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TARGET ACQUISITION PERFORMANCE OF A SATELLITE BASED MULTIPLE ACCESS SURVEILLANCE SYSTEM

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16. Abstract

A quantitative description of the detection performance of a satellite-based surveillance system is presented. This system is one which has been proposed for CONUS coverage in an advanced air traffic control system. In addition, the computer program which was used to simulate the random access surveillance link for this system is described. This computer program is appliable for analysis of a broad range of random access surveillance systems.

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PREFACE

This report was written in support of the Advanced Air Traffic Management System (AATMS) Study. It presents an analysis of the target acquisition performance of an asynchronous multiple access satellite surveillance system. The analysis is based primarily on the use of computer simulation of the radio link between the target aircraft and a surveillance satellite.

The work presented here was performed at the Transportation Systems Center, U.S. Department of Transportation as part of Project Plan Agreement OS-304. The sponsoring agency was the Office of the Assistant Secretary for Systems Development and Technology, Office of Systems Engineering, U.S. Department of Transportation.

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1. INTRODUCTION

This report presents an analysis of the target acquisition performance of an asynchronous multiple access satellite surveillance system. The analysis is based primarily on the use of computer simulation of the radio link between the target aircraft and a surveillance satellite. The computer-simulation program, which is described in detail in chapter 7, is reasonably general and can provide performance characterizations for a variety of surveillance systems. The analysis presented in chapters 2 through 4 is directed primarily toward a candidate surveillance system that is one of several which have been studied in the Advanced Air Traffic Management System (AATMS) program at TSC. The surveillance system is described in detail in reference 1. A short description is presented here.

Each aircraft in the target population has a unique waveform signature which consists of three pulsed waveforms. Each pulse is selected from a set of 16 waveforms which are selected to have good auto-and-cross-correlation properties. The second pulse is transmitted in one of 16 time slots relative to the first pulse. The third pulse is transmitted in one of 16 different time slots relative to the second pulse. Aircraft positions is estimated by computing relative time delay for the propagation of the radio signal from the aircraft, through four or more spatially separated satellites, to a ground station. The satellites are in equatorial and inclined elliptic synchronous orbits. The surveillance system services peaks traffic loads of 35,000 to 100,000 aircraft.

This study has been directed toward determining surveillance system acquisition performance in a noise environment that includes the self noise, commonly referred to as "Multiple Access Noise" generated by the targets in the surveillance system, and additive Gaussian noise.

Acquisition performance has been analyzed for a first order characterization of a surveillance system, rather than the other two areas of interest track accuracy, and track reliability. This is done because acquisition appears to be the highest risk aspect of the performance of a multiple access surveillance system of the type discussed here.

The data presented in this paper was required in order to assess the risks involved in the design and construction of a surveillance system of the type which was proposed. The curves presented in section 5 indicate that for a reasonable number of satellites (e.g., 10 to 15) and reasonable radio equipment (e.g., received pulse SNR on the order of 18-21dB) the class of surveillance system which was considered will provide adequate performance for use in a high reliability air traffic control system.

The data and the simulation program are both useful for optimization of the performance of asynchronous multiple access surveillance systems of the type that was considered.

2. DESCRIPTION OF SURVEILLANCE SUB-SYSTEM

The surveillance sub-system is described in Reference 1. The modifications to that system which are included in the system shown in Figure 1 and modeled here are:

(a) A linear satellite repeater or receiver. Performance data for the hard-limiting repeater is also presented but the improved performance of the linear receiver does not appear to impose a major cost burden.

(b) A peak detector at the output of each of the 16 analog matched filters in the receiver. This is a negligable cost and complexity performance improvement.

(c) The multiple-access noise simulation program. This simulates a system with a signal set made up of elementary waveforms 255 chips long. The candidate system waveforms are 400 chips long. This is not thought to make a major difference in performance. The change from 400 to 255 decreases the number of pulses that will be simultaneously transmitted, which improves multiple-access noise performance. This is counterballanced by the shorter waveforms having worse cross-correlation performance. Experience with the simulation program has indicated that detection performance is not strongly dependent on waveform-correlation properties when sensible waveforms are used. Therefore, these are not expected to be major effects.

There are a variety of more significant changes which could be made to the receiver and waveforms. These changes have the potential for significant performance improvements. The discussion and analysis of these modifications is beyond the scope of this paper.

The results presented here are for detection, probability and false-alarm performance at two places in the receiving equipment. The performance of the receiving equipment for the detection and

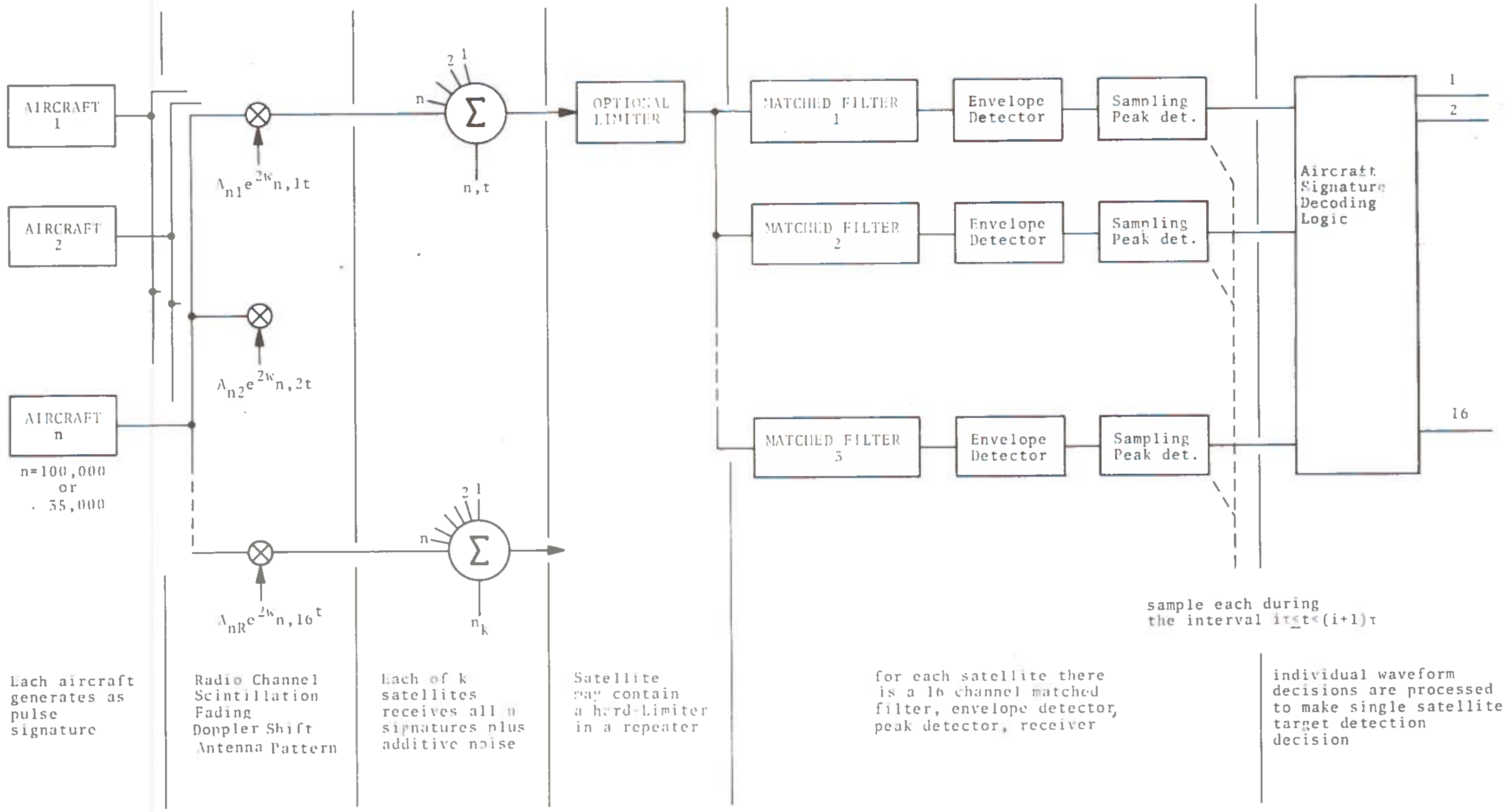
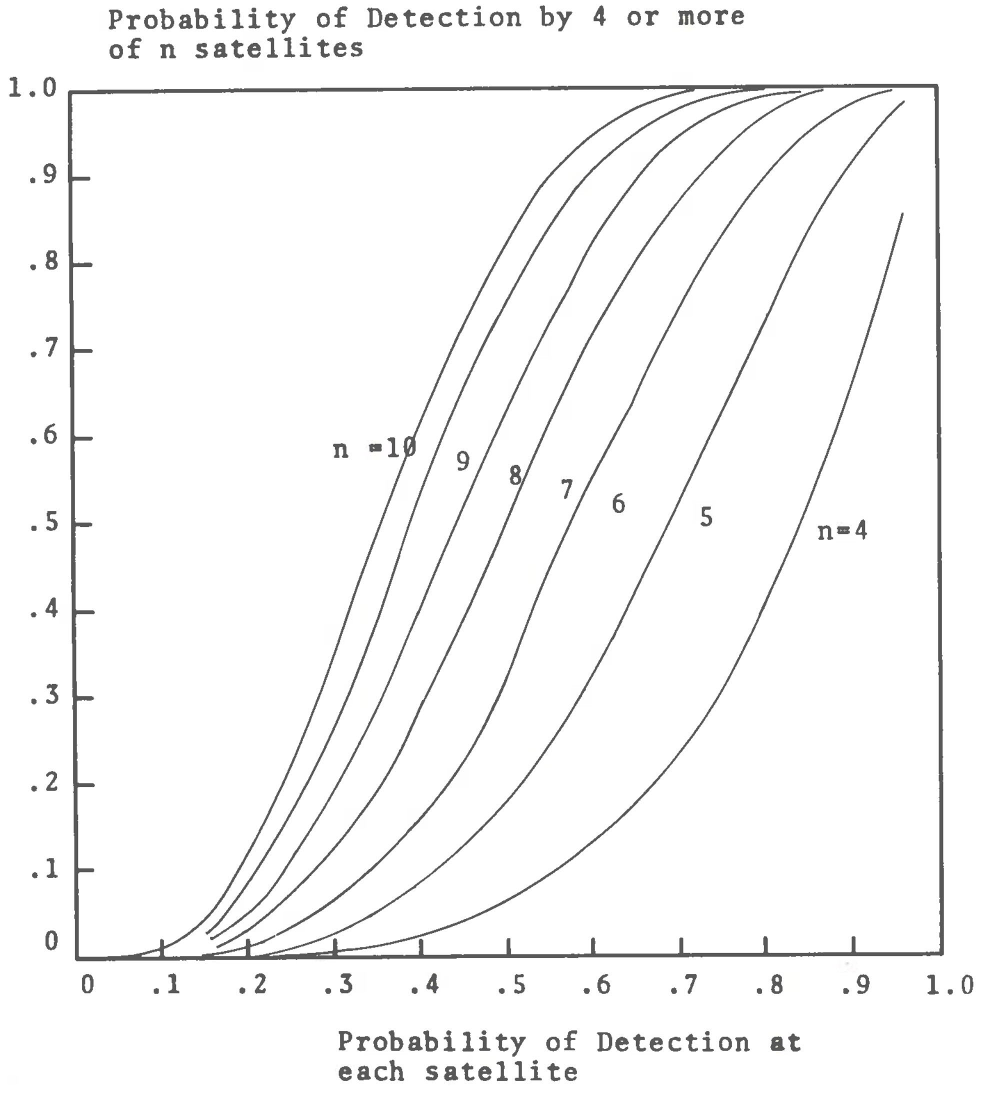


Figure 1. Block Diagram of Surveillance System

processing of single, coherent, coded pulses is presented. The performance of the receiver at the output from the three pulse target identity processor is presented separately. The latter set of curves is a complete description of the performance of a single link through one satellite. The relationship between single satellite detection performance and system target acquisition of track-performance has not been addressed. System performance is determined by a large set of processing algorithm options. The work presented in reference 1 has skimmed the surface of this subject but the performance of the presently proposed system can only be considered a lower bound of the performance which can be expected from an exhaustively designed system.

