

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

8

ADA 1 29868

A Summary of Results in Data Adaptive Detection and Estimation

Steven Kay

Department of Electrical Engineering
University of Rhode Island
Kingston, Rhode Island 02881

April 1983

Prepared for

OFFICE OF NAVAL RESEARCH (Code 411 SP)
Statistics and Probability Branch
Arlington, Virginia 22217
under Contract N00014-81-K-0144
D. W. Tufts, Principal Investigator

DTIC
ELECTE
S D
JUN 29 1983
E

Approved for public release; distribution unlimited

DTIC FILE COPY

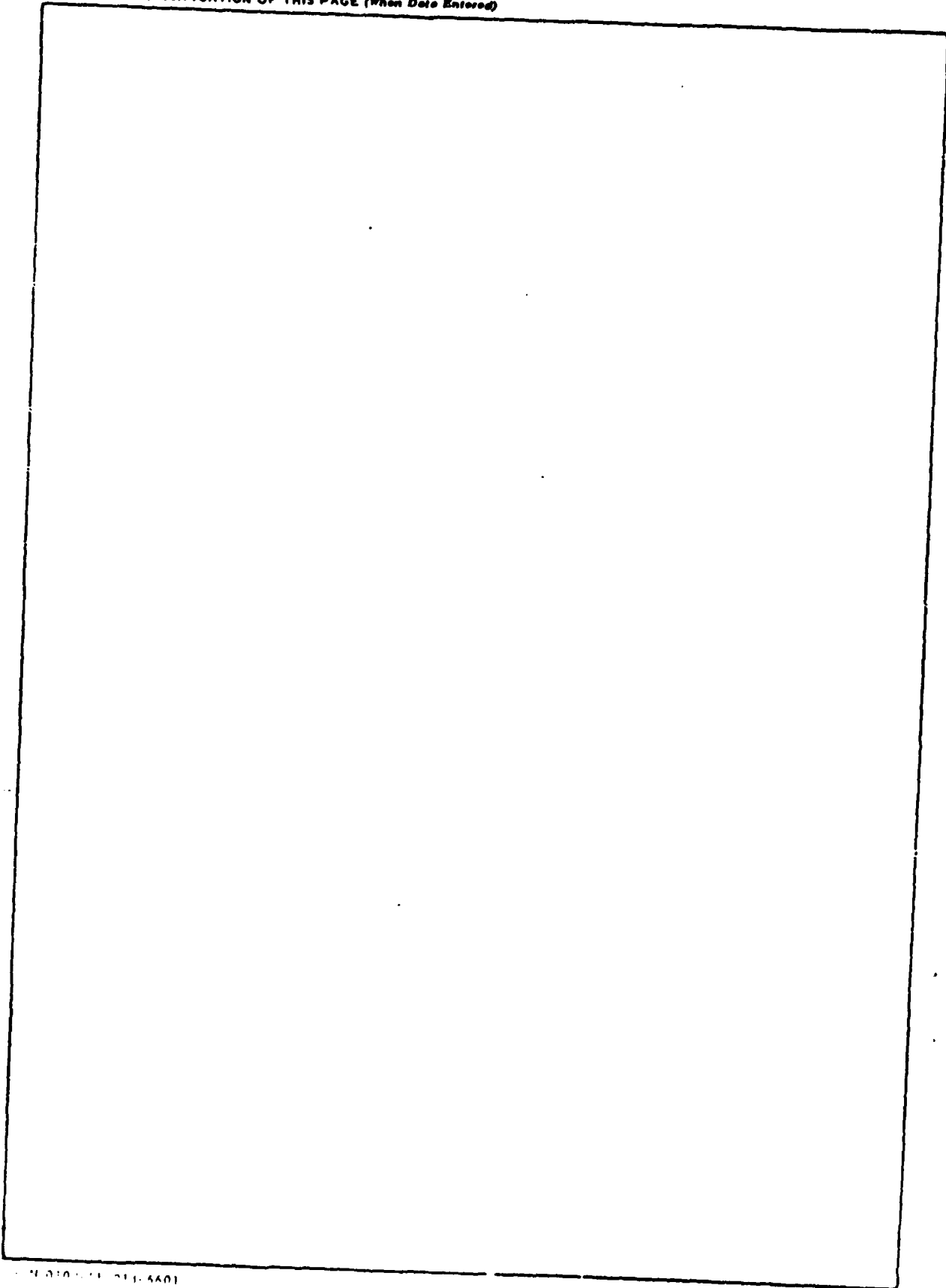
88 06 27 07 8

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER		2. GOVT ACCESSION NO AD-A129868		3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) A Summary of Results in Data Adaptive Detection and Estimation				5. TYPE OF REPORT & PERIOD COVERED	
7. AUTHOR(s) Steven Kay				8. CONTRACT OR GRANT NUMBER(s) N00014-81-0144 K	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Electrical Engineering University of Rhode Island Kingston, Rhode Island 02881				10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research (Code 411 SP)				12. REPORT DATE	
				13. NUMBER OF PAGES 15	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)				15. SECURITY CLASS. (of this report) Unclassified	
				15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited					
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)					
18. SUPPLEMENTARY NOTES					
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)					
20. <input checked="" type="checkbox"/> ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes a number of results which have been obtained in the Data Adaptive Detection and Estimation project. The various papers summarized deal with properties of autoregressive representations as they relate to detection and estimation in partially known signal and/or noise environments. Complete copies of the works can be obtained from the author. ↗					

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)



FORM NO. 104 (11-60) (4401)

A Summary of Results
in Data Adaptive Detection
and Estimation

Steven Kay
Department of Electrical Engineering
University of Rhode Island

Abstract

This report describes a number of results which have been obtained in the Data Adaptive Detection and Estimation project. The various papers summarized deal with properties of autoregressive representations as they relate to detection and estimation in partially known signal and/or noise environments. Complete copies of the works can be obtained from the author.

