OMEGA IN THE ATLANTIC (1963-1965)

In-Port Measurements from HMS VIDAL and HR. MS. SNELLIUS
on Oceanographic Survey NAVADO

E. R. Swanson and W. E. Davis · Research and Development Report · 10 January 1966
U. S. NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA 92152 · A BUREAU OF SHIPS LABORATORY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

THE PROBLEM

Analyze Omega phase differences recorded in port aboard the oceanographic survey ships HMS VIDAL and HR. MS. SNELLIUS.

RESULTS

Approximately 2500 hours of recorded phase differences from 24 ports of call and five different lines-of-position indicate that a 24-hour navigation capability of about 0.9 n.mi. (c.e.p.) may be expected in an implemented Omega system, assuming only present radiated powers and prediction ability.

RECOMMENDATIONS

Plan general refinements in the methods of synchronization and prediction, employing the data compiled for this report, to improve predictions. No further analysis specifically restricted to the Atlantic is envisioned.

ADMINISTRATIVE INFORMATION

Work was performed from October 1963 to December 1965 under SS 161 001, Task 6101 (NEL A10461). The report was approved for publication 10 January 1966.

The authors wish to express appreciation to the many persons who contributed to the success of the operation, but especially to the engineers at the transmitting stations and the officers and men of both ships. R. Gallenberger and R. Finkle, both of San Diego State College, assisted in the data analysis. Mrs. Rita Brown programmed the 1604 computer to predict skywave corrections.

CONTENTS

TABLES

ILLUSTRATIONS

REVERSE SIDE BLANK

INTRODUCTION

Although still developmental and not in continuous operation, the Omega navigation system is frequently in demand for special operations. Such an operation was the Project NAVADO oceanographic survey of the North Atlantic. Installation of an Omega receiver on HMS VIDAL was made in the fall of 1963. Subsequently the receiver was transferred to HR. MS. SNELLIUS and remained onboard until August 1965.

10.2-kc/s measurements in port analyzed

This report analyzes 10.2-kc/s signals received by the survey ships in 24 ports of call.

INSTALLATION OF EQUIPMENT

Installed on VIDAL, October 1963

The installation of HMS VIDAL was made at the request of the Bureau of Ships (Code 362A). Routine installation was accomplished at Portland Dockyard, Portland, England, in October 1963 with the assistance of a representative of the U. S. Navy Electronics Laboratory. The field engineer also accompanied the ship for a period sufficient to provide necessary assistance in operation and training.

Transferred to SNELLIUS, October 1964

Survey assignments within Project NAVADO were changed in fall of 1964 with the VIDAL being reassigned to resurvey the first four lines. The Dutch ship HR. MS. SNELLIUS continued the northern survey lines in the Atlantic. Because of the change in assignment and at the request of the Hydrographer, Royal Netherlands Navy, the Omega receiver was transferred from the VIDAL to the

Removed August 1965

SNELLIUS in October 1964 at Portland dockyard. Again, the field engineer assisted in the installation and rode the ship to assist in operation and training. Because of the loss of signals from Criggion, due to other commitments, the equipment was removed at Halifax, Nova Scotia, in August 1965.

Both installations were conventional and used the Omega receiver manufactured by ITT (Type II, Serial 2) with various whip and wire antennas. However, the internal Manson oscillator was not used on the VIDAL which had a precision frequency standard.

SUPPORT

Close liaison

An engineer from the U. S. Navy Electronics Laboratory spent a total of approximately five months aboard the ships during the two years of operation. When aboard, he assisted in navigation, receiver operation, and maintenance and helped train the officers and crew. Equally important, from the present viewpoint, he was responsible for monitoring when the ship was in port.

Tables and skywave corrections provided

NEL also provided support to the ships in the form of navigation tables and skywave corrections. Because of the large area involved (approximately 10 million square miles), this effort proved substantial although skywave corrections were computed more sparsely than would have been done for an operational system. All totalled, approximately 20 hours of computer time were used for support and evaluation of the operation.

Data received

Support was received as well as given. Both ships monitored Omega signals in port and forwarded the results to this Laboratory. Excellent cooperation was received and the data have been of substantial importance in refining the Omega system calibration.

RESULTS AT SEA

Equipment reliable

While it is not the intent of this report to evaluate the actual operation at sea, it is germane to note that the equipment functioned reliably. Exclusive of recorders, only a few failures occurred during each year of operation, including routine tube replacements. Reliable functioning was also noted in informal letter reports from Rear Admiral G. S. Ritchie, R.N., presently the Royal Hydrographer but then Captain commanding the VIDAL, and from LT CDR F. Bradander, R. Neth. N., commanding the SNELLIUS.*

Transmission schedule intermittent

It is regretted by all concerned that the developmental nature of the Omega system precluded continuous transmissions from all stations. Most transmissions were scheduled either on a 16-hour day, seven days a week, or on a 24-hour day five days a week. Frequently, it was possible to provide only one line-of-position (LOP). It should be emphasized that intermittent operation is particularly inconvenient because of the necessity of reestablishing lane count. Indeed, the discontinuity of transmissions was such as to render operation nearly marginal at certain times.

Correction problems

Particularly during the early part of the operation, skywave corrections were based on limited data. To improve calibration, the computed skywave corrections were frequently adjusted by local monitoring in port. This technique, while unnecessary for a navigator in an implemented and well calibrated system, is believed to have substantially improved the actual navigation accuracy obtained at sea during the present operation. Also, it should have mitigated or eliminated the effects of an offset mistakenly included in the Criggion-Forestport computations.

---

*See also reference 1 in list at end of report.

Good signals

In general, Forestport, Summit, and Criggion were easily received throughout the entire North Atlantic while infrequent attempts to measure Haiku were routinely successful in the Western Atlantic. In the Eastern Atlantic, Haiku was marginal in the Canary Islands (about 7000 n.mi.) and usually could not be used when the propagation path passed over Greenland (although measurements were made in the Netherlands).

It is the consensus that a system such as Omega is particularly useful for oceanographic survey work in mid-ocean. The system was also of value in standard navigation problems such as making a land-fall after prolonged operation without star sites.