To provide a method of approximating the relationship which exists between single-satellite performance and system-target acquisition performance a very simple algorithm was examined. Figure 2 shows the relationship between single-satellite, and system-detection probabilities. In many cases, false alarm probability can be ignored in system-performance calculations if it has been shown that false alarms do not overload the target-Acquisition processor. Figure 2 indicates that detection-performance is strongly dependent on the satellite-constellation as well as the detection-performance of one satellite.



The parameter n is the number of satellites at which the signal to noise ratio for an aircraft exceeds the design minimum.

Figure 2. Relation Between System Target Detection Probability and Single Satellite Target Detection Probability

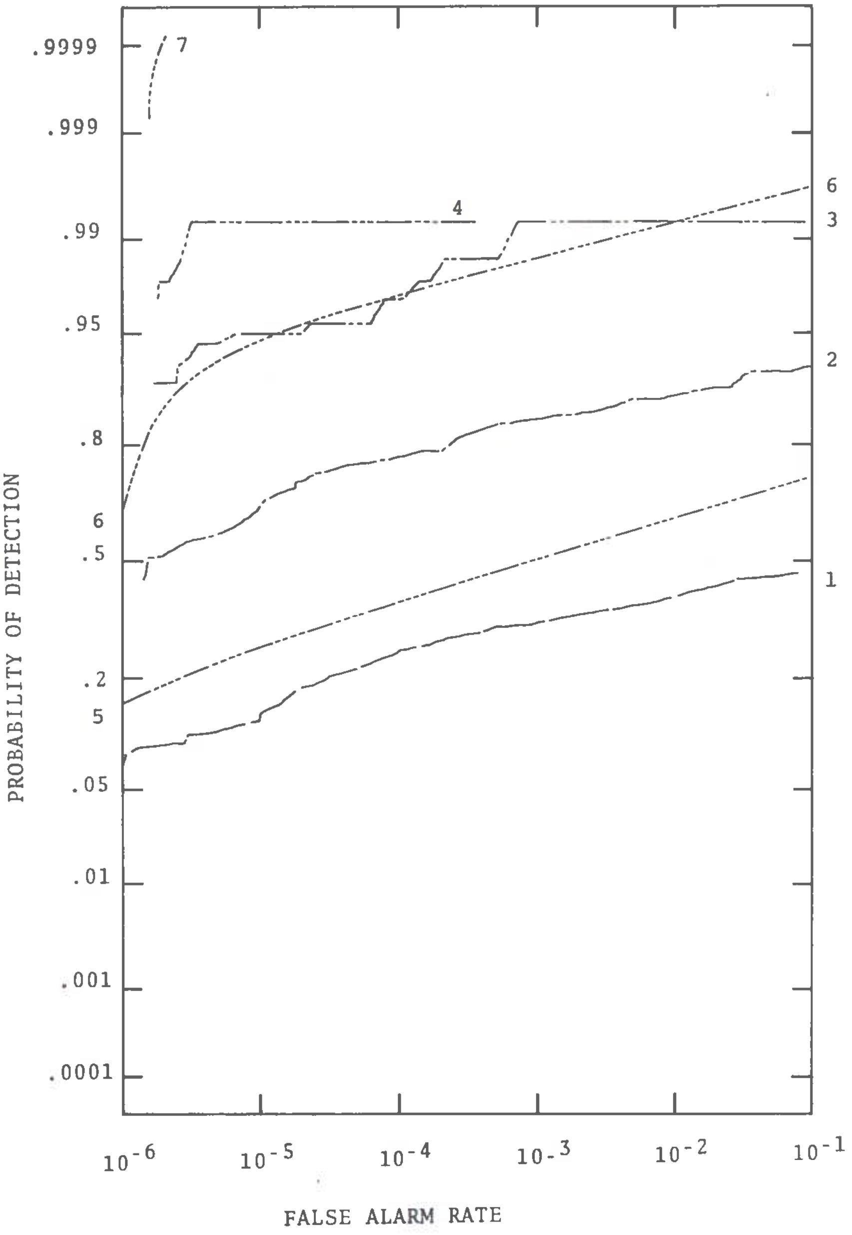
3. PERFORMANCE OF SURVEILLANCE SUB-SYSTEM

The set of situations which have been evaluated are aircraft-traffic densities of 100,000 and 35,000, average aircraft-signature repetition rate of once per eight seconds, and received signal-to-noise ratios (SNR) of 13 to 22 dB at the satellite. The received SNR as defined here does not include any correction for multiple access noise. The multiple-access noise correction is handled directly by the simulation program.

The performance curves are ROCs for the output from the three pulse aircraft signature detector. Curves for the linear receiver are shown in Figures 3 and 4. The horizontal axis, labeled "False Alarm Rate," represents the mean number of signature false alarms which occur in each 100ns. time-resolution cell. The vertical axis, labeled "Probability of Detection." Represents the probability of detecting an aircraft signature. The parameter in the plots is the received SNR. ROC stands for receiver operating characteristic.

Any point on the SNR line can be selected as the operating point for the AATMS surveillance receiver. The false alarm rate is normally selected to control processor loading or cost. For the selected false alarm rate the acheivable probability of detection (PD) is read off of the vertical axis. This number, along with satellite-constellation properties and the detection processing algorithms, determines system-performance. System-performance may be estimated by using Figure 2. The PD at the selected receiver operating point defines a vertical line on that plot. The system-detection performance may be read off of the vertical axis for any number of visable satellites. A more detailed analysis can be conducted by use of a satellite-constellation analysis program of the type used by the contractor.

Figure 5 indicates the effect of aircraft-traffic density on detection-performance. Three traffic-densities: 100,000 aircraft, 35,000 aircraft and 10,000 aircraft were examined. The range of detection-performance represented by a single vertical cut through Figure 5 will be provided by the same system when the traffic-density is the only parameter varied.

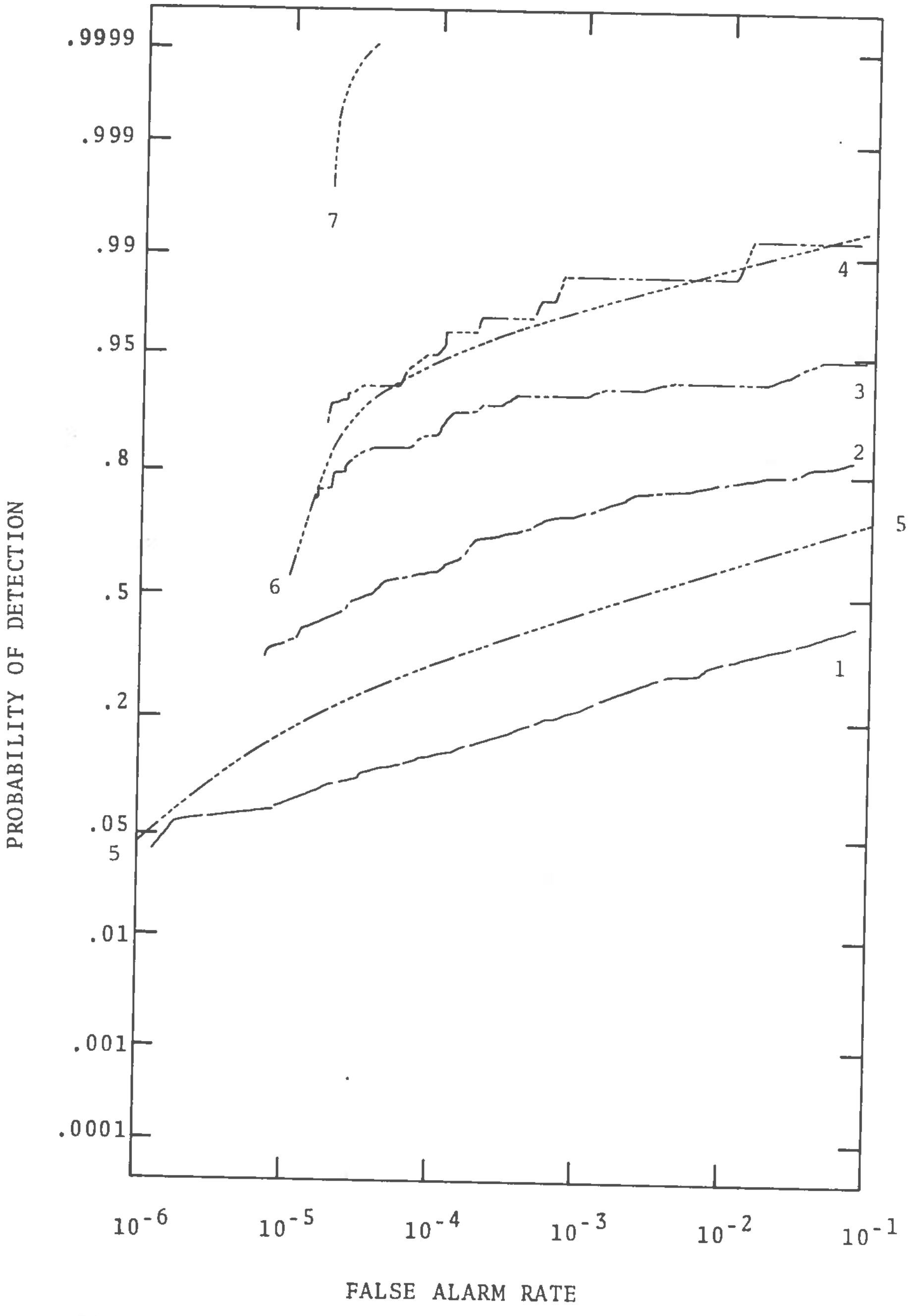


Simulation Data, and Gaussian Multiple Access Noise Reference Data. The Lines are:

1 SNR=13DB. Simulated
2 SNR=16DB. "
3 SNR=19DB. "
4 SNR=22DB. "

5 SNR=13DB. Reference
6 SNR=16DB. "
7 SNR=19DB. "

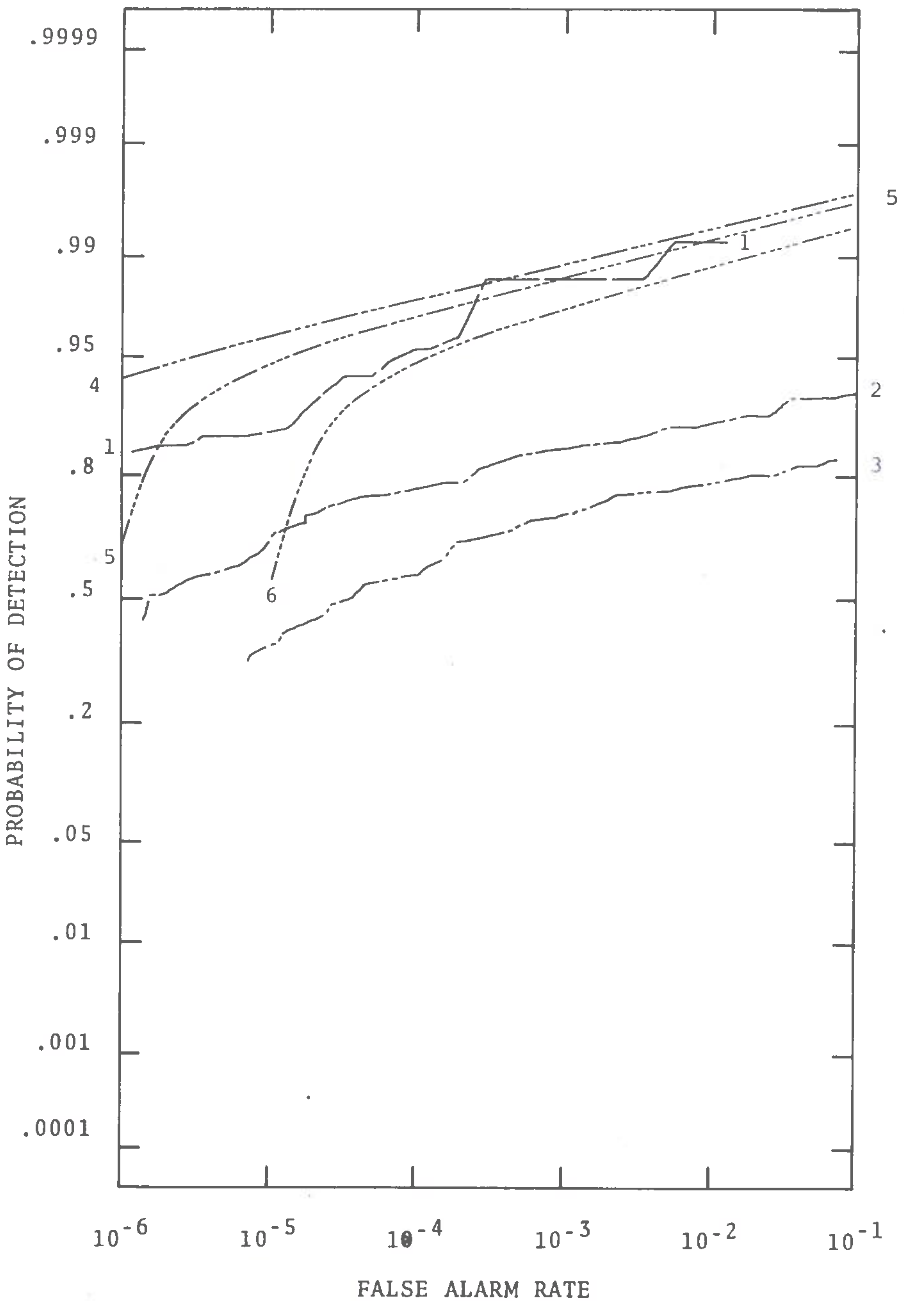
Figure 3. ROC for Three Pulse Signature Detector -- Linear Receiver with 35,000 Airborne Aircraft



