very truly yours.

[Signature]

F. B. Dyer
Project Director

FBD:mo

Approved:

R. C. Johnson
Head, Radar Branch
Mr. Paul Thiebaud
U. S. Naval Research Laboratory
Washington, D. C. 20390

Attention: Code 5315
Title: ASW Radar Tests
Subject: Monthly Progress Report 5

Dear Mr. Thiebaud:

A summary of progress for the period 1 through 30 November 1967 on the referenced contract is contained herein.

On 6 November, Bruce Cherry sailed with the USS Witek for a three day Type cruise in conjunction with the USS Dace, USS Bang, and the USS Croaker. The Westinghouse radar was operated during this period although the performance was subnormal. The antenna stabilization problems noted in earlier operations appeared to be corrected, but the system sensitivity was marginal during the entire cruise. The loss of sensitivity was later found to be due to condensation in the waveguide.

On 8 November, F. B. Dyer visited Paul Thiebaud at NRL. The morning discussions were devoted to organization and planning for the sea trials. Paul Thiebaud and F. B. Dyer met with Charles Quinnam later in the day for a discussion of target service and a review of the goals of the test program.

On 21 November, Bruce Cherry sailed with the USS Witek for a one day cruise. The purpose of this trip was to observe the performance of the Westinghouse system after the waveguide loss and antenna problems were corrected. The system sensitivity was considerably improved and no major difficulties of any sort were noted with the equipment. A
number of photographs were taken of the displays for the purpose of evaluating the proposed data analysis technique.

Efforts during the month of December will be devoted to preparation for the sea tests.

Very truly yours.

F. B. Dyer
Project Director

FSD:mo

Approved:

R. C. Johnson
Head, Radar Branch
Mr. Paul Thiebaud  
U. S. Naval Research Laboratory  
Washington, D. C. 20390  

Attention: Code 5315  
Title: ASW Radar Tests  
Subject: Monthly Progress Report  

Dear Mr. Thiebaud:  

A summary of progress for the period 1 through 31 December 1967 on the referenced contract is contained herein.  

On 18 December, Bruce Cherry and Paul Thiebaud held a conference at Naval Shipyard, Portsmouth, Va., with personnel of the USS Wilkinson and the Raytheon engineers. The purpose of this meeting was to establish the status of the radar for the return trip to Newport, R. I.  

On 19 December, Bruce Cherry and Paul Thiebaud boarded the USS Wilkinson at Naval Weapons Station, Yorktown, Va. The Raytheon equipment was operative from 1845 until 0630 on the 20th. The general operating condition of the radar was satisfactory during this time. A new computer program had been prepared and was used during part of this period with some degree of success. Complete assessment of the performance of the equipment was not possible since target services were not available. The operation was terminated by a failure in the transmitter.  

On 28 December, Paul Thiebaud called F. B. Dyer and B. M. Cherry at Georgia Tech. The purpose of the call was to arrange the assignments of the observers during the operations in January and to inform the Georgia Tech personnel of the dates and times of the various events for the month of January.  

Efforts during the month of January will be devoted to participation in the sea tests.  

Very truly yours,  

F. B. Dyer  
Project Director  

[Signature]
Dear Mr. Thiebaud:

A summary of progress for the period 1 through 29 February 1968 on the referenced contract is contained herein.

On 5 February, Bruce Cherry, Tom Miller, and John Ivey joined the NRL group at Newport, R. I. The purpose of this meeting was the continuation of the comparative sea evaluation of the two equipments. Tom Miller, John Ivey and Sam Weller sailed with the USS Witek as scheduled; however, the USS Wilkinson did not sail as the Raytheon equipment was inoperative due to transmitter failure. The exercise was cut short due to heavy seas on 7 February.

On 14 February, B. M. Cherry and F. B. Dyer visited Paul Thiebaud at NRL in Washington. The purpose of the visit was to assist in the review of the status of the test program and present an informal report of this review to Charles Quinnam and Milton Johnson. This review was also presented to Messrs. I. W. Fuller and M. I. Skolnik.

Paul Thiebaud and F. B. Dyer outlined the data reduction effort and the format for the final report. The data runs were assigned an arbitrary order of priority and divided between Georgia Tech and NRL for preliminary processing.

Efforts during the month of March will be devoted to continuing the reduction and evaluation of the data obtained during the sea tests.

Very truly yours,

F. B. Dyer
Project Director

R. C. Johnson
Head, Radar Branch
TECHNICAL REPORT NO. 1

PROJECT A-1036

ASSISTANCE ON RADAR TESTS

By

F. B. Dyer, R. W. Camp, and N. C. Currie

CONTRACT NO. N00014-67-A-0159-0004

1 JULY 1967 to 31 DECEMBER 1968
Issued 20 January 1969

Prepared for
DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
WASHINGTON, D. C. 20360
ABSTRACT

This report outlines the three major, but separate, areas of assistance to NRL by personnel at Georgia Tech under ONR Contract No. N00014-67-A-0159-0004. The original tasks were established to provide assistance in the conduct of an ASW test evaluation program and in the reduction of the data obtained on this program. This report provides an unclassified description of the evaluation program only; the official results of the evaluation will be reported by NRL.

Later, tasks were added to the contract to provide direct assistance to a NRL airborne radar measurement program in two areas: (1) oceanographic data services were provided in connection with instrumentation associated with an off-shore piling at the radar field site near Boca Raton, Florida, and (2) shore-based radar measurements were made in connection with NRL's airborne radar program. The radar measurements were made at low angles and at multiple frequencies in X-band to complement the airborne program; the oceanographic data was used to refine the description of the environment. This report also outlines the development of an analog correlation computer and the magnetic tape instrumentation which was used in connection with the radar measurement and oceanographic programs.
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SECTION I
INTRODUCTION

The primary need which led to the establishment of the subject contract was the requirement for the on-site observation of the competitive tests of two Anti-Submarine Warfare (ASW) radar systems which were being developed for the Naval Ship Engineering Center (NAVSEC) and for which the Naval Research Laboratory, Radar Division, was asked to conduct the actual test program. Georgia Tech was asked to provide consultative services which consisted of advice on test plans, on-site observations of the tests and analysis of the results of the tests. Personnel, formerly of the High Resolution Branch, of the Naval Research Laboratory participated in these tests under Mr. Paul Thiebaud (Code 5332), the Test Director.