Poor geometry

In addition to skywave correction problems, one of the most significant accuracy limitations in the Atlantic area is the purely geometric one resulting from the locations of the existing developmental stations. Figures 1 and 2 illustrate the expected Omega fix accuracy for various lines-of-position in the North Atlantic. These are based on system geometry existing during the operation and a theoretical model which assumes 4-centilane timing errors believed indicative of daytime conditions.[2] The accuracy at night and during transitions would be less than that indicated by the figures.

Figure 1. Early Omega system accuracy (Atlantic): Forestport-Summit; Criggion-Summit. (Theoretical accuracy contours based on an assumed standard deviation of 4 cel and correlation of 0.4 everywhere.)

Figure 2. Early Omega system accuracy (Atlantic): Criggion-Summit; Haiku-Summit. (Theoretical accuracy contours based on an assumed standard deviation of 4 cel and correlation of 0.4 everywhere.)

RESULTS IN PORT

Whenever the survey ships were in port, available Omega signals were monitored. These data are especially valuable since the positions of the ships were carefully determined.* Most of the in-port data were measured by the respective navigators and forwarded to NEL for analysis. The data have proved to be virtually free from incidental errors and nearly always significant.

Slaved transmissions measured in 24 ports of call

Phase differences were measured in 24 ports of call from 10.2-kc/s transmissions in the "slaved" mode. As changes in the transmission schedule caused unusual lines-of-position to be available at various times and since some of the ports were revisited, more data were obtained than might be expected from single visits using existing equipment. Also, manual and automatic time sharing were used for a few measurements. The net result was that 60 site-LOP's were obtained using five different lines-of-position. The average monitoring duration was three days.

60 site-LOP's

Half-hourly readings from a typical phase difference recording are shown in figure 3. The scatter on the graph is that actually displayed on the original recordings since no time averaging was used in the reduction. The scatter is indicative of the receiver time constant of about 30 seconds. For the particular measurement shown in figure 3, all component propagation paths are dark between

---

*Each position determination was referenced to local datum. Accurate conversion to international coordinates could not be made for all locations. The overall error resulting from inadequate geodetic information is believed small although probably appreciable. Errors at individual sites, however, may be important.

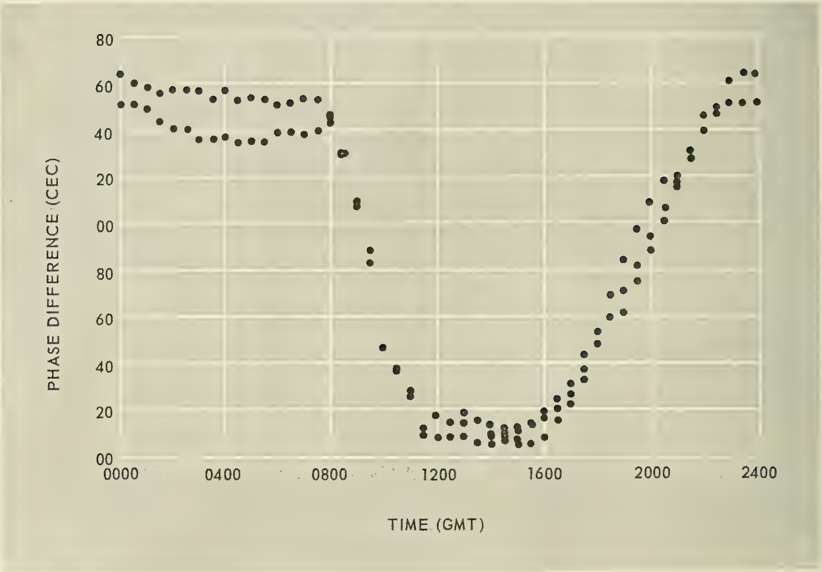

Figure 3. Typical 10.2-kc/s Omega phase difference. Half-hourly measurements on Criggion-Summit in-port at Chaguaramas, Trinidad, 21–24 Dec 63.

2300 and 0800Z while all are sunlit between 1130 and 1600Z. The figure shows the usual features of the Omega phase difference, namely, constant (or "flat") at night with a slow change (or "curvature") during the day.

Because phase differences tend to be constant at night, a single average nighttime phase difference may be meaningfully computed for each of the site-LOP's. The average values observed, combined with appropriate lane assignments, may then be compared with theoretical computations. Such a comparison is shown in table 1 where the theoretical computations were based on the determination of phase coefficients made early in 1965.[3] The last column is

TABLE 1. AVERAGE PHASE DIFFERENCES AT NIGHT

Site-LOP: LOP[a]	Site	Date	No. Nights	Wt[b]	Night Average (lanes)	Residual discrepancy with computation (cec)[c]
			Normal Site-LOP's			
FP-SU	Al Yadida, Morocco	Jul 64	2	1	64.54	1.5
FP-SU	Azores	Jun 64	2	1	59.67	4.3
CR-SU	Azores	Jun 64	3	2	152.08	- .6
CR-SU	Bathurst, Gambia	Dec 63	2	1	202.04	-10.1
FP-SU	Bathurst, Gambia	Dec 63	2	1	116.06	- 2.6
CR-SU	Bridgetown, Barbados	Jan 64	5	2	432.53	- 8.0
FP-SU	Bridgetown, Barbados	Jan 64	1	1	179.82	1.2
CR-SU	Cadiz, Spain	Jul 64	2	1	74.65	- 2.9
FP-SU	Cadiz, Spain	Jul 64	1	1	56.65	1.6
CR-SU	Casablanca, Morocco	Jul 64	1	1	90.63	- 5.8
CR-SU	Casablanca, Morocco	Apr 65	1	1	53.21	- 9.9
FP-SU	Casablanca, Morocco	Jul 64	2	1	63.35	- .4
CR-SU	Chaguaramas, Trinidad	Nov 63	10	3	452.50	- 7.9
FP-SU	Chaguaramas, Trinidad	Nov 63	5	2	194.26	- 6.5
FP-SU	Den Helder, Netherlands	Nov 64	7	3	24.42	- 5.3
CR-SU	Gibraltar	Jun 64	2	1	73.09	2.5
FP-SU	Gibraltar	Jun 64	2	1	57.07	1.4