Simulation Data, and Gaussian Multiple Access Noise Reference Data. The Lines are:

1	SNR=13DB.	Simulated	5	SNR=13DB.	Reference
2	SNR=16DB.	"	6	SNR=16DB.	"
3	SNR=19DB.	"	7	SNR=19DB.	"
4	SNR=22DB.	"			

Figure 4. ROC for Three Pulse Signature Detector -- Linear Receiver With 100,000 Airborne Aircraft



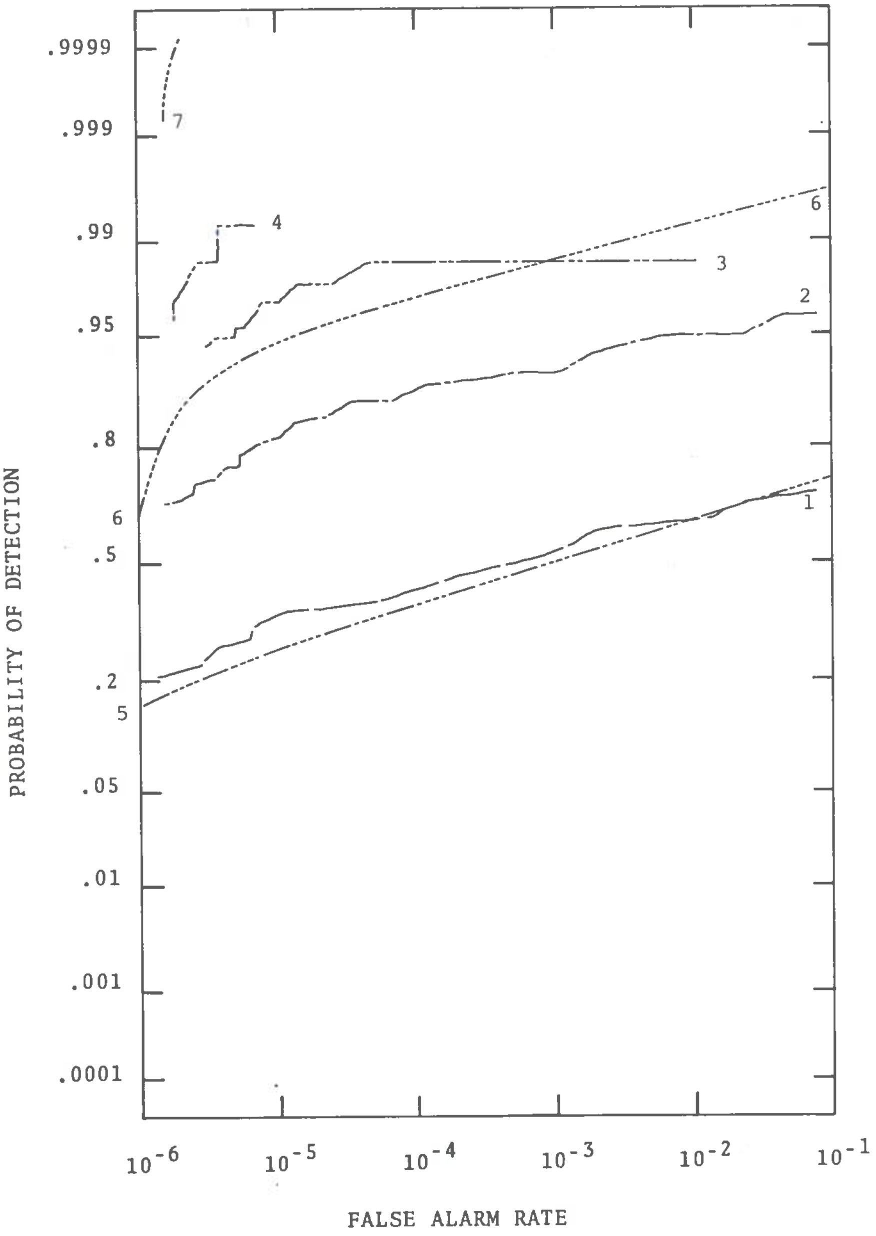
SNR is 16DB for all three lines. The Lines are:

1 10,000 Aircraft Simulated   4 10,000 Aircraft Ref.
2 35,000 Aircraft Simulated   5 35,000 Aircraft Ref.
3 100,000 Aircraft Simulated   6 100,000 Aircraft Ref.

Figure 5. ROC for Three Pulse Signature Detector -- Linear Receiver with 100,000, 35,000 and 10,000 Airborne Aircraft

Figure 6, 7 and 8 represent the same situations as 3, 4 and 5 except that a hard-limiting satellite repeater is used instead of the linear receiving system modeled in the first three performance curves. The difference between the performances of the two systems is relatively minor.

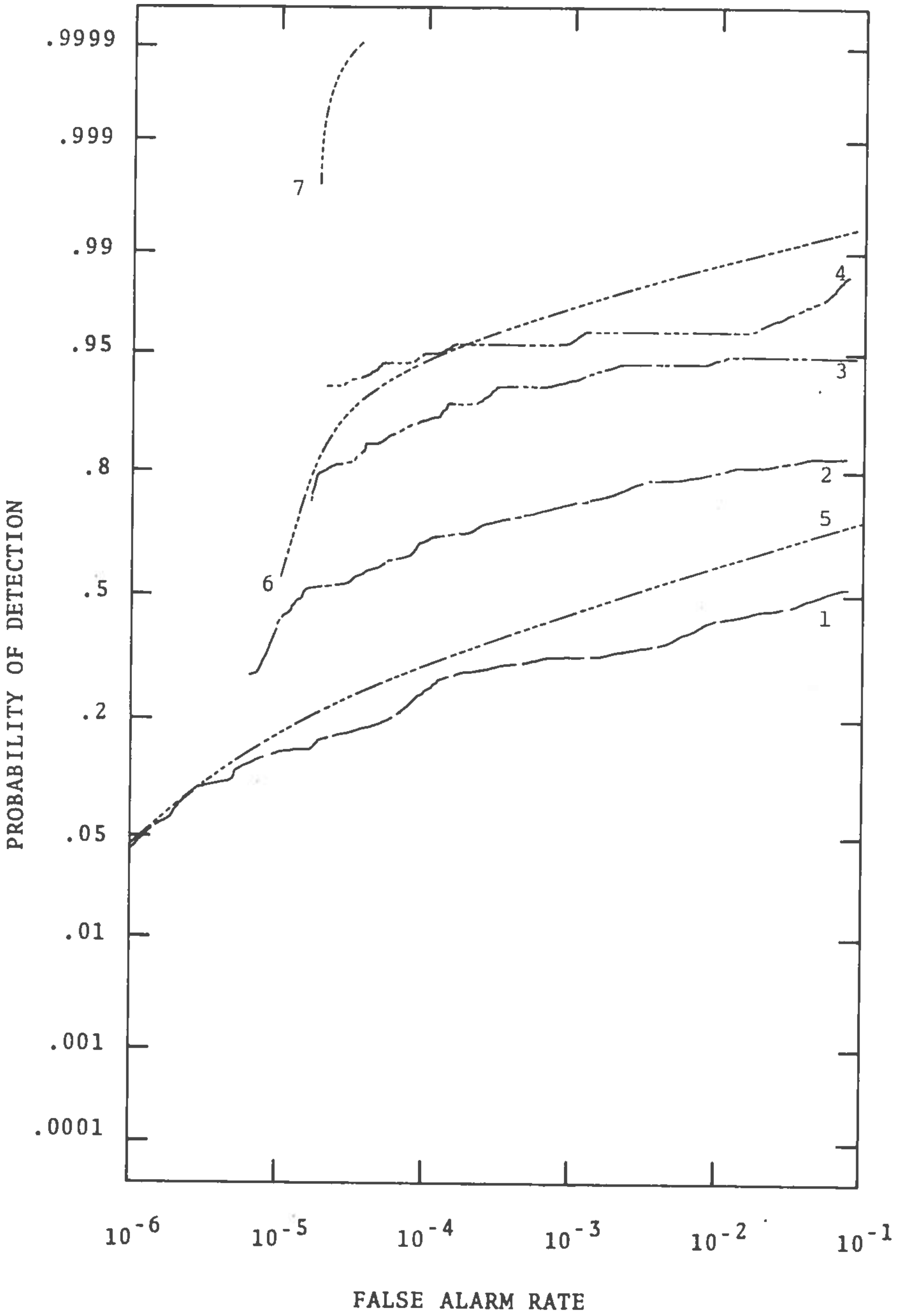
Figures 9 through 14 represent detector performance at the output from the single pulse detectors under the same conditions as in Figures 3 through 8 respectively. The data in Figures 3 through 8 was generated directly from the data in Figures 9 through 14.



Simulation Data, and Gaussian Multiple Access Noise Reference Data. The Lines are:

1	SNR=13DB.	Simulated	5	SNR=13DB.	Reference
2	SNR=16DB.	"	6	SNR=16DB.	"
3	SNR=19DB.	"	7	SNR=19DB.	"
4	SNR=22DB.	"			

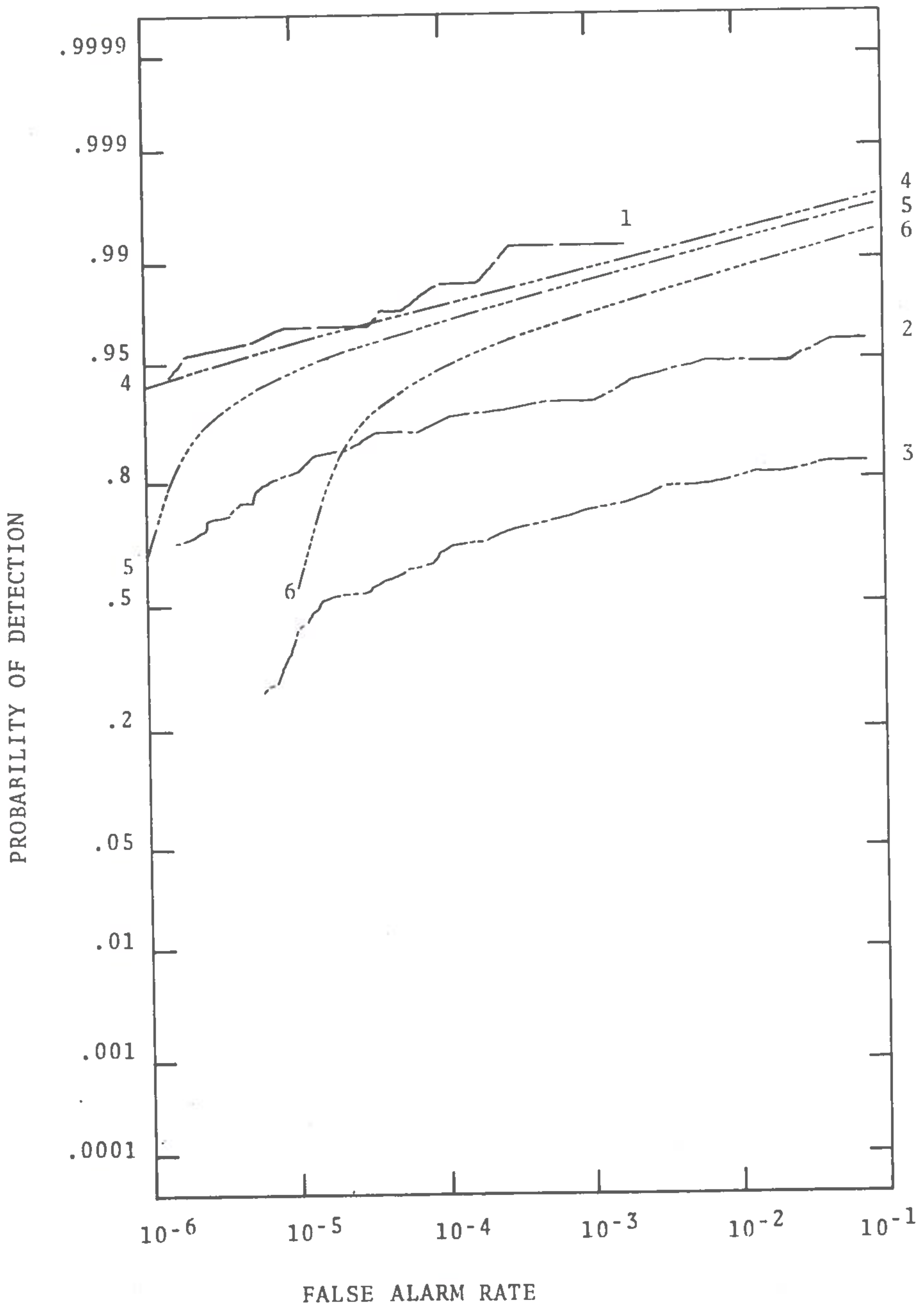
Figure 6. ROC for Three Pulse Signature Detector -- Hard-Limiting Receiver With 35,000 Airborne Aircraft