Additional tasks were later incorporated in the Work Statement which required that Georgia Tech provide assistance with the operation and maintenance of the off-shore piling and oceanographic instrumentation at the Radar Field Site at Boca Raton, Florida. This instrumentation had been established by NRL to facilitate the collection of radar sea return data for a program entirely separate from the ASW tests.

Further additional tasks were included which provided that Georgia Tech provide direct assistance to the NRL airborne radar measurement program by the design of experiments to measure the statistical properties of target signatures, by the implementation of correlation experiments, and the performance of shore-based experiments designed to complement the airborne measurements.

It is the intention of this report to provide an unclassified summary of the work which was performed under the tasks outlined above. The results of the ASW tests and evaluation will be available in the official report which is being prepared by NRL at this time. Analysis of the data gathered during the joint radar sea return measurements is proceeding at NRL; it is anticipated that NRL will report the findings of this analysis upon completion of the study.
SECTION II
SERVICES

A. ASW Test Program

The subject contract was established in order to allow Georgia Tech to assist NRL with the requirements for the on-site observation of the competitive tests of the two Anti-Submarine Warfare (ASW) radar systems which were being developed for the Naval Ship Engineering Center (NAVSEC) by Westinghouse Electric Co. and the Raytheon Company. Mr. C. J. Quinnam, the NAVSEC Program Manager, defined the requirements of these tests to Mr. Ike Fuller of NRL and Dr. R. C. Johnson and Mr. E. R. Flynt of Georgia Tech during a series of planning meetings in June 1967. Mr. Paul Thiebaud (Code 5332) of NRL was named Test Director.

The subject contract was established 1 July 1967 with the requirement that Georgia Tech provide consultative services pertaining to advice on test plans, on-site observations of the tests and analysis of the results of the tests. The initial need was for observers to assist with the shore-based tests of the contractor equipments which were held at Fisher's Island, N. Y., during July and August. The purpose of these tests was to provide for initial shakedown, performance evaluation, and reliability verification prior to installation on the ships which were to be used for the testing at sea.

A number of Georgia Tech people participated in the evaluation during the shore-based tests at Fisher's Island. A key member of the team was Mr. B. M. Cherry who was the principal observer during the tests. Messrs. T. M. Miller, Jr., J. A. Ivey, and R. G. Pearl served in turn as the second member of the team. Messrs. F. B. Dyer and E. R. Flynt and Drs. R. C. Johnson and M. W. Long also observed the tests and participated in the test program planning. Mr. H. A. Corriher, Jr., also contributed to the program planning during the formative stage.

The equipments were placed on board ship in September in preparation for tests at sea under realistic conditions. The Westinghouse system was installed on the USS WITEK (DD848) and the Raytheon system was installed on the USS WILKINSON (DL5). Target services were provided by the USS GROUPER (AGSS214).
and the USS HARDHEAD (SS365). The USS GROUPER was used during the shore-based tests and through the at-sea tests in January. The USS HARDHEAD was used for the sea trials in February, 1968.

Georgia Tech personnel made a total of 42 man-trips in connection with the ASW tests and evaluation. These trips included participation in the shore trials, the planning conferences, the shakedown cruises, and the at-sea tests. The data obtained from the sea trials were subjected to an intensive analysis at Georgia Tech which resulted in the preparation of an extensive compilation of the data from each of the twenty-eight test runs at sea. A total of approximately 80 graphs and figures were provided to Mr. Thiebaud for use in the test report.

B. Oceanographic Data Services

Personnel at NRL were aware of a need for extensive environmental and oceanographic information about the areas where they planned to make a series of airborne radar measurements, and they established the tasks of the subject contract relating to the wave gauge maintenance and data collection to meet that need. These data were necessary to facilitate the interpretation of radar sea return data obtained from the ocean near the Radar Field Site at Boca Raton, Florida, which is presently operated by Georgia Tech for the Navy. Initially the required instrumentation was established in cooperation with the personnel of the School of Ocean Engineering at Florida Atlantic University at Boca Raton, under the direction of Mr. Neil Davis of NRL. The facility consists of an offshore piling on which a resistance-type wave staff for the measurement of surface height is installed and instrumentation for measuring wind speed and wind direction together with the instrumentation necessary for readout and calibration.

Georgia Tech originally was to maintain the gauge and collect information on a daily basis for the NRL personnel for a period of six months beginning January 1968, but the project was extended and Georgia Tech assisted with the oceanographic instrumentation for the remainder of the contract period. Wave-height and wind information has been provided for each of the NRL airborne radar measurement programs in the area since the establishment of the instrumentation. In addition, Georgia Tech personnel have undertaken to develop some additional
equipment to assist in the use of this information; in particular, FM demodulator units were constructed to facilitate the recovery of the data from the magnetic tape recordings of wave height and wind speed.

Data from the wave gauge have been preserved primarily in two forms: (1) strip-chart recordings and (2) magnetic tape. The tidal variation and peak-to-peak values have been preserved on paper strip-chart recordings that run continuously so that there is a virtually continuous record of the tidal and wave heights during the contractual period. Short samples, typically 5 to 15 minutes in length, also have been recorded on magnetic tape in order to preserve the full bandwidth available from the staff. Figure 1 shows one example of the playback from the wave-staff monitoring circuits. This particular record illustrates the wave staff performance with an unusually rough sea. Wave-heights are typically less at Boca Raton, Florida.