Table 1. (Continued)

Site-LOP LOP[a]	Site	Date	No. Nights	Wt[b]	Night Average (lanes)	Residual discrepancy with computation (cec)[c]
		Normal Site-LOP's (Continued)				
CR-FP	Hamilton, Bermuda	Mar 65	1	1	308.39	- 2.7
HK-FP	Hamilton, Bermuda	Mar 65	1	1	522.46	- 1.5
FP-SU	La Coruna, Spain	Nov 64	2	1	43.56	6.7
CR-FP	Las Palmas, Canary Islands	Feb 65	3	2	89.08	- 5.1
CR-SU	Lisbon, Portugal	May 64	5	2	76.23	9.1
CR-FP	Lisbon, Portugal	May 65	2	1	49.02	4.3
FP-SU	Lisbon, Portugal	May 64	3	2	53.20	6.8
FP-SU	Matosinhos, Portugal	Oct 63	3	2	47.95	6.4
FP-SU	Portland, U.K.	Oct 63	1	1	29.35	2.7
FP-SU	Portland, U.K.	Nov 64	2	1	29.39	4.1
FP-SU	Rotterdam, Netherlands	Oct 64	1	1	26.08	6.6
CR-SU	San Juan, P.R.	Dec 64	1	1	445.74	7.0
FP-SU	San Juan, P.R.	Dec 64	1	1	168.14	3.4
		"Near" Site-LOP's				
CR-FP	Charleston, S.C.	Mar 65	3	0	351.20	10.7
HK-FP	Charleston, S.C.	Mar 65	3	0	485.08	6.6
CR-SU	Curacao	Dec 64	6	0	490.44	1.0
FP-SU	Curacao	Dec 64	6	0	209.00	3.2
HK-SU	Curacao	Dec 64	6	0	566.51	2.0

Table 1. (Continued)

Site-LOP: LOP[a]	Site-LOP: Site	Date	No. Nights	Wt[b]	Night Average (lanes)	Residual discrepancy with computation (cec)[c]
"Near" Site-LOP's (Continued)						
CR-FP	Den Helder, Netherlands	Jul 65	2	0	1.84	22.6
CR-SU	La Coruna, Spain	Nov 64	1	0	54.84	- 6.2
CR-FP	Norfolk, Va.	Apr 65	13	0	349.88	-11.2
HK-FP	Norfolk, Va.	Apr 65	5	0	510.19	- 7.5
CR-SU	Portland, U.K.	Nov 64	2	0	7.49	- 1.6
CR-SU	Rotterdam, Netherlands	Oct 64	1	0	.72	28.8
Site-LOP's With Arctic Path Component						
HK-SU	Den Helder, Netherlands	Nov 64	6	0	381.98	23.5
HK-FP	Las Palmas, Canary Islands	Feb 65	2	0	527.95	- 1.8
HK-FP	Tenerife, Canary Islands	Feb 65	1	0	528.26	5.0

Notes:

a. LOP's coded slave minus master as follows: HK, Haiku; FP, Forestport; SU, Summit; CR, Criggion. "Near" site-LOP's have path components less than 700 n.mi.; site-LOP's with arctic path components include propagation in arctic regions of poor conductivity.

b. Weights approximately equal to square root of number of nights of observation (except "near" site-LOP's and LOP's with arctic path components).

c. Residual positive if observation greater than computation, i.e., positive residual indicates additional net delay. Note that a delay on the path to the master station will yield a negative residual.

Discrepancy of night averages 5.8 cec

the residual discrepancy between the observed average and the computed value in centicycles (cec). Since the observational average from only a few nights of monitoring is not necessarily equal to a long-term mean at a particular site, the rms residual discrepancy of 5.8 cec for the 30 site-LOP's, where the prediction theory is applicable, is not completely due to prediction error. Presently, the prediction theory is invalid near transmitting stations where significant energy may be propagated by the second wave-guide mode or in cases where one of the component propagation paths passes over arctic regions of very poor conductivity.[4]

Perturbations over short paths at night

Theoretical perturbations not large

Although practical navigation was not recommended using a station within 1000 n. mi., for tabulation purposes only measurements with component propagation paths shorter than 700 n. mi. (1300 km) have been identified as "near." A theoretical estimate of the effect of the second mode on the resultant phase over short propagation paths is shown in figure 4. The curve was produced from the work of Wait and Spies[5] based on the isotropic model ionosphere.* The theoretical work is important since it indicates peak deviations of on the order of one n. mi. or less. However, the work cannot yet be considered sufficiently reliable to warrant additional corrections. In particular, if the quasi-wave length were only slightly off, corrections of the wrong sign might be

---

*Specifically an ionospheric height of 90 km, gradient of 0.5 km^{-1} and infinite surface conductivity were assumed. The curves of Wait and Spies were then used to obtain the relevant parameters for propagation at 10.2 kc/s, viz: relative velocity, attenuation rate, and excitation. The values obtained were, respectively, 1.0003; 1.6 dB/Mm; -1.3 dB at 6.3° for the first mode and 1.0303; 8.8 dB/Mm; and 1.4 dB at 20° for the second.

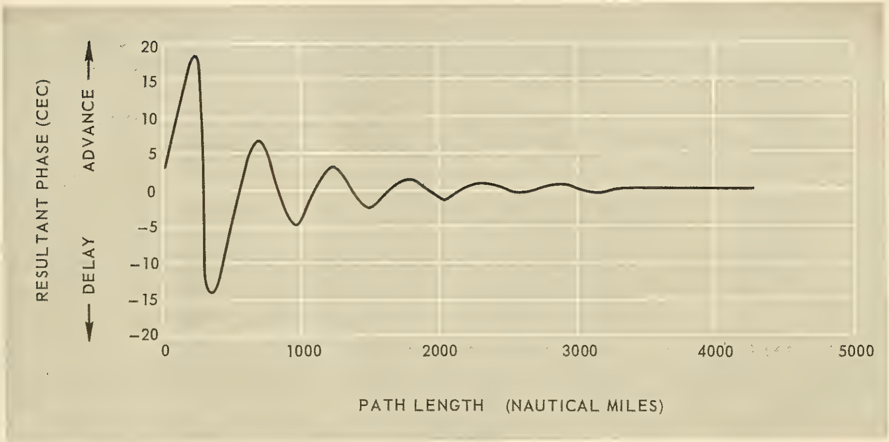

Figure 4. Phase perturbation over short paths at night. (After Wait & Spies, 10.2 kc/s.)