Simulation Data, and Gaussian Multiple Access Noise Reference Data. The Lines are:

1	SNR=13DB.	Simulated	5	SNR=13DB.	Reference
2	SNR=16DB.	"	6	SNR=16DB.	"
3	SNR=19DB.	"	7	SNR=19DB.	"
4	SNR=22DB.	"			

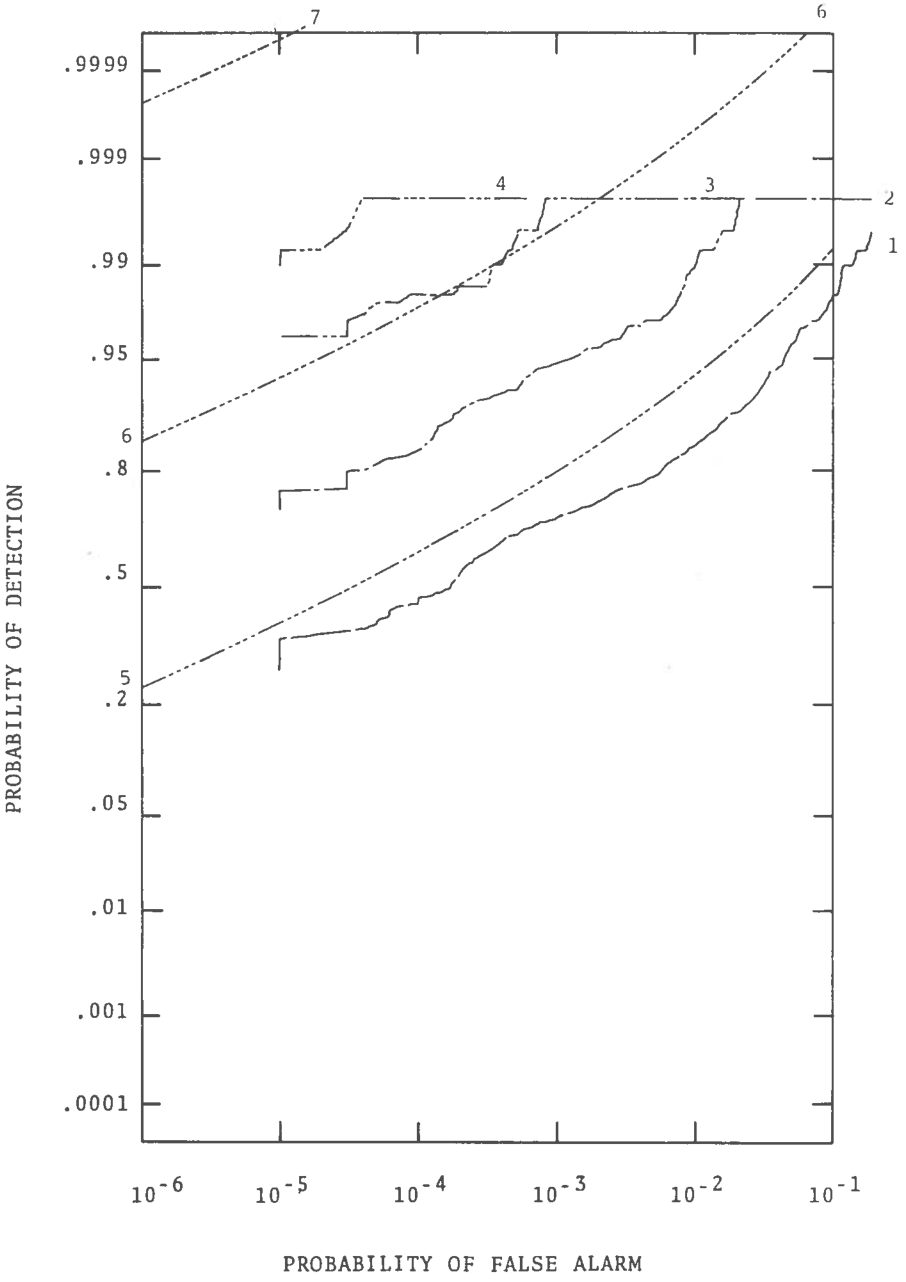
Figure 7. ROC for Three Pulse Signature Detector -- Hard-Limiting Receiver With 100,000 Airborne Aircraft



SNR is 16DB for all three lines. The lines are:

1	10,000 Aircraft Simulated	4	10,000 Aircraft Ref.
2	35,000 Aircraft Simulated	5	35,000 Aircraft Ref.
3	100,000 Aircraft Simulated	6	100,000 Aircraft Ref.

Figure 8. ROC for Three Pulse Signature Detector -- Hard-Limiting Receiver With 100,00, 35,000 and 10,00 Airborne Aircraft

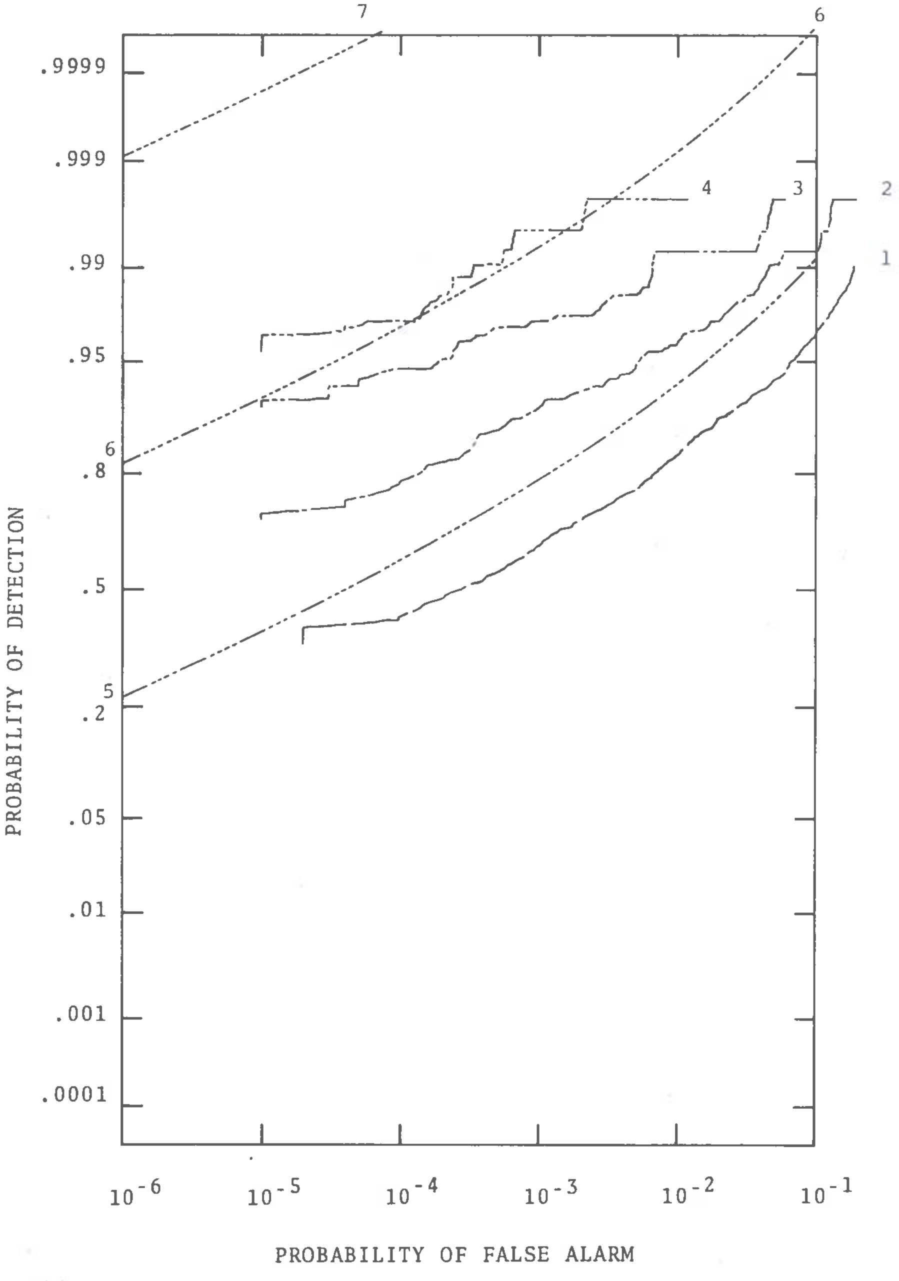


Simulation Data, and Gaussian Multiple Access Noise Reference Data. The Lines are:

1 SNR=13DB. Simulated
2 SNR=16DB. "
3 SNR=19DB. "
4 SNR=22DB. "

5 SNR=13DB. Reference
6 SNR=16DB. "
7 SNR=19DB. "

Figure 9. ROC for Single Pulse Detector -- Linear Receiver With 35,000 Airborne Aircraft