Maintenance of the wave staff has consisted primarily of efforts to solve two types of problems. The first, which was anticipated at the beginning, was the necessity for cleaning of the staff periodically to clear the element of marine growth which changed the calibration of the staff. The frequency of cleaning required has varied. Although the staff is coated to inhibit this growth, cleaning is necessary; a scheduled cleaning once a month appears to be adequate to keep a reasonable accuracy. No critical evaluation of the actual accuracy has been attempted to date.

The unanticipated problem was due to actual physical damage to the wave staff by fishing boats which bumped against the staff. This problem was partially alleviated by the placement of a guard chain in front of the staff. The protective guard chain was located in front of the wave staff so that any boat coming close to the piling would have to contact this chain first before hitting the staff. However, the bracket assembly and guard chain were not strong enough to withstand direct impact by large boats; this fact, coupled with the poor corrosion properties of the materials chosen, made this protective barrier only marginally successful.

A third problem encountered was a failure of the cable that was run to the piling. Since the piling is approximately 1/3 of a mile offshore, it is necessary that the cable survive fairly long stretches with water depths to 40 feet. It was determined that the original cable probably failed initially at one of the spliced joints; however, water was forced into the inner part
Figure 1. Surface height variation as a function of time (7 May 1968).
of the cable for some distance which resulted in extensive damage and thus made it impractical to salvage any of the cable. New cabling was installed recently but there has not been sufficient operating time to ascertain its life expectancy. It is believed that the life expectancy should be more than a year. Figures 2, 3, and 4 show typical views of the installation of the wave staff at the piling and the readout instrumentation on shore.

C. Radar Measurements

The Scope of Work of the subject contract was expanded in order to allow the use of the Georgia Tech experimental radar to extend the NRL airborne measurements to low-grazing angles and to make use of the experience with multiple-frequency radar measurements which existed at Georgia Tech. Specifically it was decided to add further tasks to the subject contract which provided that Georgia Tech provide direct assistance to the NRL airborne radar measurement program by the design of experiments to measure the statistical properties of target signatures, by the implementation of correlation experiments, and the performance of shore-based experiments designed to complement the airborne measurements.

The Work Statement called for the near simultaneous measurement of the radar sea return from the ocean surface near the Radar Field Site at Boca Raton, Florida, with both the Georgia Tech shore-based radar and the NRL airborne radar. The desired goal of this investigation was the development of a better understanding of radar sea return as a function of frequency and incidence angle. Key reasons for the choice of the Boca Raton site included: (1) the presence of deep water near to shore, (2) the availability of a highly instrumented shore-based radar, and (3) the existence of the necessary oceanographic instrumentation for definition of certain surface conditions.

Georgia Tech was asked not only to assist in the making of measurements of the radar backscatter and in the recording of oceanographic data for the area during these tests, but also to evaluate the potential usefulness of a digital correlation computer that NRL had obtained for the purpose of analyzing radar data. It was determined during an operation at the Field Site in May, 1968, (in which Georgia Tech and NRL personnel participated jointly) that the Technical Measurements Corporation correlation computer (CAT1000/CORR256) was
Figure 2. View of piling illustrating wave staff and guard chain.
Figure 3. Wave gauge readout and calibrating instrumentation.
A. Checking the Circuit

B. Divers check the Piling

Figure 4. Maintenance of piling instrumentation.
satisfactory for certain aspects of the data reduction but was somewhat cumbersome to use as a real-time monitor of the in-flight experimental measurement program. It was then decided that Georgia Tech would attempt to develop an analog correlation computer which would give essentially real-time readout of correlation coefficients to be used as an aid to experiment control during flight, and NRL personnel would implement a scatter-diagram scope to use as an alternate approach to this experiment control and data monitor. The analog correlation computer was developed and delivered to NRL with instruction manuals for its use. The computational accuracy (~ 1%) which was achieved was not as good as that which might have been obtained by the use of digital techniques but was adequate for the "quick look" use for which it was designed. Joint field operations were held in May, June, and November, 1968.

Radar measurements were made from both radars with the same basic transmitter frequency in X-band over a total frequency excursion of about 150 MHz. These measurements made use of the versatility of the frequency-agile microwave transmitters which were available in each radar which allowed pulse-to-pulse change in center frequency. The basic experiment which was performed was a dual frequency cross-correlation study in which the separation between the two frequencies could be varied manually by the radar operator so that frequency separation could be adjusted from a Δf of 0 to a Δf of 150 MHz. All of the data which was obtained for this program was taken with both radars transmitting and receiving vertical polarization. Both radars used a transmitted pulse length of approximately 1/4 μsec (3 dB width). The actual radar data was recorded on magnetic tape in both the airborne and shore-based measurement systems and thus the data was preserved for further analysis in the laboratory. Figure 5 is a photograph of the radar facility at Boca Raton, Florida. Descriptions of the experimental shore-based radar are available in the literature.

A preliminary analysis of the data showed that the results obtained from measurements in the field with the analog correlation computer and the scatter-diagram display compared reasonably well with the results obtained by more careful analysis of the recorded data in the laboratory. Figure 6 shows a typical plot of the normalized cross-correlation coefficient as a function of frequency separation. This particular run was made using the analog correlation computer; each point represents an average of more than one minute of data. The
calculated curve was computed for a video pulse width of 350 ns -- which is consistent with the effective pulsewidth at the output of the logarithmic receiver of the Georgia Tech radar. There is an effective time separation of 250 µsec between adjacent pulses in addition to the frequency separation; the time decorrelation due to this time separation contributes to the correlation coefficient which is observed at Δf = 0 being less than 1.
Figure 5. Radar facility at Boca Raton, Florida.
Figure 6. Normalized cross-correlation function; X-band, antenna height = 80 ft, $P_t = 250$ Kw, range to sample = 2 n.mi.
SECTION III

DISCUSSION AND RECOMMENDATIONS

The official conclusions and recommendations which resulted from the ASW test program will be presented by NRL in their report on the test program. The views of Georgia Tech personnel involved in this program were summarized in a letter report to Mr. Thiebaud and Mr. Quinnam dated 28 January 1969.