Short path effects observed

applied. Nonetheless, there is a rather surprising agreement between the computed effects and those actually observed. Charleston, S. C., is 675 n.mi. (1250 km) from Forestport, while Curacao is 660 n.mi. (1220 km) from Summit, so that measurements at these sites would be expected to have +6.5-cec residual discrepancies in table 1. The actual discrepancies average 4.3 cec. The theoretical work indicates that an additional delay of 12 cec should be expected over the 395 n.mi. (731 km) path from Forestport to Norfolk, Va. The sense of the measurement indicates that a residual of -12 cec would be expected. The average residual is about -9 cec. Because of the effects of higher-order modes, the theoretical model may not apply over shorter paths such as those from Criggion to the Netherlands sites. While the phase differences observed in Holland cannot be explained at present, the path lengths, 285 and 281 n.mi. (528 and 521 km), are comparable as are the residual discrepancies.*

The foregoing is not an adequate sample from which to verify the theoretical model. However, it is at least encouraging and may constitute an initial understanding of Omega operation near transmitters. It is noteworthy that both the observed and theoretical discrepancies are small at moderate distances from stations. Exclusive of sites where higher modes may be significant, the rms discrepancy of the observed data in this region is 7.2 cec if no second mode corrections are made.

Arctic propagation

A consistent picture of arctic propagation cannot be expected from brief monitoring at only five locations. However, some of the measurements in the Canary Islands and the Azores are of considerable value since the residual errors can confidently be said to include the effect of a decrease in the propagation velocity of the Haiku signal in the vicinity of Hudson's Bay and Labrador. In particular, the propagation paths may be compared with a recent conductivity map by E. L. Maxwell** from which it is found that about 3000 km of propagation occur over ground with a conductivity of one millimho per meter or less, nominally averaging 0.6 millimho per meter. While theoretical esimates of the additional phase delay expected for a 10.2-kc/s signal propagated over this path are not directly available,

---

*Criggion-Summit phase differences in Portland, U.K., reflect propagation over a very short path.

**Furnished in a personal communication to the author, 9 June 1965.

a crude estimate is possible using the work of Wait and Spies.[5,6] A delay of 10 to 20 cec may be expected. The effect is neither confirmed nor rejected by the observed phase differences because of the brief monitoring and also because of the high scatter resulting from a poor signal-to-noise ratio.

The measurements at Den Helder include propagation directly over the Greenland ice cap and also propagation at extreme northern latitudes. No attempt at analysis is justified at the present time. In fact, the lane assignment for this particular measurement is only tentative.

Daytime propagation

Phase-difference measurements during the day are more complicated to analyze than those at night, since phase velocity varies with the solar zenith angle and exhibits related seasonal changes. In general, for normal illumination of the ionosphere, phase prediction is more easily accomplished during the day than at night. In particular, propagation during the day is less sensitive to geomagnetic path orientation, latitude, and the effects of the second waveguide mode. Prediction methods have been discussed elsewhere and widely applied.[4,7] The basic prediction coefficients have been in use since December 1963.

Computer predictions

Day and night prediction coefficients have been combined in a computer program together with transition criteria to predict the phase difference observed at any location at any time of day. While neither the daytime prediction coefficients nor the transition criteria have been changed since the inception of the computer program, changes in the computation procedure at night were made early in 1965 and can affect the predictions at all times of day. Present computer results therefore differ slightly from those provided for navigational use during the early part of the operation and those used in an earlier analysis.[8] Also, an offset erroneously present in the Criggion-Forestport corrections has been corrected. Comparisons of observed phase differences with predicted diurnal variations are shown in figures 5 to 9. A complete set of such curves has been compiled as a supplement to this report.[9]

The computer predictions are no more accurate than the basic prediction model employed and hence the limitations previously discussed apply; the effects of the second and higher propagation modes should be considered when using a nearby transmitter. In practice, operation within 1000 n.mi. of a station was not advised although the corrections provided were valid first-mode predictions to 840 n.mi.

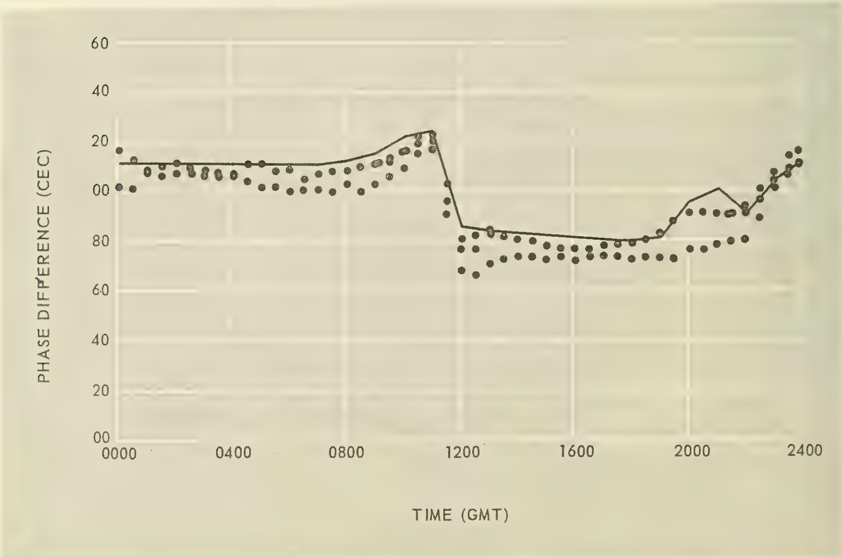

Figure 5. Bathurst, Gambia: Forestport-Summit, 10.2-kc/s Omega phase difference (4 to 6 Dec 63).