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	



SUMMARY

- 1) "On the Statistics of the Estimated Reflection Coefficients of an Autoregressive Process" (with John Makhoul of Bolt, Beranek, and Newman)--submitted to IEEE Trans. on Acoustics, Speech, and Signal Processing.

This paper derives a recursive means of computing the Cramer-Rao (CR) lower bound for the estimated reflection coefficients of an autoregressive (AR) process. The exact algorithm which computes the bound is given in Figure 1. Since the CR bound is attained asymptotically (for large data records) for a Maximum Likelihood Estimate of the reflection coefficients, one can also use the algorithm of Figure 1 to describe the statistics of the MLE. It is also shown in this paper that all currently available estimators for the reflection coefficients are MLE's for large data records. Thus, the results can be used to statistically characterize these estimators, i.e., the Burg algorithm¹ as an example. An example of the actual covariance matrix (obtained via computer simulation) and the CR bound is shown in Figure 2. The data length was 1000 points.

- 2) "Simple Proofs of the Minimum Phase Property of the Prediction Error Filter" (with Louis Pakula of U.R.I.)--IEEE Trans. on Acoustics, Speech, and Signal Processing, April 1983.

Presented are two simple proofs which assert the well known property that all the zeros of the optimal prediction error filter lie on or within the unit circle of the Z plane. The first proof is somewhat incomplete in that it only shows that the zeros lie on or within the unit circle. It gives no indication as to when the zeros must be totally within the unit circle. However, it is extremely simple. The second proof which is slightly more complex also determines conditions under which the zeros may be on the

unit circle.

3) "Recursive Maximum Likelihood Estimation of Autoregressive Processes"--

IEEE Trans. on Acoustics, Speech, and Signal Processing, February 1982.

An estimation algorithm is derived which is a closer approximation to the true MLE of the parameters of an AR process than currently existing procedures. Specifically, the algorithm does not make the standard assumption that the determinant of the filter covariance matrix can be neglected in the maximization of the likelihood function. This common assumption is not valid for short data records and/or highly peaked spectra. By incorporating the determinant and maximizing the likelihood function recursively (in model order) more accurate parameter and spectral estimates are obtained. The algorithm is summarized in Figure 3. Also, Figure 4 summarizes some simulation results which verify the improved performance of the algorithm for short data records. (RMLE = Recursive MLE, FB = Forward-Backward, YW = Yule-Walker).

4) "More Accurate Autoregressive Parameter and Spectral Estimates for

Short Data Records"--IEEE Workshop on Spectral Estimation, Hamilton, Ontario, August 1981.

This paper is a shortened version of 3.

5) "Some Results in Linear Interpolation Theory"--to be published in IEEE

Trans. on Acoustics, Speech, and Signal Processing.

The optimal finite length interpolation filter for a wide sense stationary process is derived. It is shown that for an AR process one can significantly reduce the power out of an FIR filter by performing interpolation rather than the more common one sided prediction. Also, the optimal interpolation filter for an AR process, i.e., the one which minimizes the interpolation error power, is found to be the one which attempts to interpolate at the midpoint of a data record. This result although intuitive is shown not to hold for

more general processes. Finally, some well known results in infinite length FIR filter interpolation are simply derived using AR approximations of infinite order.

- 6) "Accurate Frequency Estimation at Low Signal-to-Noise Ratios"--submitted to IEEE Trans. on Acoustics, Speech, and Signal Processing.

An iterative algorithm for frequency estimation of sinusoids in white noise is described and analyzed. The algorithm iteratively computes AR parameter estimates after the original data has been filtered by an all pole filter. The algorithm is shown to be related to the Steiglitz-McBride algorithm². It is summarized in Figure 5, where it has been termed the Iterative Filtering Algorithm (IFA). For two sinusoids closely spaced in frequency the algorithm performance is shown in Figure 6. Also, shown is the CR bound (for unbiased estimators) and the principal component (PC) approach of Tufts and Kumaresan³. The IFA outperforms the PC approach at low SNR's. The PC approach had been claimed to offer the best performance other than a direct MLE, at low SNR's. At higher SNR's a bias is present which tends to degrade the performance of the IFA. In Figure 7 a comparison is made with a direct MLE, which amounts to a nonlinear least squares estimator. Again at low SNR the IFA appears to perform better.

- 7) "Asymptotically Optimal Detection in Unknown Colored Noise via Autoregressive Modeling"--to be published in IEEE Trans. on Acoustics, Speech, and Signal Processing.

The problem of detecting a known signal in Gaussian noise of unknown covariance is addressed. The noise is assumed to be an AR process of known order but unknown coefficients. Thus, the parameterization of the covariance leads to a problem in composite hypothesis testing. Since in general no uniformly most powerful test exists, the Generalized Likelihood Ratio

Test (GLRT) is applied. The GLRT detector which results is shown in Figure 8. As expected adaptive prewhiteners are included which assume either the signal is present (upper channel) or absent (lower channel). The detector is not a single estimated prewhitener and matched filter as might be expected. The performance of the detector is shown in Figures 9 and 10 for an AR process of order $p=1$ and parameter $a=-0.9$ and for various data record lengths $N=20,100$. The optimal curve is the performance assuming a known covariance function, i.e., a prewhitener and matched filter. It is seen that even for short data records the performance is nearly optimal. Finally, it is proven that for large data records the GLRT performance is equal to that of a prewhitener (assuming a known covariance) and matched filter and hence is optimal.