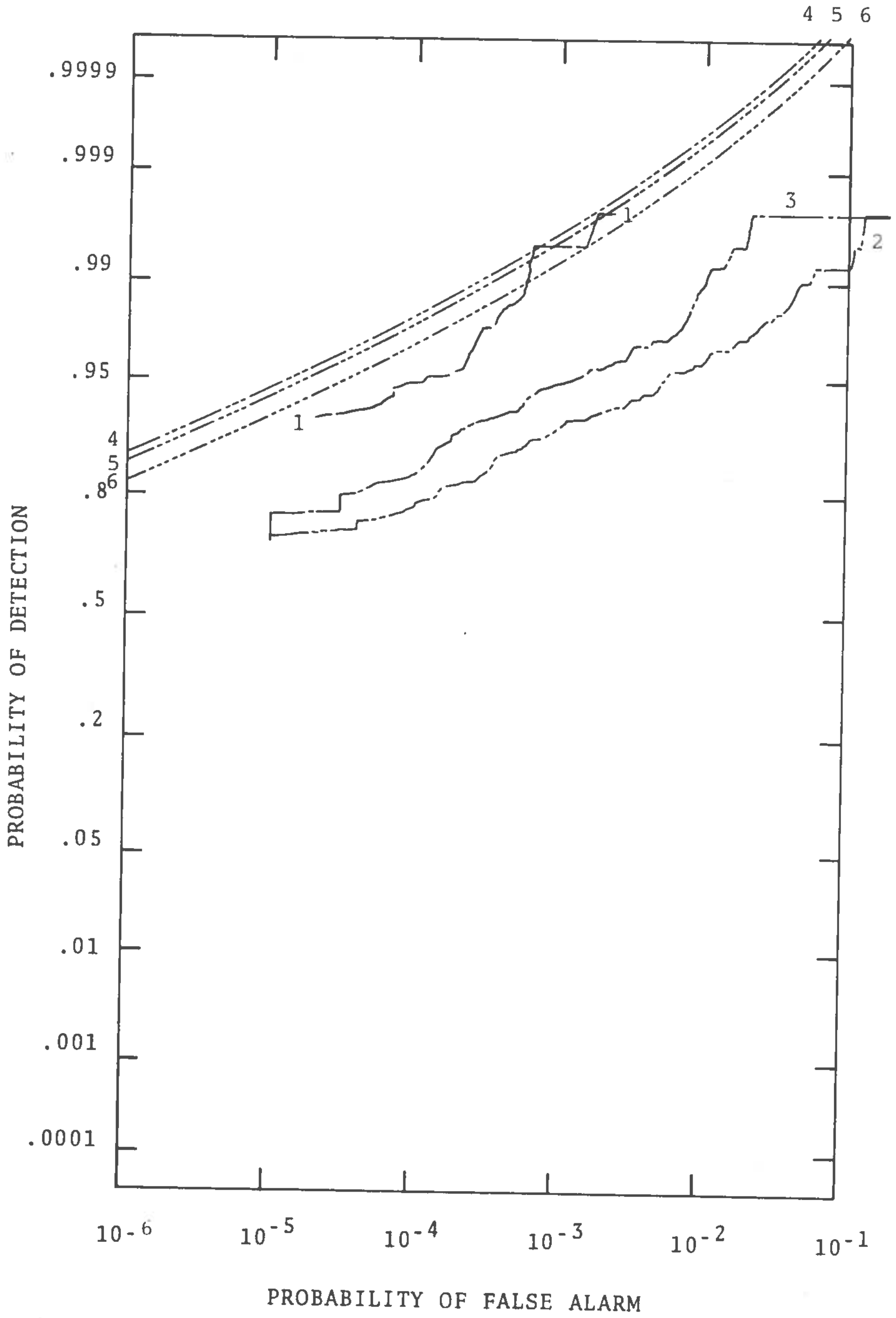


Simulation Data, and Gaussian Multiple Access Noise Reference Data. The Lines are:

1 SNR=13DB. Simulated
2 SNR=16DB. "
3 SNR=19DB. "
4 SNR=22DB. "

5 SNR=13DB. Reference
6 SNR=16DB. "
7 SNR=19DB. "

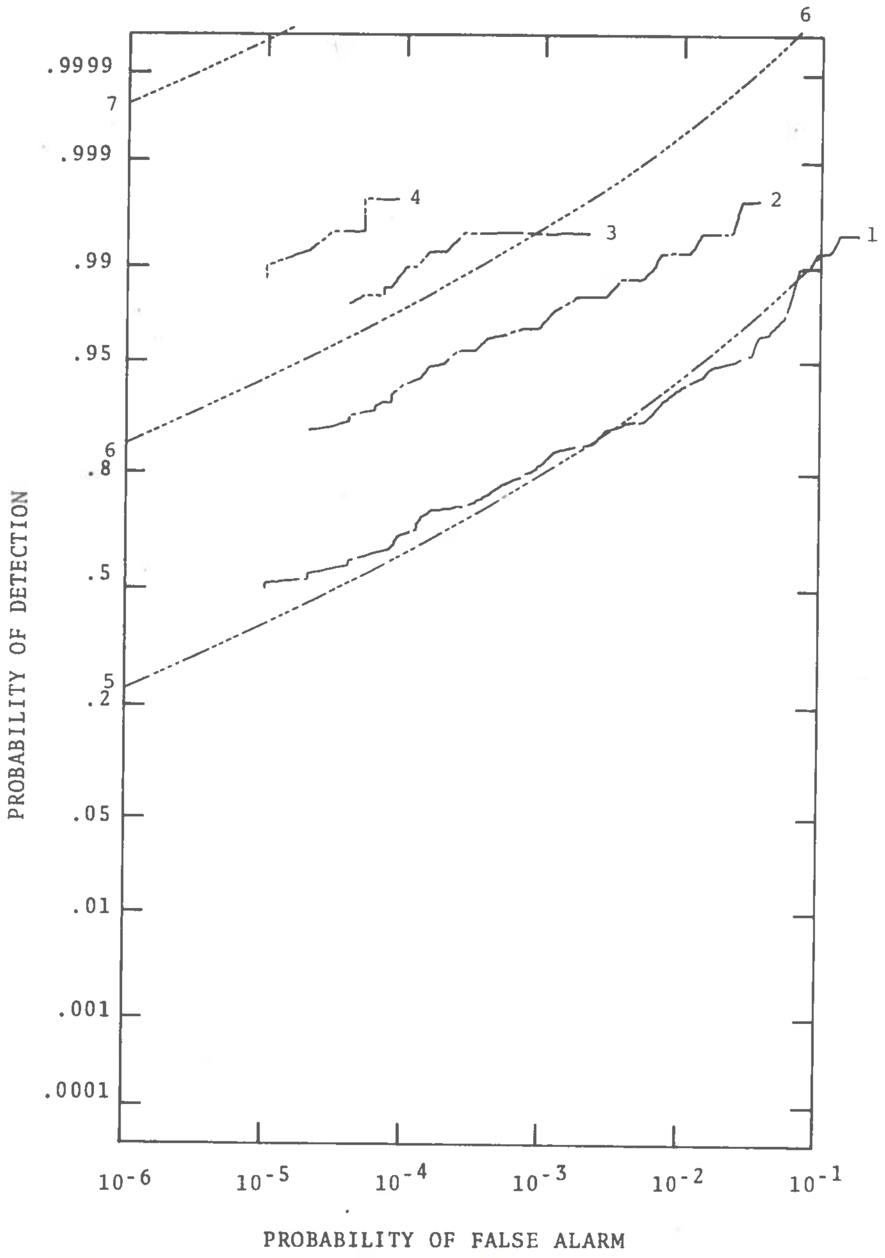
Figure 10. ROC for Single Pulse Detector -- Linear Receiver With 100,000 Airborne Aircraft



SNR is 16DB for all three lines. The Lines are:

1	10,000 Aircraft Simulated	4	10,000 Aircraft Ref.
2	35,000 Aircraft Simulated	5	35,000 Aircraft Ref.
3	100,000 Aircraft Simulated	6	100,000 Aircraft Ref.

Figure 11. ROC for Single Pulse Detector -- Linear Receiver With 100,000, 35,000 and 10,000 Airborne Aircraft

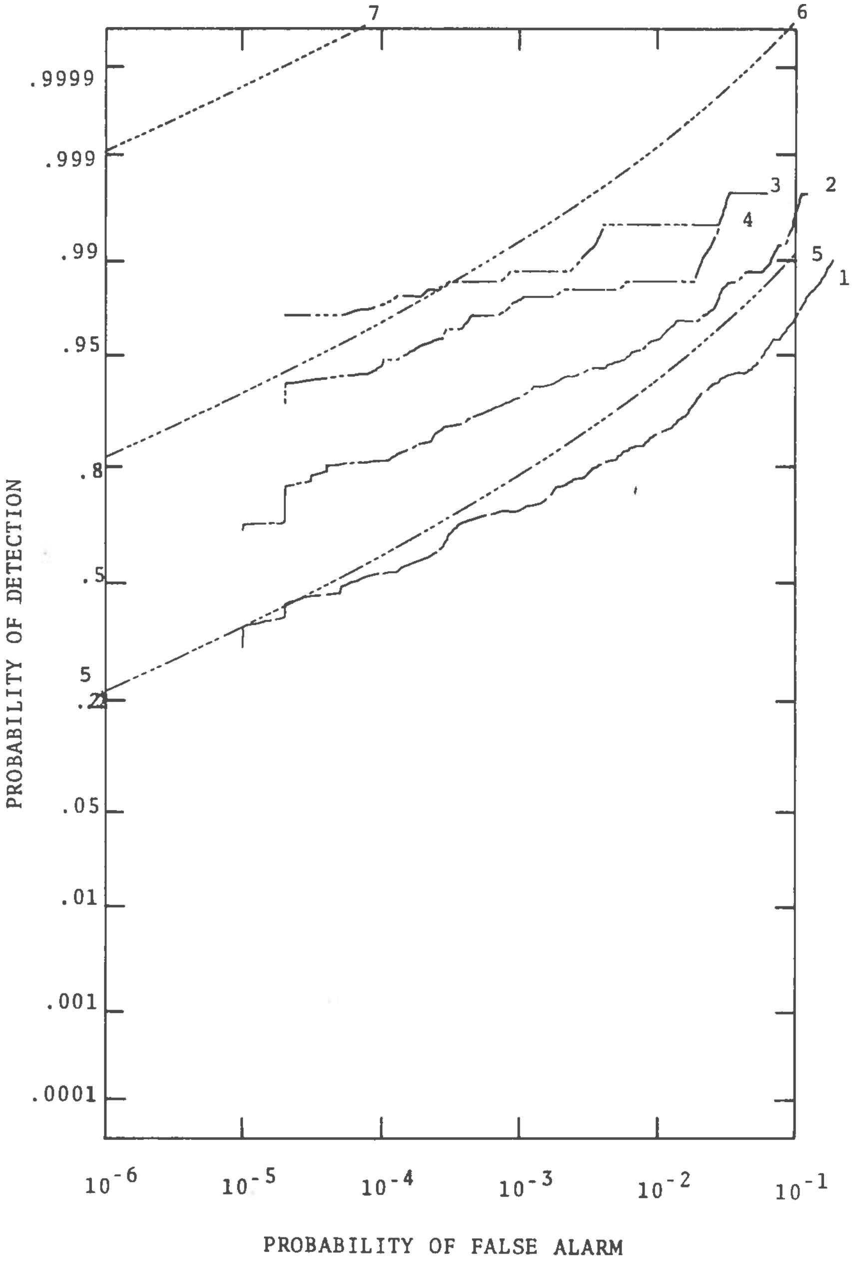


Simulation Data, and Gaussian Multiple Access Noise Reference Data. The Lines are:

1 SNR=13DB. Simulated
2 SNR=16DB. "
3 SNR=19DB. "
4 SNR=22DB. "

5 SNR=13DB. Reference
6 SNR=16DB. "
7 SNR=19DB. "

Figure 12. ROC for Single Pulse Detector -- Hard-Limiting Receiver with 35,000 Airborne Aircraft

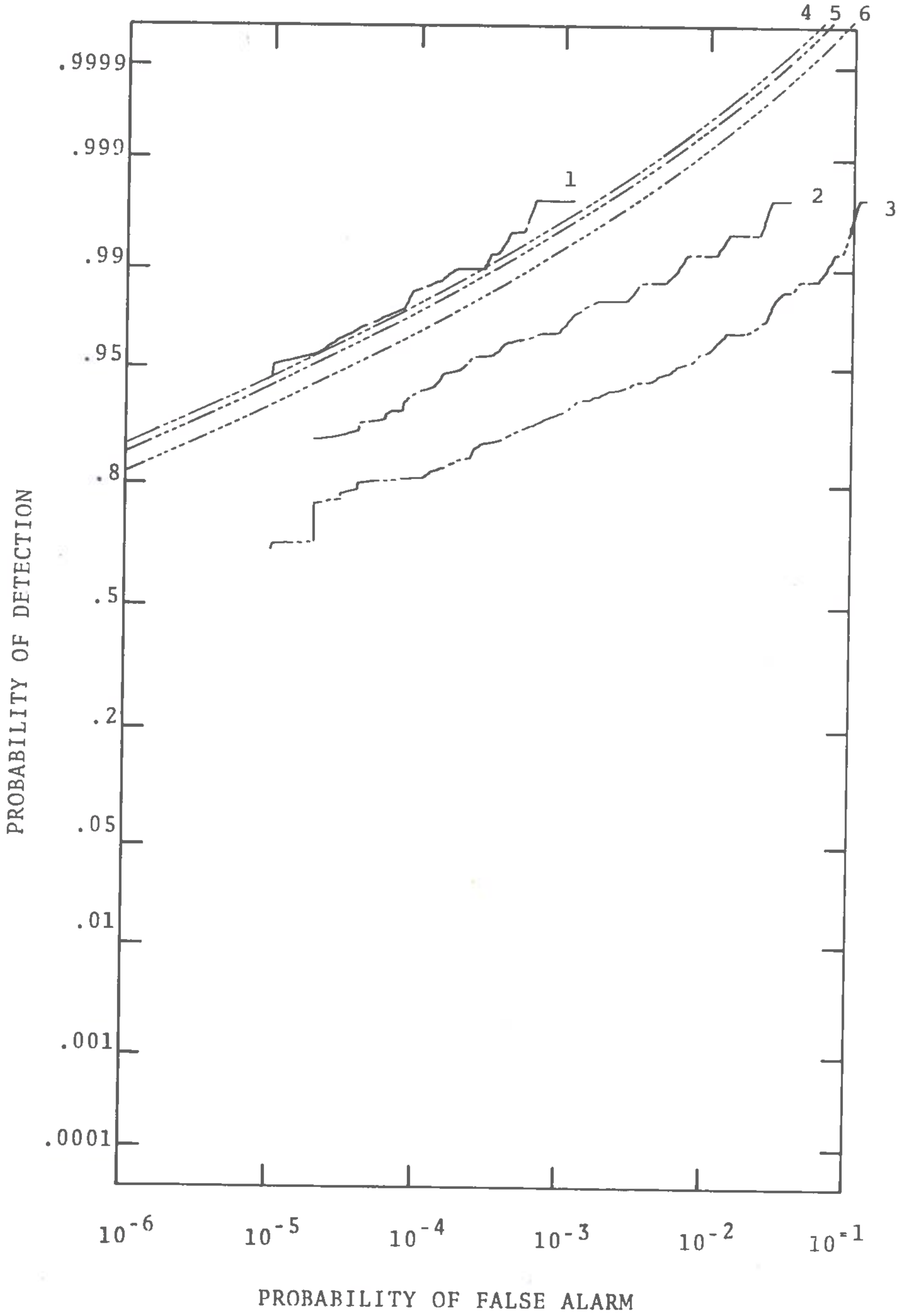


Simulation Data, and Gaussian Multiple Access Noise Reference Data. The Lines are:

1 SNR=13DB. Simulated
2 SNR=16DB. "
3 SNR=19DB. "
4 SNR=22DB. "

5 SNR=13DB. Reference
6 SNR=16DB. "
7 SNR=19DB. "

Figure 13. ROC for Single Pulse Detector -- Hard-Limiting Receiver with 100,000 Airborne Aircraft



SNR is 16DB for all three lines. The Lines are:

1	10,000 Aircraft Simulated	4	10,000 Aircraft Ref.
2	35,000 Aircraft Simulated	5	35,000 Aircraft Ref.
3	100,000 Aircraft Simulated	6	100,000 Aircraft Ref.

Figure 14. ROC for Single Pulse Detector -- Hard-Limiting Receiver with 100,000, 35,000 and 10,000 Airborne Aircraft

4. PERFORMANCE ANALYSIS

The simulation program and the mathematical model used to generate the single-pulse performance curves is described in Reference 1. The transformation between the one-pulse curves and the three-pulse signature curves is the only mathematical analysis performed here.

The false alarm conditions which have been considered exclude all cases in which more than three aircraft transmit during one time resolution cell of the receiver, and all cases in which more than one pulse in the same time/code resolution slot is present in the signature of aircraft that are transmitting. These cases have been excluded because a much more extensive analysis would be required to correctly account for the interference effects which were ignored. The full analysis would have to include geometric and waveform interference properties. For the aircraft-traffic densities which are present in the proposed system the terms which were ignored are believed to be negligible. If these terms are to be accounted for in future work an upper-bound, which complements the lower-bound presented here can be generated by replacing the detection probability in the presence of interfering pulses by one, rather than zero as done here.

The expression for False Alarm Rate used to generate the performance curves presented in this paper is:

$$R = (\tau N_A)/(T_U\ N_P)$$

$$PF \geq N_P^2\ N_Q^3\ [R\ P_D + (1-3R)PF\ ][3R\ P_D + (1-3R)PF]^2$$

$$+R([P_D + (N_P\ N_Q\ -1)\ ([1-3R]PF+3R\ P_D]^2\ [P_D+(N_Q-1)\ (1-2R)$$
$$PF]-P_D{}^3)$$

$$+R^2([2P_D+(N_P\ N_Q\ -2)([1-3R]P_F\ +3R\ P_D]^2\ [P_D+(N_Q-2)(1-2R)$$
$$PF]-PD^3)$$

N_A = Number of airborn aircraft (35,000 or 100,000 here)

N_P = Number of pulse positions in aircraft signature (currently 16)

N_Q = Number of orthogonal code sequences (currently 16)

T_U = Mean aircraft position update interval (8 seconds)

P_F = Single code sequence probability of false alarm

P_D = Single code sequence probability of detection

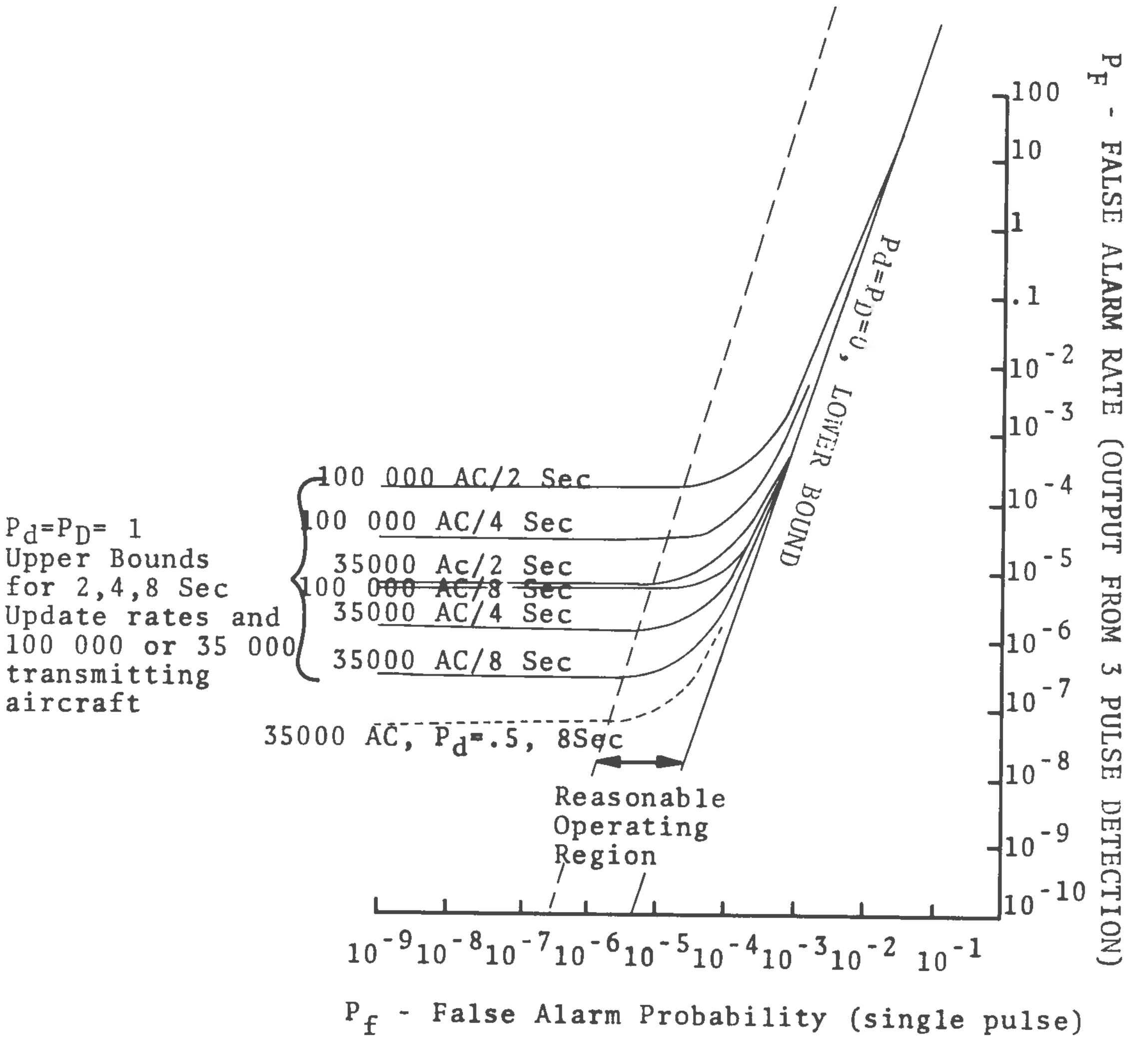
PF = Mean number of false alarms in one time resolution cell at the output of the target signature processor

τ = Time resolution of the waveform (100ns.)

The transformation from single-pulse detection-probability (P_D) to signature-detection probability is given by:

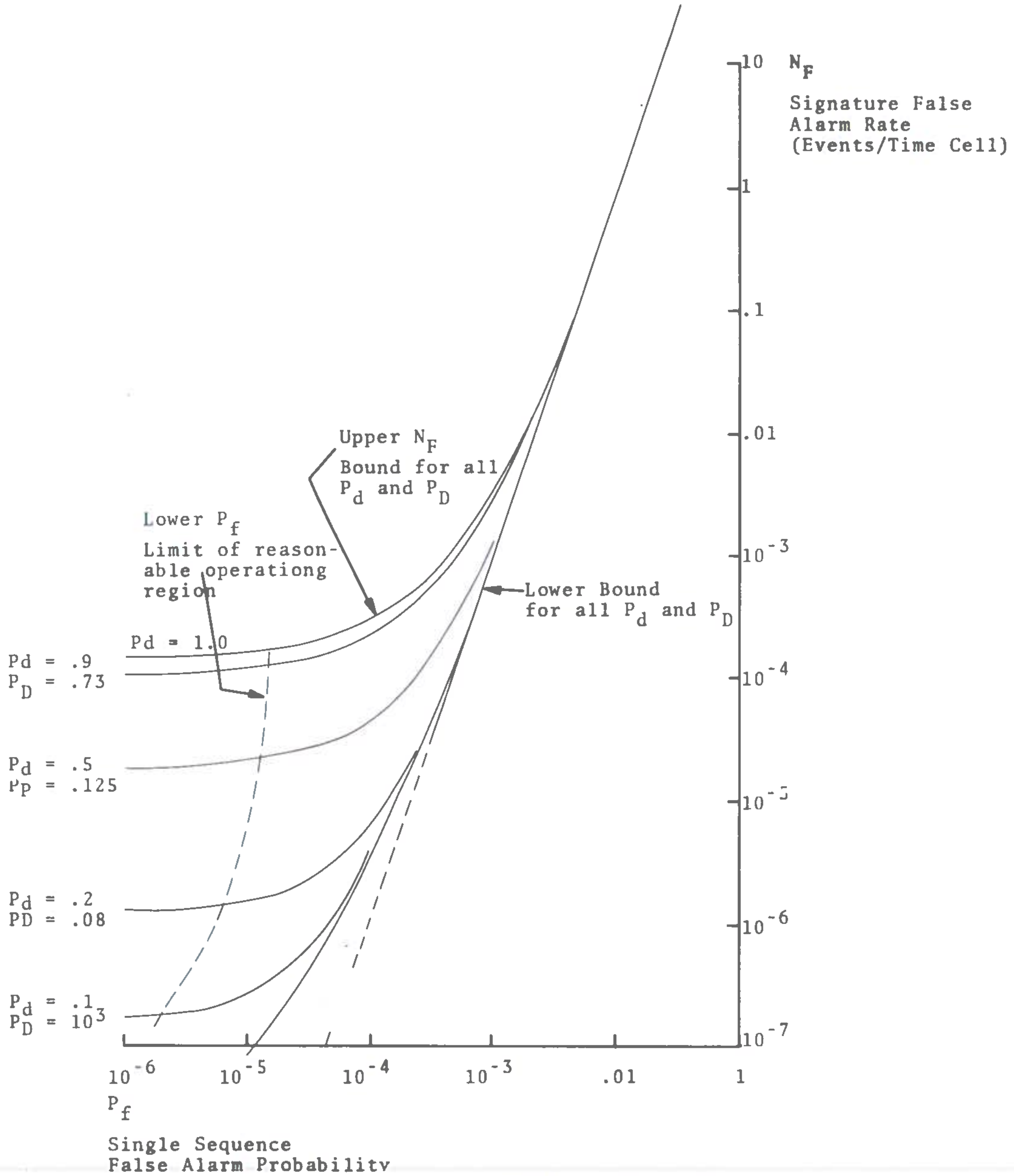
$$PD = P_D^3$$

The two transformations described above lead to a set of transformation curves for P_F to PF which are shown in Figures 15-A and B. Only the P_D=PD=1 curves are shown because the P_D greater than .5 curves are all quite close to the P_D=1 curve. The low P_F saturation effect shown by the curves in Figures 15-A and B is caused by correctly detected pulses from two or more targets creating additional apparent target signatures, this is a system property not a noise effect.