Within 840 n.mi. the computations were invalid for navigation but of some interest for analysis. Recently the computer program was modified to approximate corrections near transmitters. The modification uses simplified transition criteria and still does not include the effects of the second and higher-order propagation modes. Where applicable, comparisons with observed data have been made with modified corrections. The supplement indicates that the corrections may be adequate for some types of navigation even using nearby transmitters.[9]

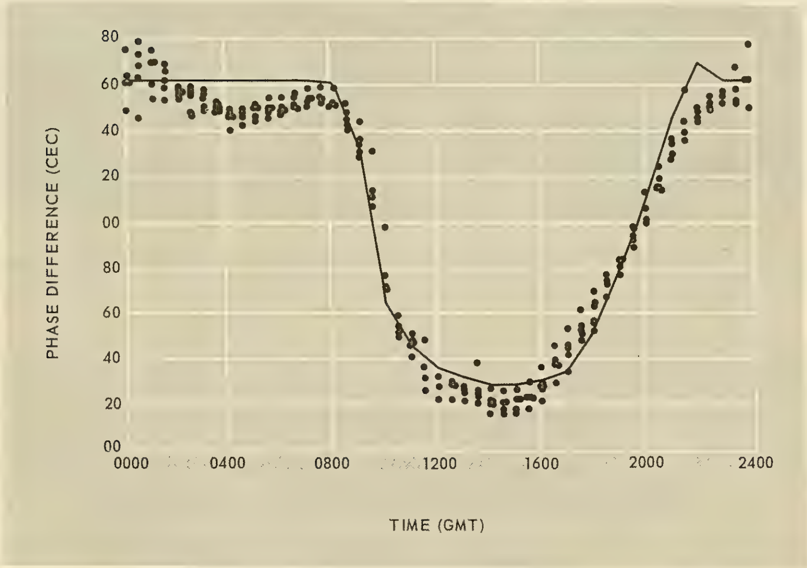

Figure 6. Bridgetown, Barbados: Criggion-Summit, 10.2-kc/s Omega phase difference (30 Dec 63 to 2 Jan 64).

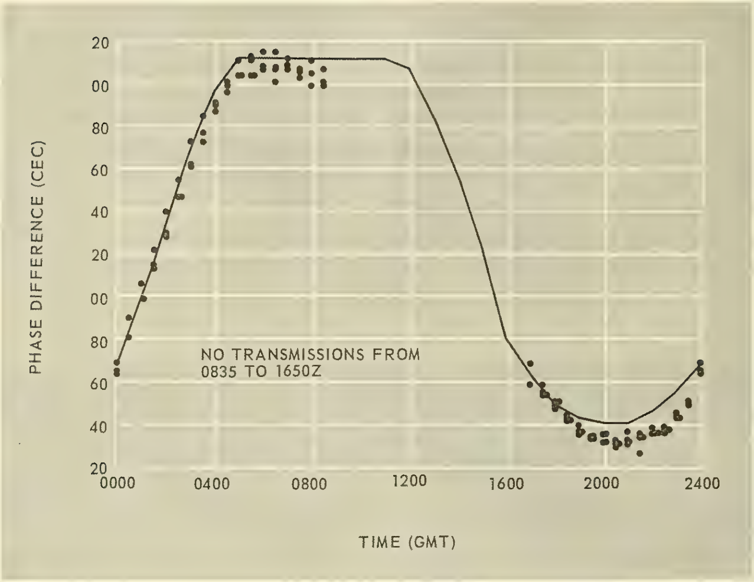

Figure 7. Charleston, South Carolina: Haiku-Forestport, 10.2-kc/s Omega phase difference (8 to 11 Mar 65).

Results

Comparison of the observed and computed phase differences permits a system evaluation in the area.* Three periods will be considered separately, namely: night (when all component propagation paths are dark); day (all illuminated); and transition (mixed). During each period, each observed value has been compared with the

---

*Because of present prediction limitations, measurements including propagation over paths less than 700 n.mi. or in arctic regions have been excluded from the analysis.

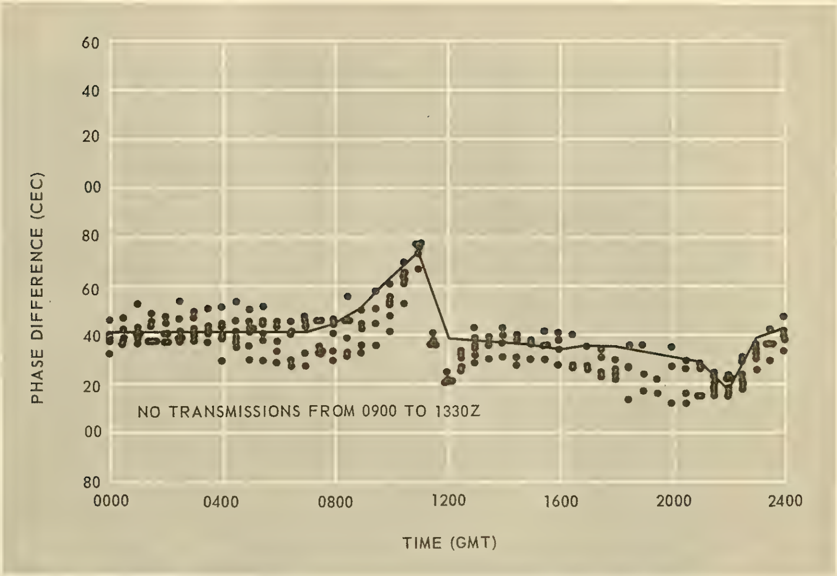

Figure 8. Den Helder, Netherlands: Forestport-Summit, 10.2-kc/s Omega phase difference (16 to 26 Nov 64).

corresponding prediction and an rms value obtained.* The results are summarized in table 2. The discrepancies reflect errors of all types but especially the stability of the propagation medium and present prediction errors. The results are consistent with previous estimates. However, the rms discrepancy during the day has been seriously affected by prediction errors and may be expected to

---

*See ref. 9 for a description of the computations and more detailed summary of the results.