- 8) "Detection for Active Sonars via Autoregressive Modeling,"--Workshop on Maximum Entropy and Bayesian Methods in Applied Statistics, University of Wyoming, Laramie, Wyoming, August 1982.

This paper is a shortened version of 7.

1) For $n=1$

$$\underline{a}_1 = a_1(1) = K_1$$

$$\underline{A}_1 = \underline{B}_1 = \underline{E}_1 = c_0^2 = 1$$

$$c_1^2 = (1-K_1^2)$$

$$\underline{C}_K^2(1) = \frac{1}{N} (1-K_1^2)$$

2) $n - n+1$

$$c_n^2 = (1-K_n^2) c_{n-1}^2$$

$$\underline{D}_{n-1} = \frac{1}{1-K_n^2} \underline{A}_{n-1} (\underline{I}-K_n \underline{J}) \underline{B}_{n-1}$$

$$\underline{C}_K^2(n) = \frac{1}{N} \begin{bmatrix} c_n^2 & \underline{D}_{n-1} \underline{E}_{n-1}^{-1} \underline{D}_{n-1}^T & \underline{0} \\ \underline{0}^T & & 1-K_n^2 \end{bmatrix}$$

3) If $n=p$, let $\underline{C}_K^2 = \underline{C}_K^2(n)$ and exit.

$$4) \quad \underline{E}_n^{-1} = \begin{bmatrix} \underline{E}_{n-1}^{-1} & \underline{0} \\ \underline{0}^T & 1/c_n^2 \end{bmatrix}$$

$$\underline{A}_{n-1} = \begin{bmatrix} (\underline{I}+K_{n-1} \underline{J}) \underline{a}_{n-2} \\ K_{n-1} \end{bmatrix}$$

$$\underline{B}_n = \begin{bmatrix} \underline{B}_{n-1} & \underline{a}_{n-1} \\ \underline{0}^T & 1 \end{bmatrix}$$

$$\underline{A}_n = \begin{bmatrix} \frac{1}{1-K_n^2} \underline{A}_{n-1} (\underline{I}-K_n \underline{J}) & -\frac{1}{1-K_n^2} \underline{A}_{n-1} (\underline{I}-K_n \underline{J}) \underline{a}_{n-1} \\ \underline{0}^T & 1 \end{bmatrix}$$

5) Go to 2

Note that $\underline{0}^T$ is $1 \times (n-1)$.

Figure 1. Summary of Cramer-Rao Bound Computation for Reflection Coefficients.

TABLE 2

	TRUE VALUES			ESTIMATED VALUES		
$K_1 K_2 K_3$	0.570	0.570	0.570	0.569	0.568	0.564
$NC_{\hat{K}}$	0.541	-0.490	0.000	0.523	-0.479	-0.006
	-0.490	0.675	0.000	-0.479	0.689	0.028
	0.000	0.000	0.675	-0.006	0.028	0.665

	TRUE VALUES			ESTIMATED VALUES		
$K_1 K_2 K_3$	0.570	-0.570	0.570	0.557	-0.563	0.563
$NC_{\hat{K}}$	7.210	-1.790	0.000	6.988	-1.858	-0.151
	-1.790	0.675	0.000	-1.858	0.716	0.016
	0.000	0.000	0.675	-0.151	0.016	0.692

Figure 2. True and estimated values of the reflection coefficients and their covariances for two AR(3) processes. The two processes differ by the sign of K_2 .

$$\delta_0 = S_{00}$$

$$\text{for } n = 1: C_n = S_{01}, \quad d_1 = S_{11}$$

to find K_1 solve

$$K_1^2 + \frac{N-2}{N-1} \frac{C_1}{d_1} K_1 - \frac{\xi_0 + Nd_1}{(N-1)d_1} - \frac{N}{N-1} \frac{C_1}{d_1} = 0$$

and choose root within $[-1, 1]$.

$$a_1^{(1)} = K_1$$

$$\delta_1 = S_{00} + 2K_1 S_{01} + K_1^2 S_{11}$$

$$\sigma_\epsilon^2(1) = \frac{1}{N} \delta_1$$

For $n = 2, 3, \dots, p$:

$$C_n = a_{n-1}^T \begin{bmatrix} q_{n-1}^T & S_{0n} \\ S_{n-2} & p_{n-1} \end{bmatrix} b_{n-1}'$$

$$d_n = b_{n-1}^T \begin{bmatrix} S_{n-2} & p_{n-1} \\ p_{n-1}^T & S_{nn} \end{bmatrix} b_{n-1}'$$

to find K_n solve (for $d_n > 0$)^{*}

$$K_n^2 + \frac{N-2n}{N-n} \frac{C_n}{d_n} K_n - \frac{n\xi_{n-1} + Nd_n}{(N-n)d_n} - \frac{N}{N-n} \frac{C_n}{d_n} = 0$$

and choose root within $[-1, 1]$.