The long-term maintenance of an oceanographic data gathering center at the Field Site at Boca Raton, Florida, is recommended as there is at present no other facility in the immediate area for the collection of tidal or wave height information. This facility should be extended to incorporate the measurement of other types of oceanographic and environmental data, as this region of the East coast of Florida is interesting, perhaps unique, due to the close proximity of the Gulf Stream to the shore. The prediction of the near-shore current patterns is not presently well-developed and effort should be directed to obtaining an improved understanding of the effect of the current on the radar sea return and the near-shore environment.

It is currently planned that the assistance to the NRL airborne program will be continued until July 1969 on an as-needed basis. Maintenance and monitoring of the wave gauge also will be continued during this period.
SECTION IV
ACKNOWLEDGEMENTS

The dedication and willingness to accomplish the necessary work on the part of the many people involved is gratefully acknowledged. In particular I would like to acknowledge the contribution of Lt. Commander James S. Moore who, while at New London TEVDET, helped make the ASW test program a reality, and also that of Mr. C. J. Quinnam of NAVSEC whose understanding and interest made possible the accomplishment of this program. Acknowledgement is due to Mr. Paul Thiebaud and Mr. Neil Davis of NRL whose interest and awareness of the need for radar measurements were of direct benefit to both the Georgia Tech and the NRL programs. Special recognition is made of the willingness of Mr. Bruce Cherry of Georgia Tech to make trips almost on a moment's notice throughout the evaluation program.

Respectfully submitted,

F. B. Dyer
Project Director

FBD:mp
Approved by

H. A. Ecker
Technical Coordinator
and Acting Head, Radar Branch
SECTION V

PERSONNEL

The following personnel made a significant contribution to the work effort:

<table>
<thead>
<tr>
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<tr>
<td>B. Bauman</td>
<td>Engineering Draftsman</td>
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<tr>
<td>E. N. Bone</td>
<td>Sr. Electronics Technician</td>
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<td>J. C. Butterworth</td>
<td>Asst. Research Engineer</td>
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<tr>
<td>R. W. Camp</td>
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<tr>
<td>B. M. Cherry</td>
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<tr>
<td>N. C. Currie</td>
<td>Asst. Research Physicist</td>
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<td>F. B. Dyer</td>
<td>Sr. Research Physicist</td>
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<tr>
<td>E. R. Flynt</td>
<td>Prin. Research Engineer</td>
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<tr>
<td>W. S. Foster</td>
<td>Asst. Research Engineer</td>
</tr>
<tr>
<td>R. C. Johnson</td>
<td>Chief, Electronics Division</td>
</tr>
<tr>
<td>T. M. Miller</td>
<td>Research Engineer</td>
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<tr>
<td>A. Mintz</td>
<td>Research Technician</td>
</tr>
<tr>
<td>W. K. Rivers</td>
<td>Sr. Research Physicist</td>
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SECTION VI

BIBLIOGRAPHY

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2. Tennant, Jeffrey S., and Manring, J. E., "Oceanographic Variability Study (Part II)," ONR Contract No. N00014-67-C-0561, Requirement 00173-7-006286-1 (NRL), Department of Ocean Engineering, Florida Atlantic University, 1 September 1968.


SECTION VII
APPENDICES
APPENDIX A
ANALOG CROSS-CORRELATION COMPUTER

I. Introduction

Many times during the course of an experimental investigation, a timely answer is needed to the question of how the relationship between two variables changes as other parameters are varied. In the case of radar, such a question has frequently arisen concerning the amount of correlation between two returns from the same resolution cell as the time or frequency separation of the returns is varied. Although such investigations have been successfully performed in the past, they have not in general been in real time. The concept, design, and operation of an analog instrument which will, in real time, indicate continuously an approximation of the correlation coefficient of two input voltages is the subject of this appendix.

The operation of this analog correlation-coefficient computer depends on the use of basic analog computational blocks to perform the indicated operations in a simplified mathematical expression for the correlation coefficient. The required basic operations for the simplified expression are multiplication, division, addition, subtraction, and integration.

The primary application of the unit which is described here is to measure the degree of correlation between two stretched pulse trains as the transmitted frequency spacing or relative time delay between the two changes. This unit also may be used to compute the correlation coefficient between any two signals of appropriate spectral content.

II. Cross-Correlation

The normalized linear correlation coefficient, $\rho_{xy}$, between two functions, $X$ and $Y$, is given by:

$$
\rho_{xy} = \frac{E \{ (X - M_x) (Y - M_y) \}}{\sqrt{E \{ (X - M_x)^2 \} E \{ (Y - M_y)^2 \}}} = \frac{\mu_{11}}{\sqrt{\sigma_x^2 \sigma_y^2}}
$$
where: \( M_x = \mathbb{E}\{X\} \) = expected or mean value of \( X \)
\( M_y = \mathbb{E}\{Y\} \) = expected or mean value of \( Y \)
\( u_{11} \) = joint first moment of \( X \) and \( Y \)
\( \sigma_x \) = standard deviation of \( X \)
\( \sigma_y \) = standard deviation of \( Y \)

It can be shown that \( \rho_{xy} \) is normalized so that \(-1 \leq \rho_{xy} \leq 1\). A value of +1 implies that the two functions are identical except, perhaps, for a real, positive multiplicative constant. When the resulting value is -1, the functions are identical except for a real, negative multiplicative constant. A value of zero implies statistical independence. Intermediate values imply that the functions could be broken down into two parts each, one set of such functions being identical except possibly for the sign and the other set having complete statistical independence. The relative proportions of related and independent functions would then determine the magnitude of the linear correlation coefficient.