Figure 9. Las Palmas, Canary Islands: Criggion-Forestport, 10.2-kc/s Omega phase difference (10 to 14 Feb 65).

TABLE 2. TYPICAL DISCREPANCIES BETWEEN OBSERVED AND PREDICTED PHASE DIFFERENCES

Period	RMS Discrepancy (cec)
Day	6.7
Night	8.1
Transition	10.8
Overall	9.2

substantially improve when the daytime propagation coefficients have been revalued.*

Probable fix accuracy during survey if using present predictions: 1-1/2 n.mi.

The overall accuracy which would be actually obtained using present prediction in the entire North Atlantic area may be estimated from figures 1 and 2 and the overall rms discrepancy. Apparently, a typical circular error probable on the order of 1-1/2 n.mi. is appropriate for the 24-hour day. However, results during the day would be better than nominal while results at night and during transitions would be worse; and, of course, the expected accuracy varies considerably with position. In practice, actual results might be either better or worse. The earlier skywave corrections provided to the ships were not as refined as those used in the present analysis. Computations for Criggion-Forestport were in error. At best, the spatial density of corrections was rather sparse, thus presenting a possibility for interpolation errors. However, adjustment of the computed diurnals by local monitoring in port may have considerably reduced the effect of prediction errors.

Accuracy of implemented system:

Day	0.7 n.mi.
Night	0.8 n.mi.
Transition	1.1 n.mi.
Overall	0.9 n.mi.

The results may also be used to evaluate the accuracy available in an implemented Omega system. The application is not direct but depends on assumptions of eventual system geometry, possible effects of spatial correlation, and the effect of operating in the absolute mode instead of operating with some stations actually synchronizing as slaves to a master station. It has been shown that an approximate conversion from LOP error in the synchronized mode to fix error in an implemented system may be made by multiplying the present results by 0.1 n.mi./cec.** Hence, the

*See footnote on page 8 of reference 7 and also reference 4.

**See references 2, 10, and 11. In particular, multiplication by 0.106 n.mi./cec yields rms fix error while multiplication by 0.093 n.mi./cec yields the c.e.p.

observed phase differences are indicative of an implemented system accuracy of 0.7 n.mi. during the day, 0.8 n.mi. at night and 1.1 n.mi. during transitions, based on present radiated powers and predictability.

CONCLUSIONS

Omega phase differences on various lines-of-position were measured over ten million square miles during a period of two years. Most data are well explained by present propagation theory while the additional data measured should serve as a useful basis for extending the theory to arctic and short propagation paths.

The results continue to indicate that a 24-hour accuracy of about 0.9 n.mi. will be obtained in an implemented Omega system.

The operation was also noteworthy from the standpoints of reliable equipment operation for an extended period and of excellent and mutually beneficial international cooperation. This Laboratory is especially appreciative of the fine cooperation received from the entire complements of both ships.

REFERENCES

1. Canada. Hydrographic Service. NAVADO III, NAVADO III H. Neth. M.S. SNELLIUS, by M.M. DeLeeuw, 14 September 1965

2. Navy Electronics Laboratory Report 1188, Estimating the Accuracy of Navigation Systems, by E.R. Swanson, 24 October 1963

3. Navy Electronics Laboratory Technical Memorandum 781, Present Predictability of Omega 10.2 kc/s Nighttime Signals, by E.R. Swanson, 18 March 1965

4. Navy Electronics Laboratory Report, Propagation of 10.2 kc/s Electromagnetic Waves, by E. R. Swanson (In preparation)

5. National Bureau of Standards Technical Note 300, Characteristics of the Earth-Ionosphere Waveguide for VLF Radio Waves, by J.R. Wait and K.P. Spies, 30 December 1964

6. Wait, J.R. and Spies, K.P., "Influence of Finite Ground Conductivity on the Propagation of VLF Radio Waves," Journal of Research of the National Bureau of Standards. Section D: Radio Science, v.69D, p.1359-1373, October 1965

7. Navy Electronics Laboratory Report 1226, Omega Navigation Capability Based on Previous Monitoring and Present Prediction Ability, by E.R. Swanson, 5 June 1964

REFERENCES (Continued)

8. Navy Electronics Laboratory Letter Report 103, Omega Operations Aboard H. M. S. VIDAL (1963-1964), 25 September 1964

9. Navy Electronics Laboratory Technical Memorandum 897, Data Supplement to NEL Report 1350, by E. R. Swanson, 10 January 1966

10. Navy Electronics Laboratory Report 1185, Accuracy of the Omega Navigation System, by M. L. Tibbals and D. P. Heritage, 2 October 1963

11. Navy Electronics Laboratory Report 1305, Omega Lane Resolution, by E. R. Swanson, 5 August 1965

Note: Since this report was prepared, the work by E. L. Maxwell referred to on page 18 has been published in:

Deco Electronics, Inc., Report 54-F-1, OMEGA Navigational System Conductivity Map, by R. R. Morgan and E. L. Maxwell, December 1965

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
U.S. Navy Electronics Laboratory
San Diego, California 92152

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b GROUP

3. REPORT TITLE
OMEGA IN THE ATLANTIC (1963-1965)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Research and Development; October 1963 - December 1965

5. AUTHOR(S) *(Last name, first name, initial)*
Swanson, E. R. and Davis, W. E.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
10 January 1966	28	11

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. SS 161 001, Task 6101
(NEL A10461)

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
1350

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES
Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Bureau of Ships, Department of the Navy,
Washington, D. C. 20360

13. ABSTRACT

Measurements were made of 10.2-kc/s phase difference in 24 ports of call in the Atlantic area. The measurements are generally well explained by present propagation models which indicate that an implemented Omega system will have an accuracy of about 0.9 n. mi. (c.e.p.) over the 24-hour day.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Very Low Frequencies						
Phase-Difference Measurements						
Omega Navigation System						
NAVADO						
Oceanographic Surveys						
HMS VIDAL						
HR. MS. SNELLIUS						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

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.

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

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

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

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

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.

Navy Electronics Lab., San Diego, Calif.
Report 1350

OMEGA IN THE ATLANTIC (1963-1965), by E. R. Swanson and W. E. Davis, 28 p., 10 Jan 66.