A. curves for several **update rates and aircraft** traffic loads.

Figure 15-A. Transformation Between Single Pulse False Alarm Probability (PF) and Signature False Alarm Rate (PF)



B. curves for several detection probabilities with 35,000 aircraft and 8 second update rate.

Figure 15-B. Transformation Between Single Pulse False Alarm Probability (PF) and Signature False Alarm Rate (PF)

5. EXAMPLES

Several examples of the use of the curves presented in this paper to evaluate detection-performance of the surveillance system are presented in Figures 16 through 19. In all of these examples it is assumed that a single-pulse false alarm probability of 10^{-4} is selected as the receiver operating point. This candidate number was selected because it is at the high end of the surveillance data-processing threshold region as shown in Figures 15-A and B. The performance curves presented here were generated from the ROCs, by using the data presented in Figure 2. Although the data in the example plots is presented as continuous lines it should be clear that only the points for integer numbers of satellites are meaningful.

These plots are representitive of the performance which can be achieved by this type of surveillance system, but the multiple satellite detection and tracking algorithms are not the same as would be used in a completed system. Also satellite constellation effects have not been included in detail.

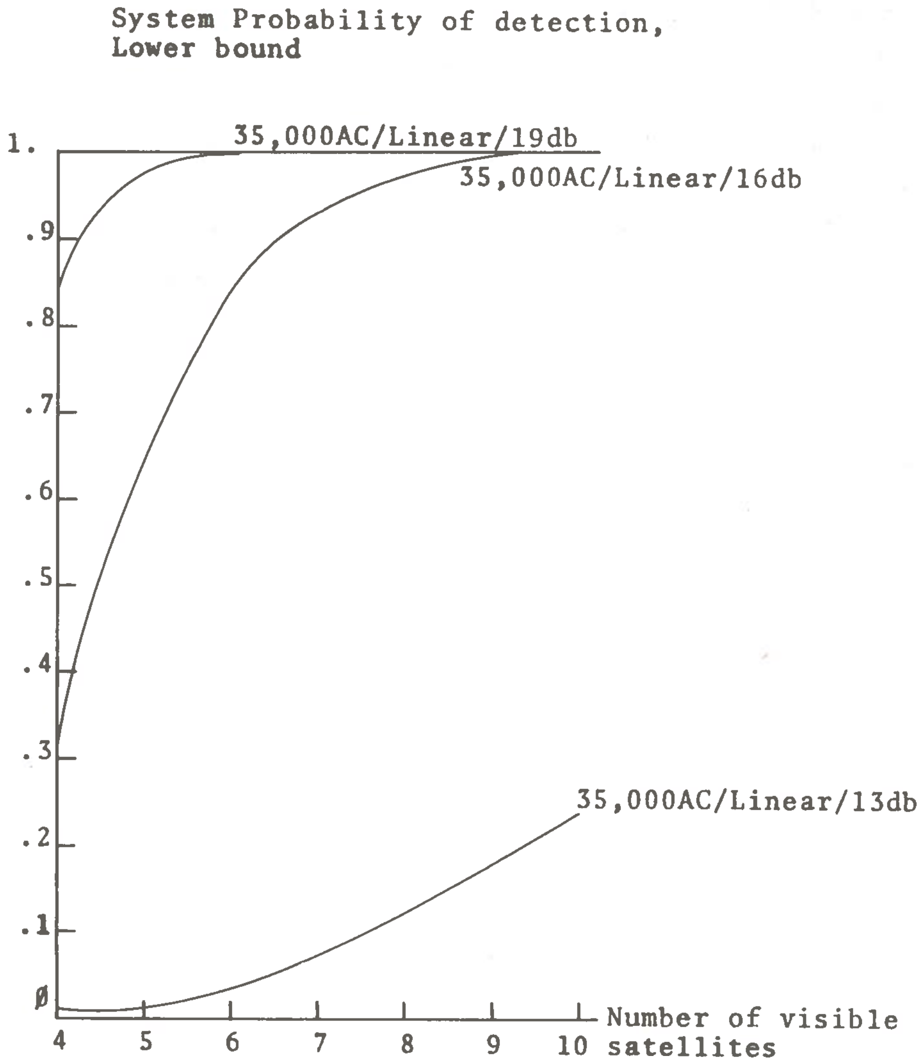


Figure 16. Detection Performance for 35,000 Aircraft -- $PF=10^{-4}$, Linear Receiver

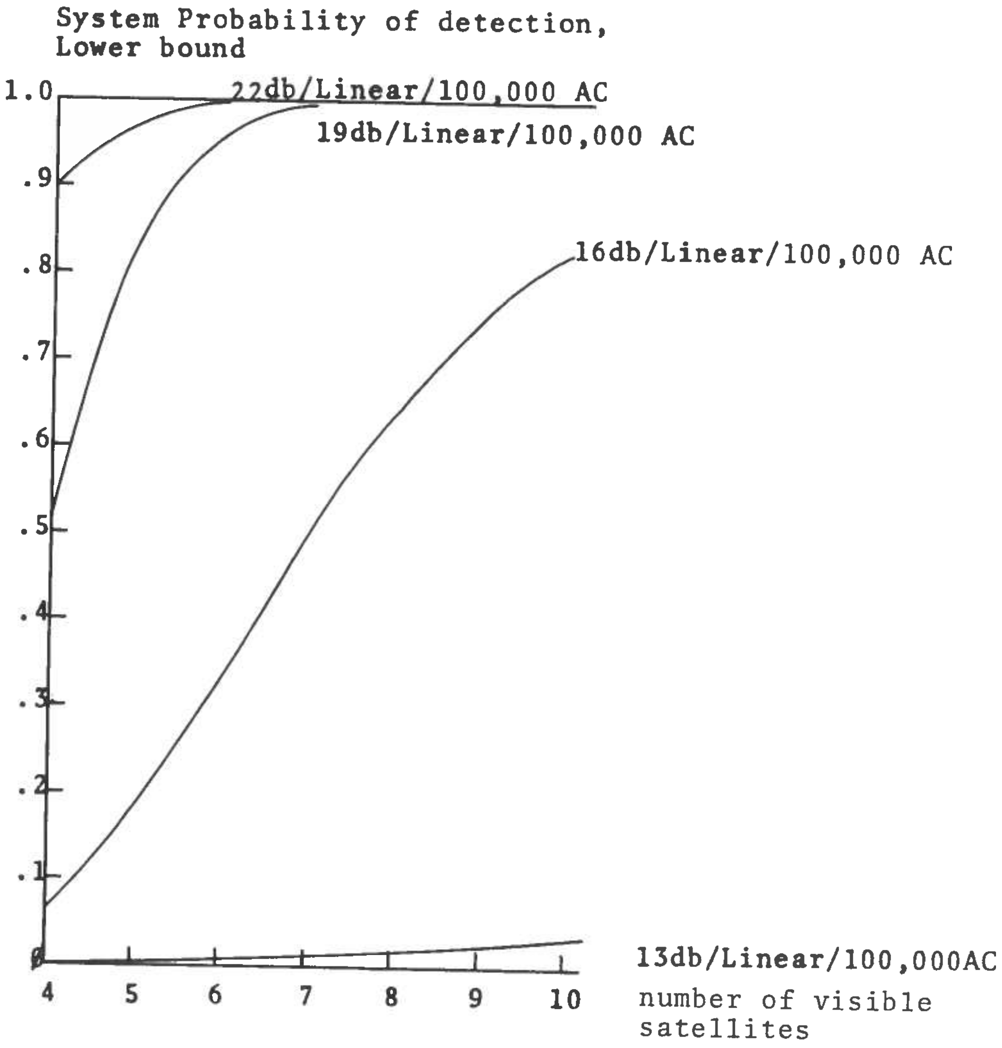


Figure 17. Detection Performance for 100,000 Aircraft -- PF=10^{-4}, Linear Receiver

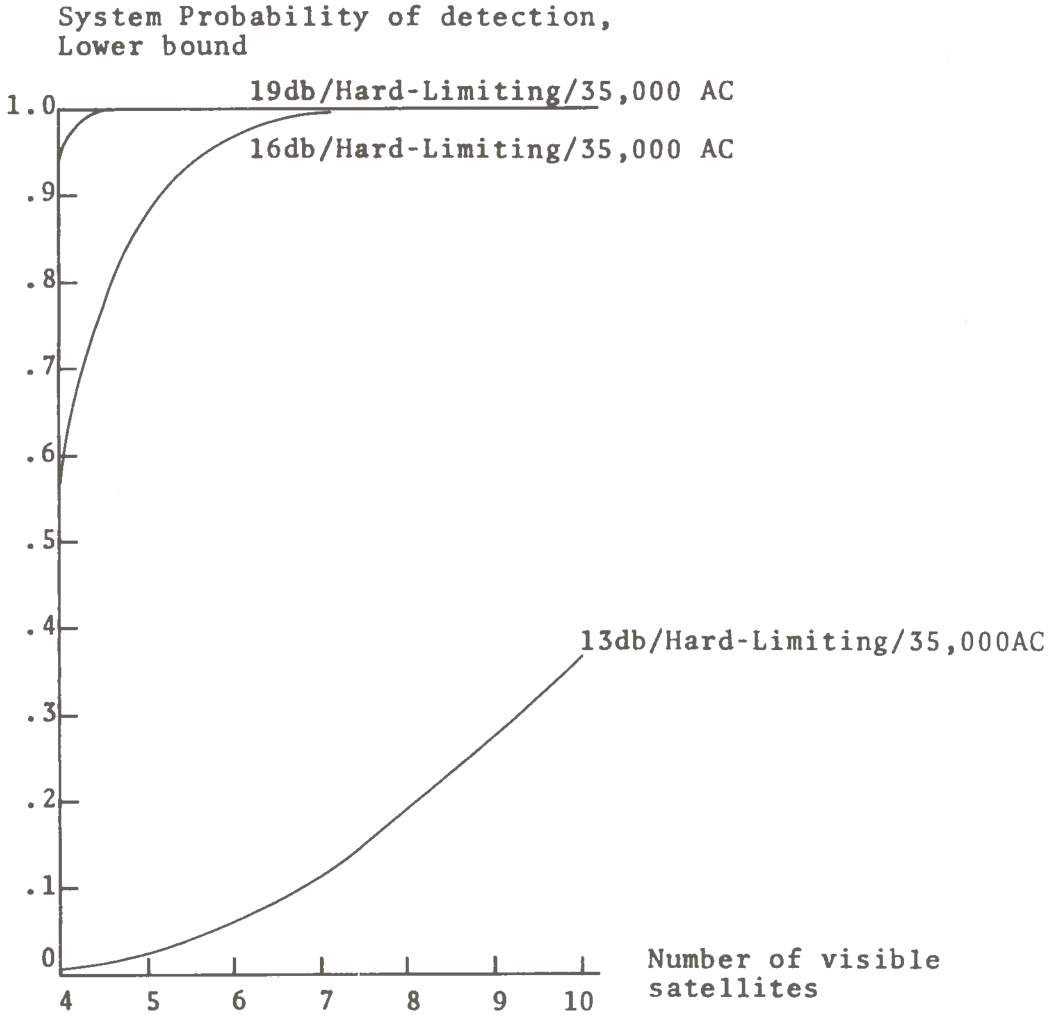


Figure 18. Detection Performance for 35,000 Aircraft -- PF=10^{-4}, Hard-Limiting Receiver