The signals of interest are time-varying voltages. Accordingly, the equation for the correlation coefficient should be expressed in terms of time functions. The expected value of a stationary time function, \( X(t) \) is:

\[
\mathbb{E}\{X(t)\} = \int_{-\infty}^{\infty} X(t) f(x) \, dx,
\]

where \( f(x) \) is the distribution of \( X(t) \), and the assumption of stationarity implies that it is not a function of time. If, as will be assumed, the functions are ergodic then time averages will be equal to statistical averages and:

\[
\mathbb{E}\{X(t)\} = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} X(t) \, dt = M_x.
\]

Using the above relationships, the correlation coefficient equation may be expressed as follows:

\[
\rho_{xy} = \frac{\lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (X-M_x)(Y-M_y) \, dt}{\sqrt{\left[ \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (X-M_x)^2 \, dt \right] \left[ \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (Y-M_y)^2 \, dt \right]}}.
\]
Using algebra and the property that \( E \{ K X(t) \} = K E \{ X(t) \} \), the numerator may be simplified as follows:

\[
\lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (X - M_x)(Y - M_y) \, dt = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (XY - XM_y - YM_x + MM_y) \, dt
\]

\[
= \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (XY - 2M_x M_y + M_x M_y) \, dt
\]

\[
= \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (XY - M_x M_y) \, dt = E \{ XY - M_x M_y \}.
\]

Each integral under the square root operator may be simplified in the following manner:

\[
\lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (X - M_x)^2 \, dt = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (X^2 - 2M_x X + M_x^2) \, dt
\]

\[
= \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (X^2 - 2M_x^2 + M_x^2) \, dt = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} (X^2 - M_x^2) \, dt
\]

\[
= E \{ X^2 - M_x^2 \}.
\]

The equation for \( \rho_{xy} \) then becomes:
To this equation the specific restraints and assumptions of the desired signals were applied to determine the analog operations needed to implement the analog correlation-coefficient computer.

III. Assumptions and Approximations to Facilitate Implementation

If the two signals to be examined are assumed to be stationary, then their statistics are not functions of time, and the simplifications on the equation which have been performed are valid. This assumption will also allow the samples from which estimators are calculated to be taken from a restricted time interval if the interval is sufficiently long to assure a low variance for the estimators. Accordingly the equations will now be written as averages over a finite time interval $2\Delta T$

If the signals to be compared have the property of ergodicity then their time averages are equal to the statistical averages. The expected values may then be computed by straightforward time averaging rather than by the more complex process of finding the expected values from the distribution. It was anticipated that the radar returns would be ergodic over the interval chosen for the averaging. Much simplification of the correlation-coefficient equation results if the two signals are assumed to possess the same mean value and standard deviation. If the mean values are equal, then the equation for $\rho_{xy}$ becomes:

$$\rho_{xy} = \frac{\frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (XY - M_x M_y) \, dt}{\sqrt{\left[ \frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (X^2 - M_x^2) \, dt \right] \left[ \frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (Y^2 - M_y^2) \, dt \right]}}$$

where $M_x = M_y = M.$
If, in addition, the standard deviations are equal then:

\[
\rho_{xy} = \frac{\frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (XY - M^2) dt}{\sqrt{\frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (X^2 - M^2) dt \cdot \frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (Y^2 - M^2) dt}}
\]

where \( \sigma_x^2 = \sigma_y^2 = \frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (X^2 - M^2) dt \).

The operation of taking the square root has been avoided as have several other calculations.

Because no practical operational amplifiers have infinite gain and zero D.C. drift an ideal integrator is not possible. Furthermore, it is only desired to maintain averages over the last few seconds and constantly update them. For these reasons, the "integrators" used have a transfer characteristic of \( 1/j\omega \) only over the part of the spectrum where the inputs signals have appreciable power components.

IV. Implementation

The required operators are indicated by the equation for \( \rho_{xy} \),

\[
\rho_{xy} = \frac{\frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (XY - M^2) dt}{\sqrt{\frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (Y^2 - M^2) dt \cdot \frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (X^2 - M^2) dt}}
\]

\[
\frac{1}{2\Delta T} \int_{-T}^{T} XY dt - \frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} X dt \int_{-\Delta T}^{\Delta T} Y dt
\]

\[
\frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (X^2 - M^2) dt \cdot \frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} (Y^2 - M^2) dt
\]

\[
\frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} X^2 dt - \frac{1}{2\Delta T} \int_{-\Delta T}^{\Delta T} X dt \int_{-\Delta T}^{\Delta T} X dt^2
\]

23
Instead of allowing the mean value of one variable to suffice for both, it was decided to calculate both in order to loosen the restriction for equal mean values. The resulting equation then requires the following analog operators:

1. multipliers
2. subtractors
3. integrators
4. divider

Step by step interpretation of the equation results in the block diagram of Figure 7. The two blocks marked "high pass filters" were added so that the unit would properly handle three additional types of signals other than those for which it was originally intended. These are: (1) signals with equal variances but unequal means, (2) signals with a non-negligible amount of power at frequencies where the integrator approximation is not good, and (3) signals which are not always positive. The high pass filters were designed to remove unwanted spectral components of the input signals and then reinsert equal artificial mean values.