UNCLASSIFIED

Measurements were made of 10.2-kc/s phase difference in 24 ports of call in the Atlantic area. The measurements are generally well explained by present propagation models which indicate that an implemented Omega system will have an accuracy of about 0.9 n. mi. (c.e.p.) over the 24-hour day.

1. Omega
2. Radio Navigation Systems

I. Swanson, E. R.
II. Davis, W. E.

SS 161 001, Task 6101
(NEL A10461)

This card is UNCLASSIFIED

Navy Electronics Lab., San Diego, Calif.
Report 1350

OMEGA IN THE ATLANTIC (1963-1965), by E. R. Swanson and W. E. Davis, 28 p., 10 Jan 66.

UNCLASSIFIED

Measurements were made of 10.2-kc/s phase difference in 24 ports of call in the Atlantic area. The measurements are generally well explained by present propagation models which indicate that an implemented Omega system will have an accuracy of about 0.9 n. mi. (c.e.p.) over the 24-hour day.

1. Omega
2. Radio Navigation Systems

I. Swanson, E. R.
II. Davis, W. E.

SS 161 001, Task 6101
(NEL A10461)

This card is UNCLASSIFIED

Navy Electronics Lab., San Diego, Calif.
Report 1350

OMEGA IN THE ATLANTIC (1963-1965), by E. R. Swanson and W. E. Davis, 28 p., 10 Jan 66.

UNCLASSIFIED

Measurements were made of 10.2-kc/s phase difference in 24 ports of call in the Atlantic area. The measurements are generally well explained by present propagation models which indicate that an implemented Omega system will have an accuracy of about 0.9 n. mi. (c.e.p.) over the 24-hour day.

1. Omega
2. Radio Navigation Systems

I. Swanson, E. R.
II. Davis, W. E.

SS 161 001, Task 6101
(NEL A10461)

This card is UNCLASSIFIED

Navy Electronics Lab., San Diego, Calif.
Report 1350

OMEGA IN THE ATLANTIC (1963-1965), by E. R. Swanson and W. E. Davis, 28 p., 10 Jan 66.

UNCLASSIFIED

Measurements were made of 10.2-kc/s phase difference in 24 ports of call in the Atlantic area. The measurements are generally well explained by present propagation models which indicate that an implemented Omega system will have an accuracy of about 0.9 n. mi. (c.e.p.) over the 24-hour day.

1. Omega
2. Radio Navigation Systems

I. Swanson, E. R.
II. Davis, W. E.

SS 161 001, Task 6101
(NEL A10461)