$$a_i^{(n)} = \begin{cases} a_i^{(n-1)} + K_n a_{n-i}^{(n-1)}, & i = 1, 2, \dots, n-1 \\ K_n, & i = n \end{cases}$$

$$\delta_n = \delta_{n-1} + 2C_n K_n + d_n K_n^2$$

$$\sigma_\epsilon^2(n) = \frac{1}{N} \delta_n$$

where

$$a_{n-1}' = [1 \quad a_1^{(n-1)} \quad a_2^{(n-1)} \quad \dots \quad a_{n-1}^{(n-1)}]^T$$

$$b_{n-1}' = [a_{n-1}^{(n-1)} \quad a_{n-2}^{(n-1)} \quad \dots \quad a_1^{(n-1)} \quad 1]^T$$

$$[S_n]_{ij} = S_{ij} = \sum_{t=1}^{N-i-j} x_{t+i} x_{t+j} \quad i = 0, 1, \dots, n \\ j = 0, 1, \dots, n$$

$$S_n = \begin{bmatrix} S_{00} & q_{n-1}^T & S_{0n} \\ 1 \times 1 & 1 \times (n-1) & 1 \times 1 \\ q_{n-1} & S_{n-2} & p_{n-1} \\ (n-1) \times 1 & (n-1) \times (n-1) & (n-1) \times 1 \\ S_{n0} & p_{n-1}^T & S_{nn} \\ 1 \times 1 & 1 \times (n-1) & 1 \times 1 \end{bmatrix}$$

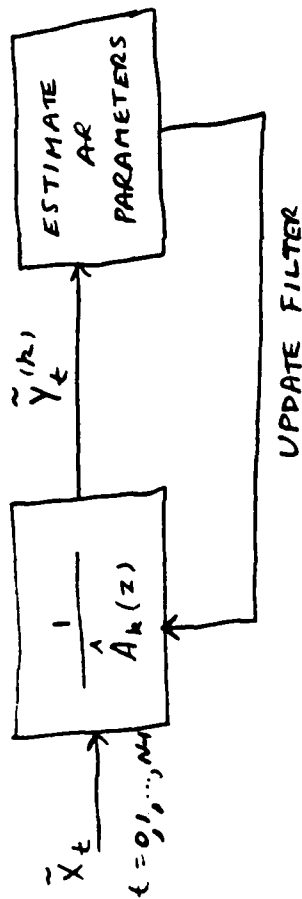
*For $d_n = 0$ see Section III for discussion of roots.

Figure 3. Summary of Recursive MLE Algorithm.

TABLE I
COMPARISON OF AR PARAMETER ESTIMATION METHODS

N = 11 Data Points				
	a_1	a_2	a_3	a_4
True AR Parameters	-2.76070	3.81060	-2.65350	0.92386
Mean-YW	-1.01527	0.61949	0.04466	0.05735
Mean-FB	-2.59333	3.42185	-2.27303	0.77262
Mean-RMLE	-2.62975	3.51086	-2.37156	0.81412
Variance-YW	3.13780	10.29627	7.33884	0.75840
Variance-FB	0.11598	0.52574	0.49303	0.08462
Variance-RMLE	0.10960	0.33371	0.26227	0.04148
N = 50 Data Points				
	a_1	a_2	a_3	a_4
True AR Parameters	2.76070	3.81060	-2.65350	0.92386
Mean-YW	1.30552	0.92378	0.05153	0.06719
Mean-FB	2.72368	3.71024	-2.54984	0.87639
Mean-RMLE	2.71515	3.69876	-2.54345	0.87765
Variance-YW	2.22544	8.56804	6.90835	0.74526
Variance-FB	0.00758	0.04138	0.04219	0.00858
Variance-RMLE	0.01076	0.04485	0.04069	0.00741