Perhaps the most difficult analog operator to obtain is a stable precision multiplier. The key to the successful operation of the correlation-coefficient computer is in obtaining adequate multiplier performance. Multipliers are sold by several companies, but at the time this work was done, none combined the desired accuracy with adequate speed. In addition, the cost for those with specifications near to that required for this use was very high. The decision was made to develop a special multiplier. Approaches tried but discarded for various reasons were: quarter-square, pulse width-pulse height, and logarithmic approaches. The approach which seemed most reasonable for the moderate accuracy, high-speed requirements consisted of a differential transistor-pair in which the small signal transconductance was varied by the emitter current. The circuit which was chosen was essentially the same as that found in the Fairchild Linear Integrated Circuits Handbook. The multiplier is restricted to one bipolar input and one unipolar input, but the circuit is so wired that the correct polarity signals are always present at the inputs under normal operating conditions.
Figure 7. Block diagram of analog correlation coefficient computer.
In order to achieve an adequate dynamic range of the input signals, the transfer characteristic of two of the multipliers was made 1/2 XY. The loss of gain was made up in the integrators which followed. If this had not been done, dynamic clipping at just under the power supply voltage would have occurred for signals whose product was equal to the power supply voltage.

The integrators are of standard design using a gain reduced operational amplifier. The resulting time constant is about three seconds and is closely matched among integrators. The summing amplifier uses an operational amplifier in the standard configuration. The high pass filter with DC offset is simply an operational amplifier used as a buffer with capacitive coupling. The cutoff frequency is chosen well above the break point of the integrators. A trimpot is included to vary the output DC level over a restricted range.

Division is accomplished by connecting a multiplier as a feedback element for an operational amplifier to which the numerator is applied. The feedback ratio is then controlled by the denominator on the other input to the multiplier.

Although precision parts were used in the construction of these units, it was often found that the cumulative errors were more serious than previously anticipated. For this reason, attempts were made to select precise values of the non-precision components that were available.

An extra buffer amplifier with short-circuit-proof output was added to give an analog output of the computed result for recording or other use.

V. Results of Tests

The first tests and adjustments to the completed unit were made with sine and square waves from a Hewlett Packard Model 203A Variable-Phase Function Generator. The two input signals were equalized in amplitude and varied in phase. Adjustments were made using the square wave in an attempt to minimize the RMS error over the five volt peak-to-peak input range of the instrument. With peak-to-peak inputs of less than one volt, satisfactory operation was somewhat difficult to obtain. This was because the resulting computed values were not large enough to render the fixed, internal errors negligible before the division operation was performed.
A test to investigate the degree of the correlation between two samples of band-limited random noise as a function of the relative time spacing between samples also was conducted. The experimental set-up is shown in Figure 8 and data are presented in Figure 9. Approximate bandwidth of the noise was 4 MHz.

Actual clutter input signals were processed with this unit on several occasions, both in the laboratory and at the Georgia Tech Field Site at Boca Raton, Florida. Some difficulty was experienced in the early attempts in which the high pass filter was not used. This was attributed to the low frequency components of the radar return which it is believed were associated with swells. On later attempts, the integration time constant was increased to three seconds and the high pass filter was added to remove any frequency components which were not short in period compared to three seconds. Satisfactory results were obtained after these modifications and data was taken as the two sampled and stretched signals were changed in frequency from pulse-to-pulse. Good agreement was found between the predicted results and those measured, as is indicated by the data shown in Figure 6.
Figure 8. Block diagram showing set-up for measuring correlation coefficient versus time delay between samples of detected I.F. noise.
Figure 9. Correlation coefficient versus time delay between samples of detected I.F. noise measured on 14 June 1968.
APPENDIX B
TAPE RECORDER INSTRUMENTATION

I. Wave Gauge Demodulator

The acquisition of a Wave Height and Tide Monitor, which was installed at the Field Site in Boca Raton, Florida, gave rise to the need for a method for recovering the wave-height data both at the site and from the magnetic tape records that were to be analyzed in the laboratory. This Appendix describes an FM demodulator which is compatible with both the Wave Height and Tide Monitor and a portable tape recorder, and also discusses the accuracy achieved in the recovery of wave-height data which was recorded on tape.

The output of the Wave Height and Tide Monitor consists of a 3 kHz sine wave which is frequency modulated with a $\pm 7.5\%$ maximum deviation for wave heights between 0 and 10 feet. After studying a number of methods of recovering the wave height signal from the FM modulated carrier, the scheme which is illustrated in the block diagram of Figure 10 was selected. The basic operation of this circuit is outlined below.

The FM modulated input signal is passed through a low-pass filter to remove noise components above the band of frequencies of interest. The cutoff frequency of the low-pass filter is chosen to be 6 kHz (an octave above the input carrier frequency) to eliminate phase shift problems due to the large change in phase of the filter output near the cutoff frequency.

The output of the filter is fed into a Fairchild $\mu$A710 High-Speed Comparator to perform the limiting function. Figure 11 shows the output of the demodulator versus the input voltage level. The demodulator shows no change in the output voltage for changes in input voltage level when input levels are above -20 dBm.

The square-wave output of the comparator is differentiated and the negative spikes obtained are used to trigger a fixed-width monostable multivibrator. The pulse width of the monostable is chosen to be one-half of the period of the three kHz carrier, i.e., 167 $\mu$s. The output of the monostable thus consists of a train of "quantized" pulses whose duty cycle is directly proportional to the input frequency. The relationship between input frequency and the duty cycle of the pulse train is linear over a wide range and is capable of a much
Figure 10. Block diagram of wave height gauge demodulator.
Figure 11. Output of 3 kHz demodulator versus input voltage level for a 2.8 kHz sinewave input.
higher level of performance than other schemes using approximations such as \( \frac{1}{jw} \) (integration) detection.

The output of the monostable is low-passed with an active filter to eliminate the carrier component of the signal, leaving only the signal containing wave height information. The bandwidth of the filter is chosen to be 100 Hz which is wide enough to pass all frequency components of the wave height spectrum. The roll-off of the filter is 60 dB/decade so that the carrier signal is attenuated by about 80 dB which is well below the noise generated by the tape recorder.