This card is UNCLASSIFIED

INITIAL DISTRIBUTION LIST

CHIEF, BUREAU OF SHIPS
CODE 210L (2)
CODE 320
CODE 360
CODE 362C CODE 362A (10)
CODE 670 CODE 685B
CODE 684
CODE 686
CODE 686K
CODE 687A (2)
CODE 742C
CHIEF, BUREAU OF NAVAL WEAPONS
DLI-3
DLI-304
R-56
RA-221
RAAV-6
RAAV-33
RU-222
RUDC
CHIEF OF NAVAL PERSONNEL
PERS 11B
CHIEF OF NAVAL OPERATIONS
OP-312 F OP-035
OP-07T
OP-506 G
OP-701
OP-03EG
OP-09B5
OP-94G
CHIEF OF NAVAL RESEARCH
CODE 418 CODE 5440
CODE 427
COMMANDER IN CHIEF US PACIFIC FLEET
COMMANDER IN CHIEF US ATLANTIC FLEET
COMMANDER OPERATIONAL TEST AND
EVALUATION FORCE
COMMANDER SUBMARINE FORCE
US PACIFIC FLEET
US ATLANTIC FLEET
DEPUTY COMMANDER SUBMARINE FORCE,
US ATLANTIC FLEET
COMMANDER ANTISUBMARINE WARFARE FOR
US PACIFIC FLEET
COMMANDER FIRST FLEET
COMMANDER SECOND FLEET
COMMANDER TRAINING COMMAND
US ATLANTIC FLEET
COMMANDER SERVICE FORCE
US ATLANTIC FLEET
DESTROYER DEVELOPMENT GROUP PACIFIC
US NAVAL AIR DEVELOPMENT CENTER
NADC LIBRARY
US NAVAL MISSILE CENTER
TECH. LIBRARY
CODE N3232
PACIFIC MISSILE RANGE /CODE 3250/
CODE 4320
CODE 3160
US NAVAL AIR TEST CENTER
NANEP
WEAPONS SYSTEMS TEST DIVISION
US NAVAL ORDNANCE LABORATORY
SYSTEMS ANALYSIS GROUP OF THE ASW
R-D PLANNING COUNCIL,
US NAVAL ORDNANCE TEST STATION
PASADENA ANNEX LIBRARY
CHINA LAKE
US NAVAL WEAPONS LABORATORY
LIBRARY
PEARL HARBOR NAVAL SHIPYARD
SAN FRANCISCO NAVAL SHIPYARD
PHILADELPHIA NAVAL SHIPYARD
DAVID TAYLOR MODEL BASIN
/LIBRARY/
US NAVY MINE DEFENSE LABORATORY
USN UNDERWATER SOUND LABORATORY
LIBRARY
US NAVAL AIR ENGINEERING CENTER
USN MARINE ENGINEERING LABORATORY
US NAVAL CIVIL ENGINEERING LAB.
L54
US NAVAL RESEARCH LABORATORY
CODE 2027
CODE 5250
CODE 5320
CODE 5330
CODE 5400
CODE 5440
US NAVAL ORDNANCE LABORATORY
CORONA
BEACH JUMPER UNIT TWO
USN UNDERWATER ORDNANCE STATION
OFFICE OF NAVAL RESEARCH
PASADENA
US NAVAL SHIP MISSILE SYSTEMS
ENGINEERING STATION
US NAVAL OCEANOGRAPHIC OFFICE
SUPERVISOR OF SHIPBUILDING US NAVY
GROTON
US NAVAL POSTGRADUATE SCHOOL
LIBRARY(CODE 0384)
OFFICE OF NAVAL RESEARCH BR OFFICE
LONDON
BOSTON
CHICAGO
US NAVAL APPLIED SCIENCE LABORATORY
CODE 9200, ELECTRONICS DIVISION
CODE 9832
CODE 9560
US NAVAL ACADEMY
ASSISTANT SECRETARY OF THE NAVY R+D
USN SCIENTIFIC + TECHNICAL
INTELLIGENCE CENTER /1E/
US NAVAL SECURITY GROUP HDQTRS(G43)
INSTITUTE OF NAVAL STUDIES
LIBRARY
AIR DEVELOPMENT SQUADRON ONE /VX-1/
CHARLESTON NAVAL SHIPYARD
DEFENSE DOCUMENTATION CENTER (20)
DOD RESEARCH AND ENGINEERING
TECHNICAL LIBRARY
WEAPONS SYSTEMS EVALUATION GROUP
DEFENSE ATOMIC SUPPORT AGENCY
FEDERAL AVIATION AGENCY
SYSTEMS RESEARCH + DEVELOPMENT SERV.
FEDERAL COMMUNICATIONS COMMISSION
NATIONAL SEVERE STORMS LABORATORY
NORMAN, OKLAHOMA 73069
NATIONAL SECURITY AGENCY
C-15
C 1211
P 224
R 31
DEFENSE COMMUNICATIONS AGENCY
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
ELECTROMAGNETIC COMPATIBILITY
ANALYSIS CENTER, NAVENGRXSTA
NAFEC LIBRARY
US ARMY MATERIAL COMMAND
ASST CHIEF OF STAFF FOR INTELLIGENCE
DEPARTMENT OF ARMY
ABERDEEN PROVING GROUND, MD. 21005
US ARMY TEST + EVALUATION COMMAND
US ARMY R-D ACTIVITY
ELECTRONIC WARFARE DIVISION
REDSTONE SCIENTIFIC INFORMATION
CENTER
US ARMY ELECTRONICS R-D LABORATORY
ELECTRONIC WARFARE LABORATORY
CS/TA LAB. AMSEL-HL-R
AMSEL-RD-MAT
XL-C
HARRY DIAMOND LABORATORIES
ATTN- LIBRARY
PICATINNY ARSENAL
US ARMY RESEARCH OFFICE /DURHAM/
WHITE SANDS MISSILE RANGE
US ARMY ELECTRONIC WARFARE LAB.
MOUNTAIN VIEW OFFICE
52D USASASOC
FORT HUACHUCA,
US ARMY ENGINEER R-D LABORATORIES
TECHNICAL DOCUMENT CENTER
HEADQUARTERS, US AIR FORCE
AFRSTA
AIR DEFENSE COMMAND
ADOOA
AIR UNIVERSITY LIBRARY
AIR FORCE EASTERN TEST RANGE
/AFMTC TECH LIBRARY - MU-135/
ROME AIR DEVELOPMENT CENTER
EMLAL-1 (DOCUMENT LIBRARY)
EMIA
AIR PROVING GROUND CENTER, PGBPS-12
1ST STRATEGIC AEROSPACE DIVISION
HQ AIR WEATHER SERVICE
WRIGHT-PATTERSON AF BASE
SYSTEMS ENGINEERING GROUP (RTD)
AVWE-3, ANTENNA-RADOME GROUP
SEG/SEQDE/
USAF SECURITY SERVICE
ESD/ESG
ELECTRONICS SYSTEMS DIVISION/ESTI/
L. G. HANSCOM FIELD
UNIVERSITY OF MICHIGAN
OFFICE OF RESEARCH ADMINISTRATION
UNIVERSITY OF CALIFORNIA
ELECTRONICS RESEARCH LAB
UNIVERSITY OF MIAMI
THE MARINE LAB. LIBRARY
MICHIGAN STATE UNIVERSITY
INSTITUTE OF COURANT
MATHEMATICAL SCIENCES
COLUMBIA UNIVERSITY
HUDSON LABORATORIES
ELECTRONIC RESEARCH LABS
LAMONT GEOLOGICAL OBSERVATORY
DARTMOUTH COLLEGE
RADIOPHYSICS LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY
CORNELL UNIVERSITY
HARVARD COLLEGE OBSERVATORY
GEORGIA INSTITUTE OF TECHNOLOGY
CHIEF, ELECTRONICS DIVISION
UNIVERSITY OF MICHIGAN
RADAR + OPTICS LABORATORY
THE RADIATION LABORATORY
UNIVERSITY OF WASHINGTON
DIRECTOR, APPLIED PHYSICS LABORATORY
OHIO STATE UNIVERSITY
ANTENNA LABORATORY
PROFESSOR L. E. BOLLINGER
UNIVERSITY OF ALASKA
GEOPHYSICAL INSTITUTE
UNIVERSITY OF HAWAII
ELECTRICAL ENGINEERING DEPT
HARVARD UNIVERSITY
GORDON MCKAY LIBRARY
THE UNIVERSITY OF TEXAS
DEFENSE RESEARCH LABORATORY
ELECTRICAL ENGINEERING RESEARCH LAB
UNIVERSITY OF ILLINOIS
ELECTRICAL ENGINEERING DEPT.
UNIVERSITY OF CALIFORNIA-SAN DIEGO
MARINE PHYSICAL LAB
UNIVERSITY OF CALIFORNIA
ENGINEERING DEPARTMENT
STANFORD ELECTRONICS LABORATORIES
ATTN- DOCUMENTS LIBRARY
NAVAL WARFARE RESEARCH CENTER
STANFORD RESEARCH INSTITUTE
MASSACHUSETTS INST OF TECHNOLOGY
RESEARCH LAB OF TECHNOLOGY
ENGINEERING LIBRARY
MIT-LINCOLN LABORATORY
LIBRARY, A-082
RADIO PHYSICS DIVISION
HEAD, RADAR DIVISION
UNIVERSITY OF NEW MEXICO
BUREAU OF ENGINEERING RESEARCH
THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
INSTITUTE FOR DEFENSE ANALYSES