Figure 4. Comparison of AR Parameter Estimation Methods



$$\hat{A}_k(z) = 1 + \sum_{n=1}^p \hat{a}_n^{(k)} z^{-n}$$

Figure 5 - Generic Iterative Filtering Algorithm

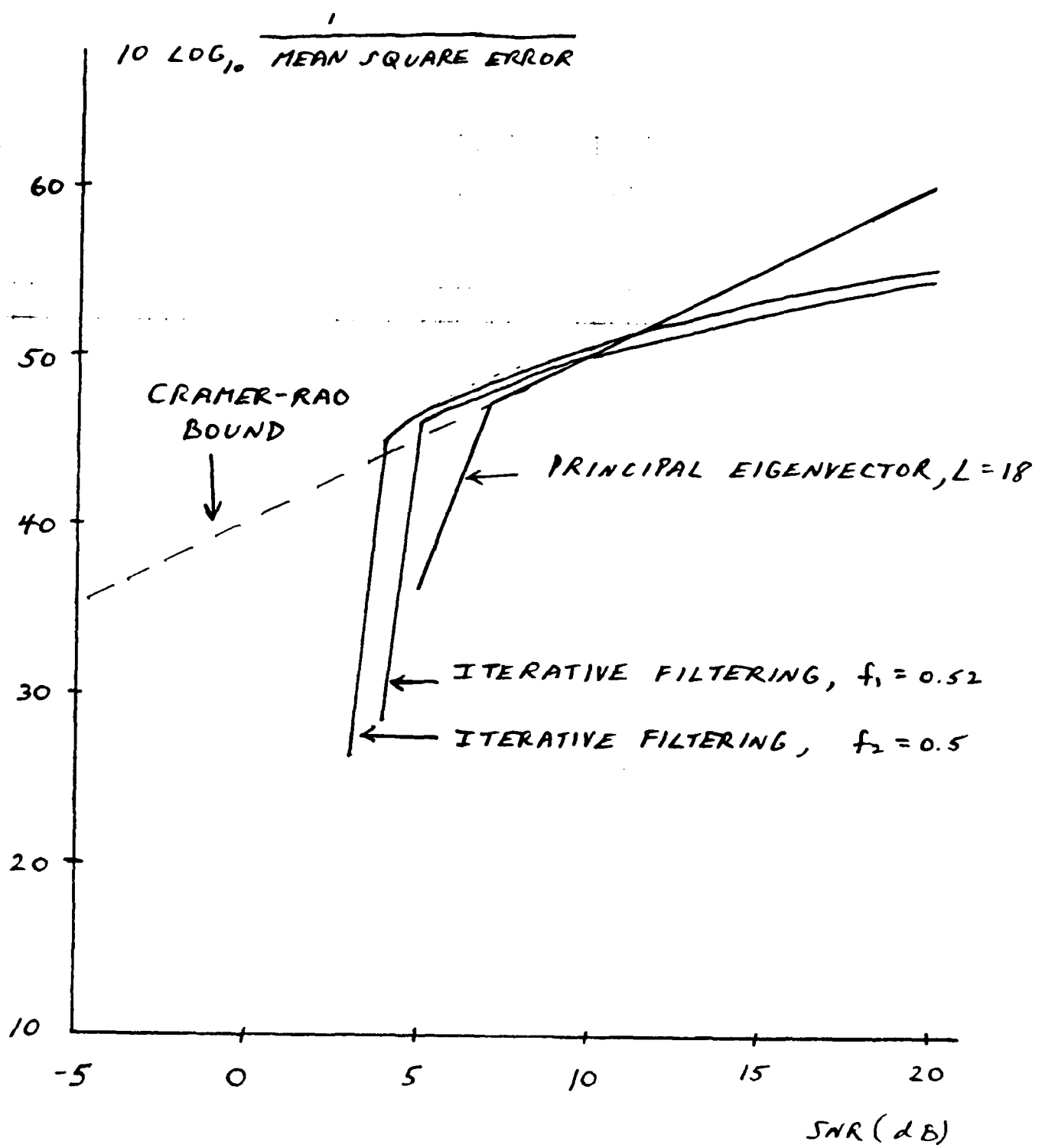


Figure 6. Comparison of Frequency Estimators,
 $\varphi_1 = \pi/4, \varphi_2 = 0$