The output of the low-pass filter is inverted with respect to the input so that it is necessary to follow the filter with an inverter. This inverter stage is also used to provide a DC offset adjustment. Finally, a buffer stage results in the output being brought out at an impedance level of 1000 ohms.

Figure 12 gives the response curve for the kHz demodulator. The output voltage change to input frequency change ratio is 1 volt/0.1 kHz and is linear over the operating range of 2.8 kHz to 3.2 kHz.

II. Development of Other Magnetic Tape Instrumentation

It was necessary to develop an FM modulator and demodulator pair for use with a portable FM tape recorder in order to record data in connection with the radar studies at the Georgia Tech Field Site in Boca Raton, Florida. The initial specifications were such that the demodulator unit described above would provide the basis for the desired tape instrumentation. Due to the nature of the radar return data, it was desirable that a data bandwidth of 2 kHz be achieved. This requirement and the inherent limitation of low-cost, portable tape transports were key factors in the choice of a 10 kHz carrier frequency with a frequency deviation of ±30%. This Appendix also discusses some of the problems which were encountered and which lead to these specifications.

a. The FM Modulator

The FM modulator which was developed is illustrated by the block diagram in Figure 13. The basic component of the modulator is a current controlled multivibrator which is a normal multivibrator except that the two resistors which charge the feedback capacitors are replaced with voltage-
Figure 12. Response curve of 3 kHz wave gauge demodulator.
Figure 13. Block diagram of FM modulator.
controlled transistor current sources. The output currents of the two current sources are made to be directly proportional to the input signal. Hence the recovery time per side, and thus the frequency of oscillation, is proportional to the input signal. The DC bias on the current sources is set so that the multivibrator oscillates at a 10 kHz rate for an input voltage of 0 volts, and the output of the multivibrator is therefore a 10 kHz FM-modulated square wave.

The square wave output level of the multivibrator switches between 0 volts and +12 volts but this signal is DC level shifted and attenuated to range between -3 volts and +3 volts. Finally the signal is low-passed with a 15 kHz low pass filter to eliminate all of the frequency components except the fundamental component. The signal is passed through a buffer to yield an output of a +3 volt, 10 kHz frequency-modulated sine wave at an impedance level of 1000 ohms, which is compatible with the portable tape recorders. Figure 14 gives the response curve for the FM modulator. The frequency deviation vs. input voltage ratio is 500 Hz/volt.

b. The FM Demodulator

The FM demodulator which is used with the 10 kHz modulator is simply the same basic circuit used in the 3 kHz Wave Height Gauge Demodulator but with a center frequency of 10 kHz and with a transfer characteristic of 1 volt/0.5 kHz in order to match the FM modulator. Explanation of operation of the demodulator was given previously in the discussion of the Wave Height and Tide Monitor Demodulator; its response curve is illustrated in Figure 15.

c. Interface Problems Between Modulator-Demodulator Pair and Tape Recorder

Initial attempts to use the FM Modulator-Demodulator pair with a portable tape recorder disclosed two major difficulties. First, the center frequency of the FM modulator tended to drift with temperature change which resulted in an offset problem when the recorded signal was demodulated; second, the signal-to-noise ratio of the demodulated signal was seriously degraded due to spurious frequency modulation introduced by the wow and flutter of the low-cost tape transport. The signal-to-noise ratio of a
Figure 14. Response curve of 10 kHz modulator.
Figure 15. Response curve of 10 kHz demodulator
frequency-modulated signal which was recorded and played back through the demodulator was found to be less than 24 dB. Changes were made in the FM modulator and demodulator in order to eliminate these two problems.

An improved modulator circuit, which is illustrated in Figure 16, was designed to overcome the center frequency stability problem. In this circuit a voltage-controlled current source is used to charge a capacitor linearly with time, and a silicon-controlled rectifier is used to reset the capacitor when the voltage across the capacitor reaches a preset level. The fast voltage spike which is developed across the cathode resistor of the SCR upon reset is used to trigger a bistable multivibrator. The square-wave output of the multivibrator is capacitively coupled out of a driver circuit in order to yield a bipolar signal at the required impedance level. This circuit was made to be very frequency-stable by the use of an operational amplifier as a current source and by careful compensation of the SCR. Although this circuit is capable of being linearly modulated over a frequency range of greater than $\pm 50\%$ of the center frequency, the modulator was designed for $\pm 30\%$ deviation.

In order to improve the signal-to-noise, the demodulator was redesigned to accept an increase in the percent modulation of the carrier to $\pm 30\%$ of the 10 kHz carrier. Since the maximum FM noise frequency shift due to flutter and wow was found to be $\pm 50$ Hz, this yielded a signal-to-noise ratio of about 44 dB. However, carrier feedthrough is the limiting factor in the signal-to-noise ratio since the bandwidth of the system is 2 kHz and the roll-off of the low-pass filter used to eliminate the carrier frequency is only 80 dB/decade. Because of the compromise which was necessary between these two factors, the maximum signal-to-noise ratio that was achieved with the system was about 40 dB. In addition, some of the recorders which were tested introduced transients into the output which rendered their use for data recording marginal. However, for selected recorders (i.e., with minimum flutter and transient problems) the FM modulator-demodulator circuits were used successfully as a data recording system.
Figure 16. Block diagram of improved FM modulator.
This report outlines the major, but separate, areas of assistance to NRL by personnel at Georgia Tech under ONR Contract No. N00014-67-A-0159-0004. The original tasks were established to provide assistance in the conduct of an ASW task evaluation program and in the reduction of the data obtained on this program. This report provides an unclassified description of the evaluation program only; the official results of the evaluation will be reported by NRL.