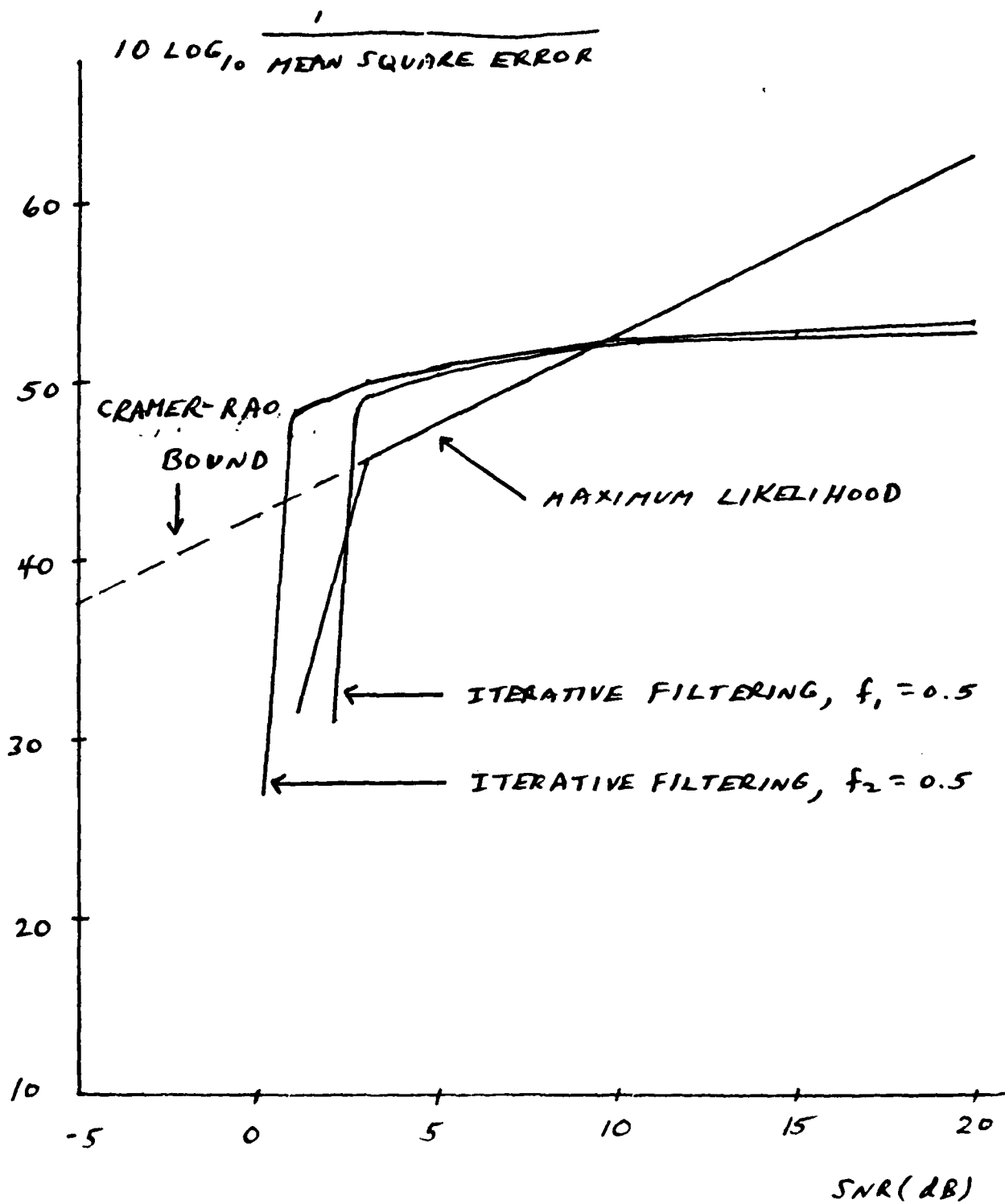
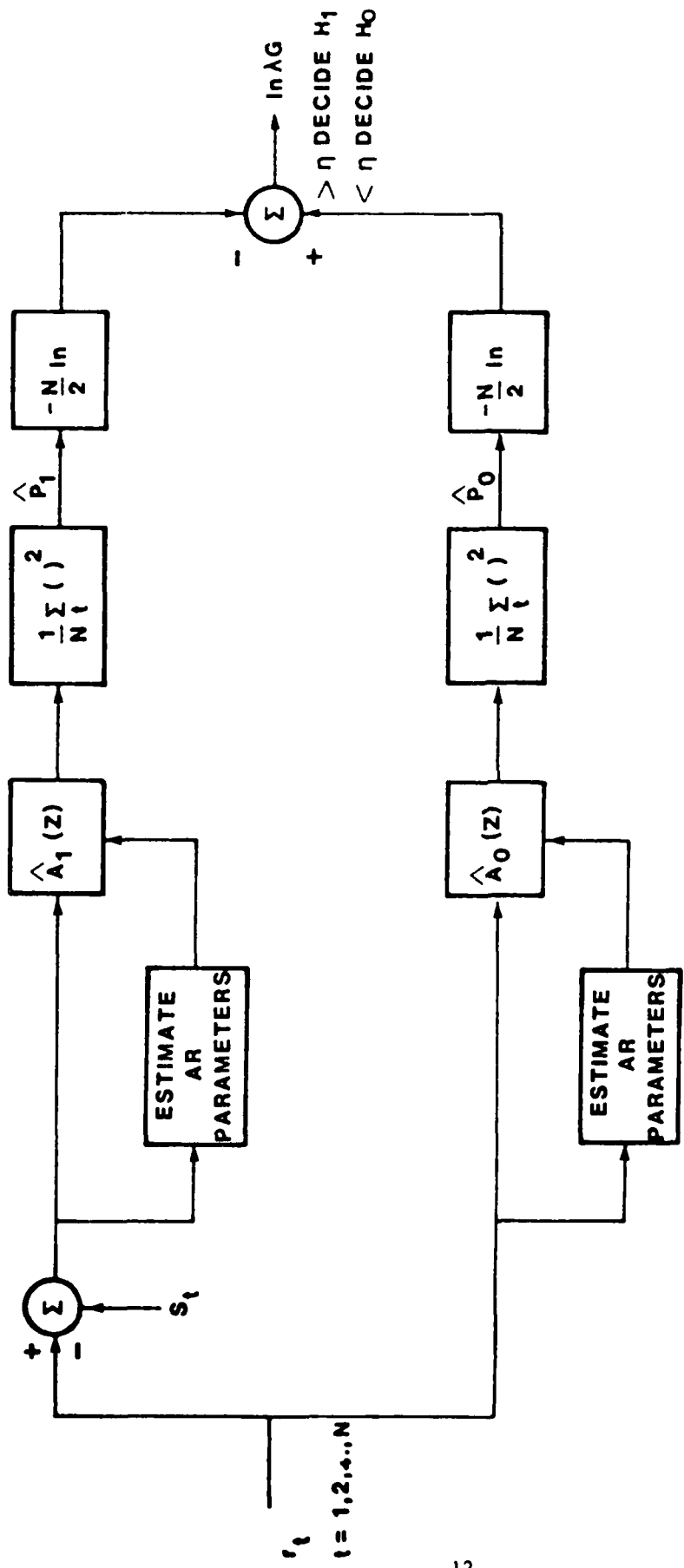


Figure 7. Comparison of Frequency Estimators,
 $\rho_1 = 0, \rho_2 = 0$



WHERE $\hat{A}_i(z) = 1 + \sum_{k=1}^p \hat{a}_{ik} z^{-k}$ = ESTIMATED PREWHITENER UNDER H_i

Figure 8. Generalized Likelihood Ratio Test Detector

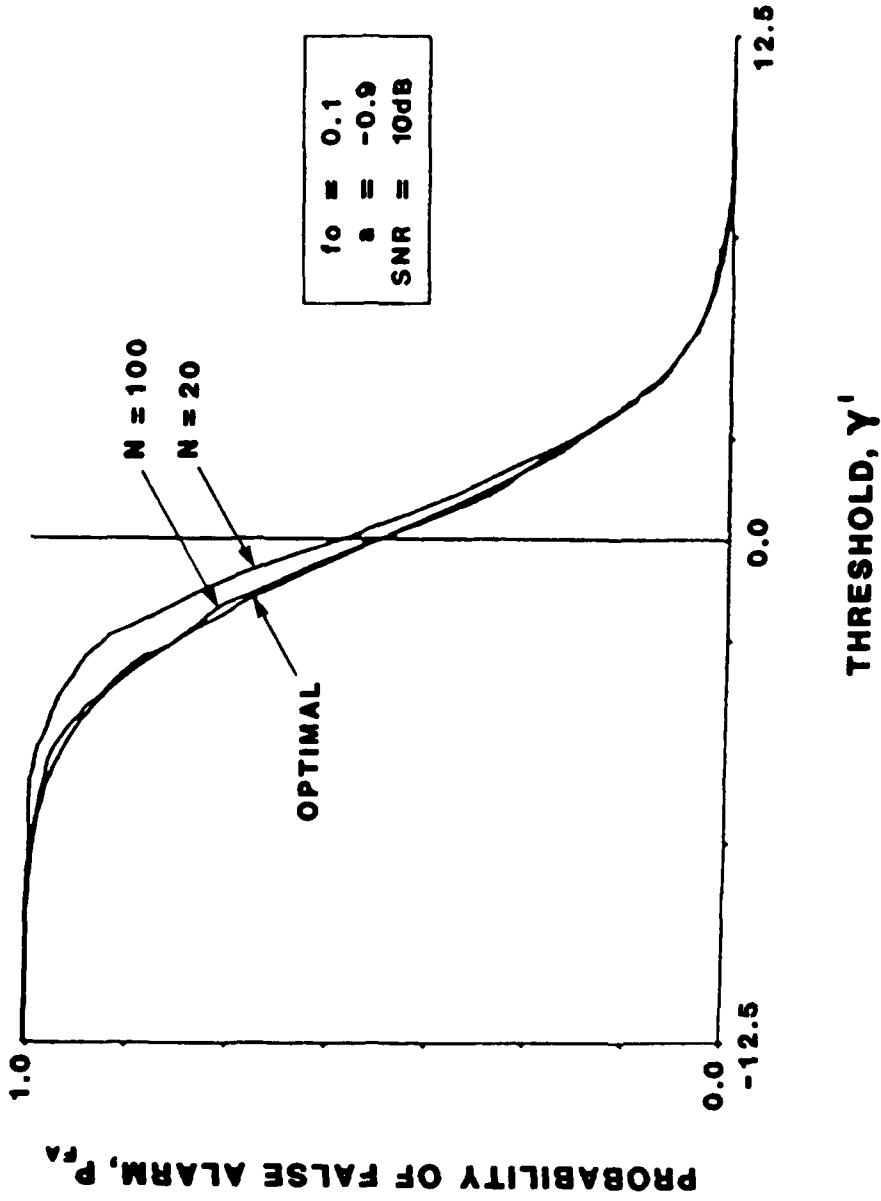


Figure 9. Probability of False Alarm of GLRT Detector

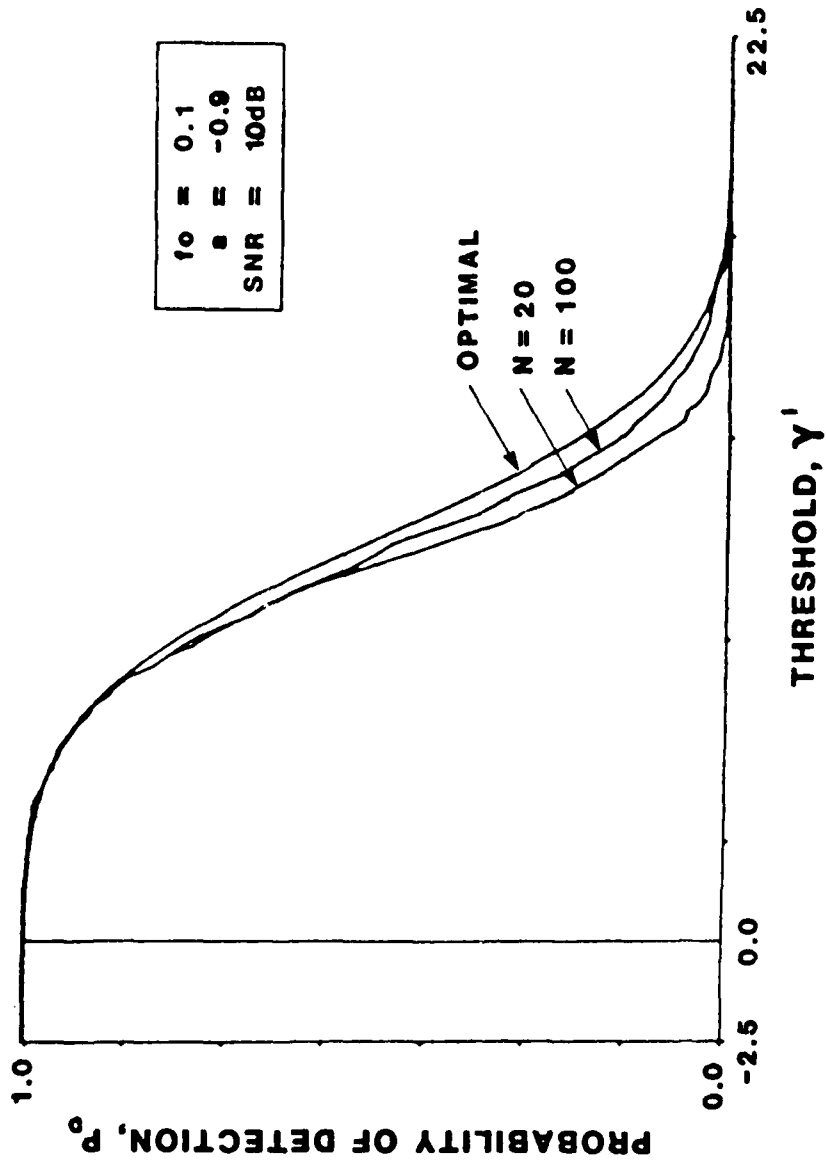


Figure 10. Probability of Detection of GLRT Detector

REFERENCES

- 1) J. Burg, "Maximum Entropy Spectral Analysis," Ph.D. Dissertation, Stanford University, Stanford, CA, 1975.
- 2) K. Steiglitz, L.E. McBride, "A Technique for Identification of Linear Systems," IEEE Trans. on Aut. Control, Vol. AC-10, pp. 461-464, October 1965.
- 3) D. Tufts, R. Kumaresan, "Estimation of Frequencies of Multiple Sinusoids: Making Linear Prediction Perform Like Maximum Likelihood," IEEE Proc., Vol. 70, pp. 975-989, September 1982.

OFFICE OF NAVAL RESEARCH
STATISTICS AND PROBABILITY PROGRAM

BASIC DISTRIBUTION LIST
FOR
UNCLASSIFIED TECHNICAL REPORTS

FEBRUARY 1982

Copies	Copies
Statistics and Probability Program (Code 411(SP)) Office of Naval Research Arlington, VA 22217 3	Navy Library National Space Technology Laboratory Attn: Navy Librarian Bay St. Louis, MS 39522 1
Defense Technical Information Center Cameron Station Alexandria, VA 22314 12	U. S. Army Research Office P.O. Box 12211 Attn: Dr. J. Chandra Research Triangle Park, NC 27706 1
Commanding Officer Office of Naval Research Eastern/Central Regional Office Attn: Director for Science Barnes Building 495 Summer Street Boston, MA 02210 1	Director National Security Agency Attn: R51, Dr. Maar Fort Meade, MD 20755 1
Commanding Officer Office of Naval Research Western Regional Office Attn: Dr. Richard Lau 1030 East Green Street Pasadena, CA 91101 1	ATAA-SL, Library U.S. Army TRADOC Systems Analysis Activity Department of the Army White Sands Missile Range, NM 88002 1
U. S. ONR Liaison Office - Far East Attn: Scientific Director APO San Francisco 96503 1	ARI Field Unit-USAREUR Attn: Library c/o GDCSPER HQ USAEREUR & 7th Army APO New York 09402 1
Applied Mathematics Laboratory David Taylor Naval Ship Research and Development Center Attn: Mr. G. H. Gleissner Bethesda, Maryland 20084 1	Library, Code 1424 Naval Postgraduate School Monterey, CA 93940 1