Later, tasks were added to the contract to provide direct assistance to an NRL airborne radar measurement program in two areas: (1) oceanographic data services were provided in connection with instrumentation associated with an off-shore piling at the radar field site near Boca Raton, Florida, and (2) shore-based radar measurements were made in connection with NRL's airborne radar program. The radar measurements were made at low angles and at multiple frequencies in X-band to complement the airborne program; the oceanographic data was used to refine the description of the environment. This report also outlines the development of an analog correlation computer and the magnetic tape instrumentation which was used in connection with the radar measurement and oceanographic programs.
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5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

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8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

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12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (paying for) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.
Naval Research Laboratory  
Department of the Navy  
Washington, D. C. 20390  

Attention: Mr. Neil Davis, Code 5332

Subject: Final Report on Contract  
N00014-67-A-0159-0004,  
"Assistance with ASW Radar Tests"

Dear Mr. Davis:

The purpose of this letter report is to summarize the activities under the subject contract and is to serve as the Final Report on this program.

The activities under the subject contract during the period 1 July 1967 through 31 December 1968 are summarized in Technical Report No. 1, "Assistance on Radar Tests," dated 20 January 1969. The efforts reported therein consisted of three main areas: (1) assistance with the evaluation of two ASW radar systems, (2) joint participation in the NRL airborne radar measurement program, and (3) the providing of on site observations on an as needed basis in order to support the NRL measurement program. Technical Report No. 1 also described the analog correlation computer and wave staff monitoring equipment which were developed during the course of the program.

The work during this current year has consisted of a continuation of the on site support of the NRL measurement program on an as needed basis and a continuation of the monitoring of the wave height at the Boca Raton, Florida Radar Field Site. The only direct support was provided during the March, 1969 flights in the Boca Raton area. Maintenance of the wave staff and a limited analysis of the resultant wave height data have been the primary areas of effort. During this current calendar year, the effort on the development of improved oceanographic monitoring capabilities has been restricted due to funding limitations.

Wave staff maintenance has continued to be a significant problem due to the relatively high failure rate of the resistance element. As was reported in Technical Report No. 1, the failures have been almost totally due to physical damage caused by fishing boats and their fishing tackle. Protective measures have been only partially successful in preventing
this damage. The marine cable has also continued to fail. The spliced cable had an obvious failure; however, the last cable which failed, in November, was damaged in the surf by high seas. A solution to this problem is probably best achieved by burying the cable well below the surf line. Neither of these two problems was successfully resolved due to lack of funds.

The decision was made to attempt to repair the damaged resistance elements of the wave staff. The core was found to be sound on several of the old units and these were stripped and cleaned using a ten per cent solution of hydrochloric acid followed by a neutralizing bath. Visual inspection and repair of the grooved surface was found to be necessary in order to achieve reliable rewinding. The manufacturer would not divulge the source and composition of the wire and potting compounds which were used in the original element; however, an investigation of the properties of the element indicated that an alloy called Protoloy B, manufactured by the Moleculoy Corporation, Farmingdale, New Jersey, was a satisfactory replacement. The wire size chosen was B & S # 32 which has a resistance of approximately 10 ohms per foot. The total resistance of the element is 1000 ohms. Since the tolerance of the original elements is unknown it is difficult to compare the accuracy of the present elements with the original; however, the reworked elements appear to give essentially the performance of the original ones. The potting compound which worked best was Flexane, a urethane rubber compound. Additional field use is needed to determine the long term suitability of the Flexane.

The output of the wave staff monitor is actually related to the height of the surface above an arbitrary reference level rather than wave height, which is defined as the difference in height of adjacent peaks and valleys. Since both surface height and wave height are varying quantities, they are usually described in terms of some statistical parameter, the choice of which is determined by the investigator appropriate to his particular needs. The distribution of surface height has been found by many investigators to be very well described by the gaussian distribution; limited computer analysis of the data which were available on magnetic tape has enabled us to confirm this result for the wave staff and sea conditions at the Boca Raton field site. Because the direct determination of wave height by the computer required the development of a new analysis program which was anticipated to be expensive both in personnel and computer time, the decision was made to make use of the formalism developed by Longuet-Higgins (M. S. Longuet-Higgins, "On the Statistical Distribution of the Heights of Sea Waves," J. of Marine Research, XI, (1952), pp. 245-266) in order to relate wave height to surface height. This approach allowed the use of an existing analysis program and should be valid as long as changes in the wave staff and other instrumentation do not cause modifications of the characteristics of the distribution of surface heights in such a manner as to violate the original assumptions.
The daily wave height summaries which are attached are averages which were prepared from manually obtained tabulations of hourly summaries from the original strip chart recordings. The gaps which exist in these summaries are the result of wave staff damage and are periods about which no data are available. The original hourly summaries were based on the average of the highest one-third wave heights for one hour due to the choice of the parameters in the recording system. These wave height estimates have been shown to be remarkably close to $h^{(\frac{1}{3})}$ as determined by computer analysis of the few comparison cases which were available. The relationship which was used is

$$h^{(\frac{1}{3})} = 4 \sigma_z,$$

where $h^{(\frac{1}{3})}$ is the average of the highest one-third wave heights and $\sigma_z$ is the standard deviation of the surface height, $z$. This expression differs from that of Longuet-Higgins by a factor of two since his results are expressed in terms of wave amplitude. His root-mean-square amplitude, $\Pi$, is a factor of $\sqrt{2}$ times $\sigma_z$. In the computer analysis, a series of records, each five minutes in duration, was used for each comparison in order to insure that stationarity of the process was not a problem.

We at Georgia Tech would like to extend our appreciation to the scientific personnel at the Naval Research Laboratory who have participated in this contract. Their interest and guidance have been valuable to the achievement of the goals of this program. Please let us know if we can be of any assistance in your future programs.

Yours truly,

F. B. Dyer
Project Director

Approved:

R. M. Goodman, Jr.
Head, Sensor Systems Branch

cc: Addressee (2)
ONR Resident Representative
Electronics Division
Sensor Systems Branch
A-1036 Project Files
GTRI Files
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