Commandant of the Marine Corps (Code AX) Attn: Dr. A. L. Slafkosky Scientific Advisor Washington, DC 20380 1	Technical Information Division Naval Research Laboratory Washington, DC 20375 1
	OASD (I&L), Pentagon Attn: Mr. Charles S. Smith Washington, DC 20301 1

Copies

Copies

Director
AMSAA
Attn: DRXSYP-MP, H. Cohen
Aberdeen Proving Ground, MD 1
21005

Dr. Gerhard Heiche
Naval Air Systems Command
(NAIR 03)
Jefferson Plaza No. 1
Arlington, VA 20360 1

Dr. Barbara Bailar
Associate Director, Statistical
Standards
Bureau of Census
Washington, DC 20233 1

Leon Slavin
Naval Sea Systems Command
(NSEA 05H)
Crystal Mall #4, Rm. 129
Washington, DC 20036 1

B. E. Clark
RR #2, Box 647-B
Graham, NC 27253 1

Naval Underwater Systems Center
Attn: Dr. Derrill J. Bordelon
Code 601
Newport, Rhode Island 02840 1

Naval Coastal Systems Center
Code 741
Attn: Mr. C. M. Bennett
Panama City, FL 32401 1

Naval Electronic Systems Command
(NELEX 610)
Attn: John Schuster
National Center No. 1
Arlington, VA 20360 1

Defense Logistics Studies
Information Exchange
Army Logistics Management Center
Attn: Mr. J. Dowling
Fort Lee, VA 23801 1

Reliability Analysis Center (RAC)
RADC/RBRAC
Attn: I. L. Krulac
Data Coordinator/
Government Programs
Griffiss AFB, New York 13441 1

Technical Library
Naval Ordnance Station
Indian Head, MD 20640 1

Library
Naval Ocean Systems Center
San Diego, CA 92152 1

Technical Library
Bureau of Naval Personnel
Department of the Navy
Washington, DC 20370 1

Mr. Dan Leonard
Code 8105
Naval Ocean Systems Center
San Diego, CA 92152 1

Dr. Alan F. Petty
Code 7930
Naval Research Laboratory
Washington, DC 20375 1

Dr. M. J. Fischer
Defense Communications Agency
Defense Communications Engineering
Center
1860 Wiehle Avenue
Reston, VA 22090 1

Mr. Jim Gates
Code 9211
Fleet Material Support Office
U. S. Navy Supply Center
Mechanicsburg, PA 17055 1

Mr. Ted Tupper
Code M-311C
Military Sealift Command
Department of the Navy
Washington, DC 20390 1

Copies

Copies

Mr. F. R. Del Priori
Code 224
Operational Test and Evaluation
Force (OPTEVFOR)
Norfolk, VA 23511

1

ATE
LMED
8