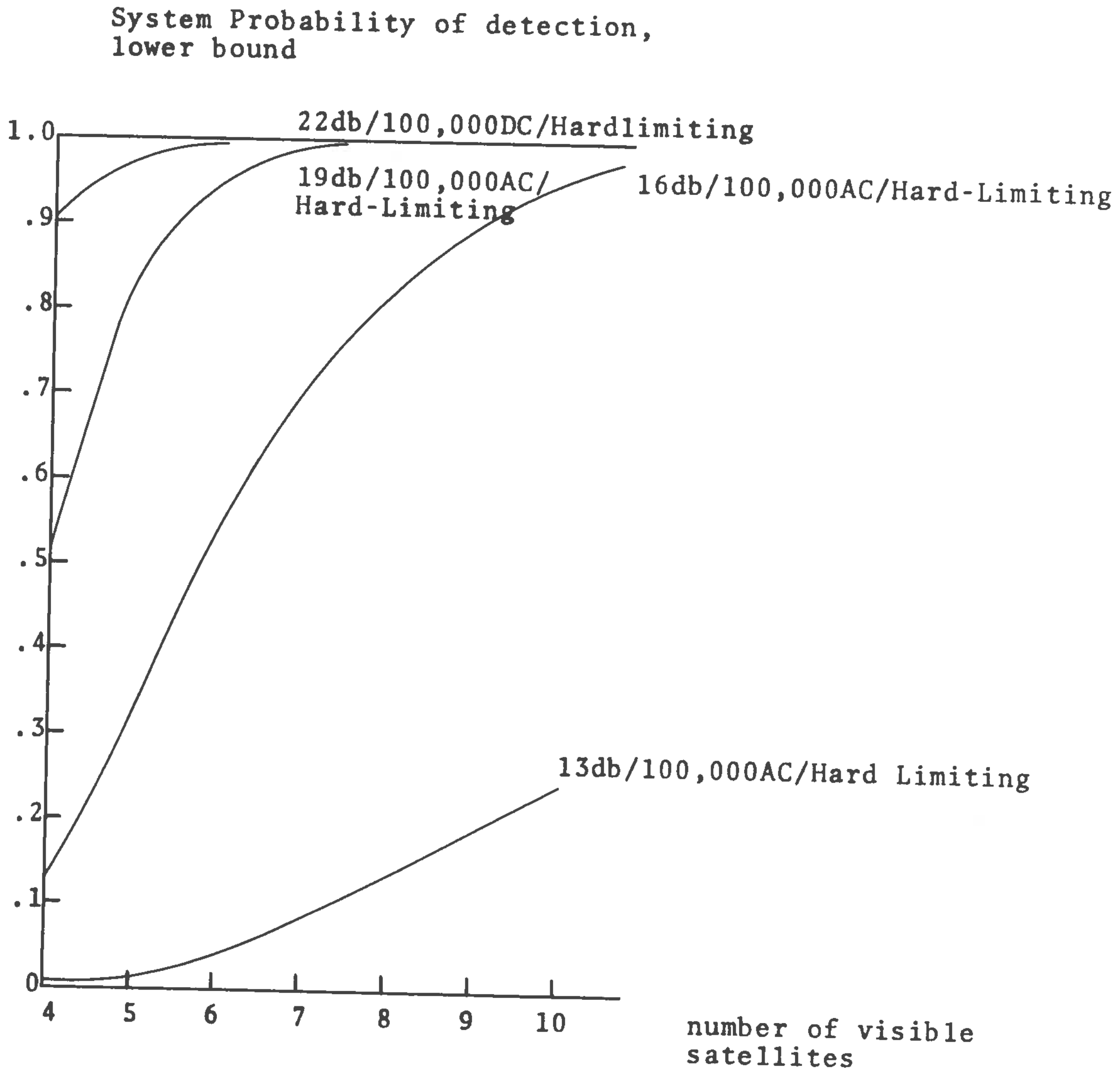


Figure 19. Detector Performance for 100,000 Aircraft -- PF=10^{-4}, Hard-Limiting Receiver

6. CONCLUSIONS

Together, the work presented here and the work presented in reference 1 indicate that with appropriate design of the satellite-constellation the type of asynchronous multiple-access surveillance-system which is proposed in reference 1 can be made to provide any aircraft-detection performance which is required. There is a wide range of system-performance tradeoffs which can be made by tailoring the constellation, and if the number of satellites required is not excessively large, the surveillance system is practical.

The work presented here and in reference 1 has not included an exhaustive tradeoff analysis and optimization of the receiver system. Nevertheless, it does lower-bound the performance of the final system, and provide a sufficient data base for making cost estimates. The analysis required to develop a satellite constellation which will provide required detection-performance with the minimum cost has been performed by the contractor using the Gaussian Multiple Access Noise Model. The use of the multiple access noise data presented here might lead to a requirement for a significantly larger number of satellites.

7. ANALYSIS OF MULTIPLE ACCESS NOISE IN RANDOM ACCESS SURVEILLANCE SYSTEMS

7.1 INTRODUCTION

This section describes an analysis of the performance of asynchronous multiple-access surveillance systems. The class of systems analyzed includes the LIT type of system described in reference 1. The work reported here used a computer simulation to generate a Receiver Operating Characteristic (ROC) for the system and parameters being considered. The simulation approach has allowed detailed modeling of all important effects which are expected to affect the performance of the radio transmitter, receiver, and detection portions of the systems of this type currently being considered for incorporation into advanced air-traffic control systems. The analysis and simulation have been directed solely toward the generation of ROCs for different system configurations and no attempt has been made to produce system performance measures.

7.2 BACKGROUND

Asynchronous multiple-access surveillance systems have been proposed for use in advanced air-traffic control systems[1&2]. Analysis of the performance of such systems has been based primarily on modeling the signals received from all targets other than the target of interest as white Gaussian noise. This model is believed to be reasonably accurate for large numbers of simultaneously received signals. The candidate air-traffic control systems transmit two or three overlapping signals. The accuracy of the Gaussian noise model has not been determined.

More recently analysis based on the use of Chernov bounds[3] for the multiple-access noise have been performed. These analyses have not been able to model the relatively complex signal structure which have been proposed for these systems and have provided only bounds on possible system performance levels. In addition, the radio channel models have been quite restrictive and have not included effects such as incoherent receivers or signal level fluctuation due to aircraft antenna, and motion, or scintillation.

The use of Edgeworth series expansion to provide an analytic solution for system performance has been proposed,[4] and promises to provide useful results. No work of this type has been completed to date.

7.3 RESULTS

The analysis and simulation performed under this program has had three results. A set of representative performance curves, which will be useful for the evaluation of the performance of proposed surveillance system, has been generated. A computer program which will be useful for the analysis of the proposed asynchronous multiple-access signaling systems has been developed. And the accuracy of the relatively easy to work with Gaussian multiple-access noise model has been determined.

7.3.1 Typical Performance Curves

In this section the results of several simulation runs are presented. The model of the system which is being simulated is presented in Section 4. The parameters of the simulation are described in Table 1. Whenever the parameter or option used for a particular run differ from the values given in Table 1 it is explicitly specified in the caption.

TABLE 1. SIMULATION PARAMETERS AND OPTIONS

Notation	Description	Default Value	Units
	Signal set	ML sequence described in Appendix 4	
	Number of different signals	16	
	Length of each signal	255	chips
τ	Time duration of each waveform chip	100	ns.
$2E_s/N_0$	Non-fluctuating signal-to-noise ratio	$-\infty$	db
$2E_r/N_0$	Fluctuating signal-to-noise ratio	$-\infty$	db
ω_d	RMS doppler shift	0	$1/\tau$ sec.
N_p	Average number of simultaneously transmitting targets	2.5	
	Length of simulation run	100,000	τ sec.
τ_s	Time delay between receiver output samples	0	

7.3.1.1 Performance as a Function of Signal to Noise Ratio - Figures 20 and 21 show ROC's as a function of signal-to-noise ratio. The parameters used in the generation of these graphs are representative of a satellite surveillance system with an average pulse rate of 100,000 255-bit sequences per second. This is representative of the situation where each of 100,000 targets is transmitting a three-pulse signature once every three seconds and the receiver is making a present/not-present decision on each pulse independently. In Figure 20 the receiver-matched filter is continuously monitored, and actual peak values used for detection decisions. In Figure 21, the receiver filter is sampled once for each range/time resolution cell.

7.3.1.2 Performance as a Function of Target Density - Figures 22 and 23 show ROC's at a single signal-to-noise ratio with target density as a parameter. In Figure 22, the receiver-output is continuously monitored, in Figure 23, it is sampled once per range/time cell. In addition to indicating the effects that different target-densities will have on system performance, these plots illustrate some properties of the simulation model. The zero target-density line on each graph lies essentially on top of its reference line. These lines have lower statistical significance than the other lines on the graph and are, therefore, relatively bumpy. This line must be in this position because in this case both models should be exact except for the statistical errors in the simulation process.

The two high target-density lines also lie nearly on top of their reference lines. This is true because of overlapping target pulses the multiple-access noise-amplitude probability-density approximated in quite well by the Gaussian density used for the reference curves.

7.3.1.3 Sensitivity to Code Sequences - Figures 24 and 25 show ROC's under identical conditions for three different target-waveform code sequences. The receiver-output sampling for the two figures is the same as in the previous sections.

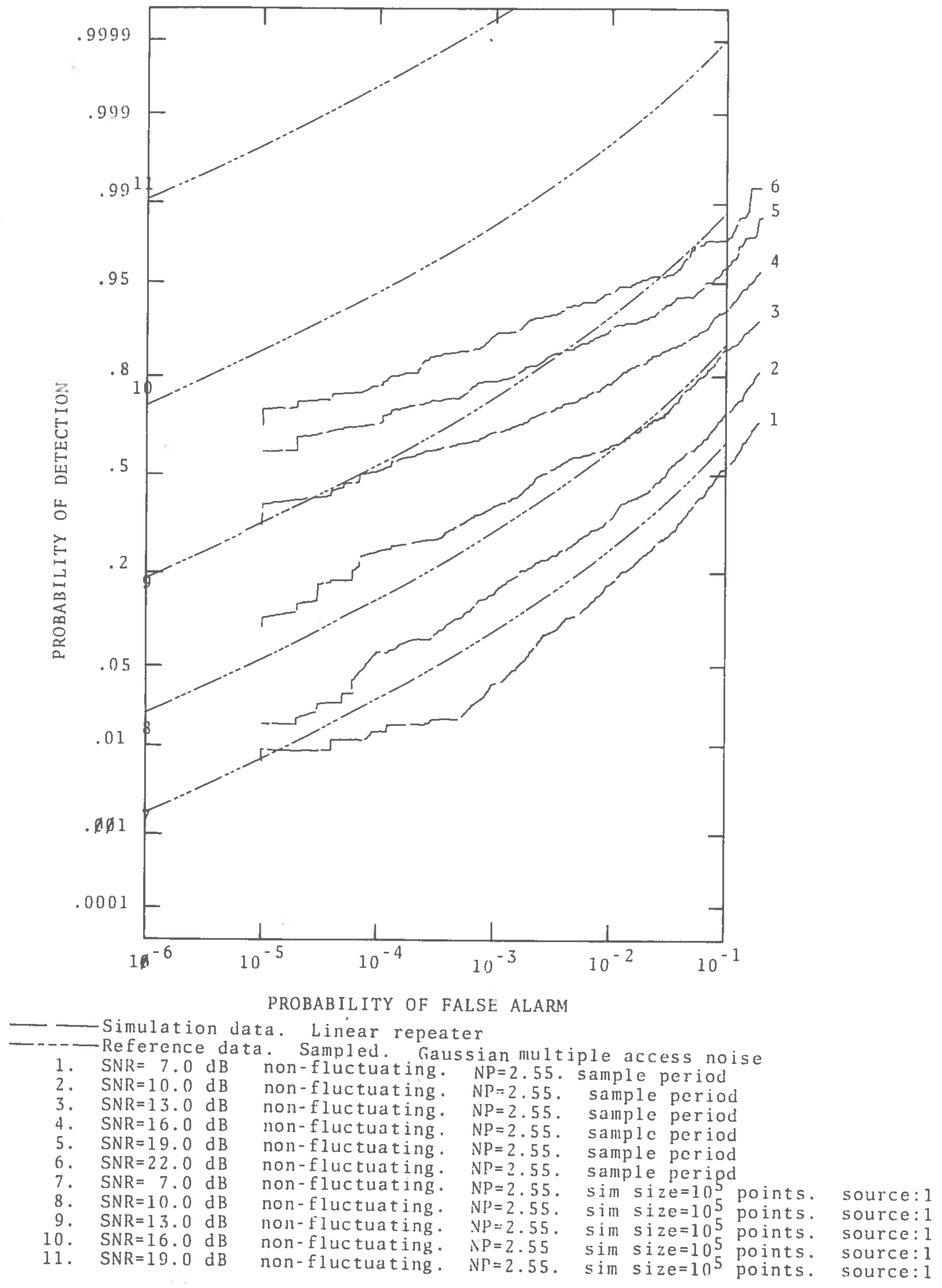


Figure 20. ROC With Signal-To-Noise Ratio as a Parameter -- Continuously Sampled Receiver Output

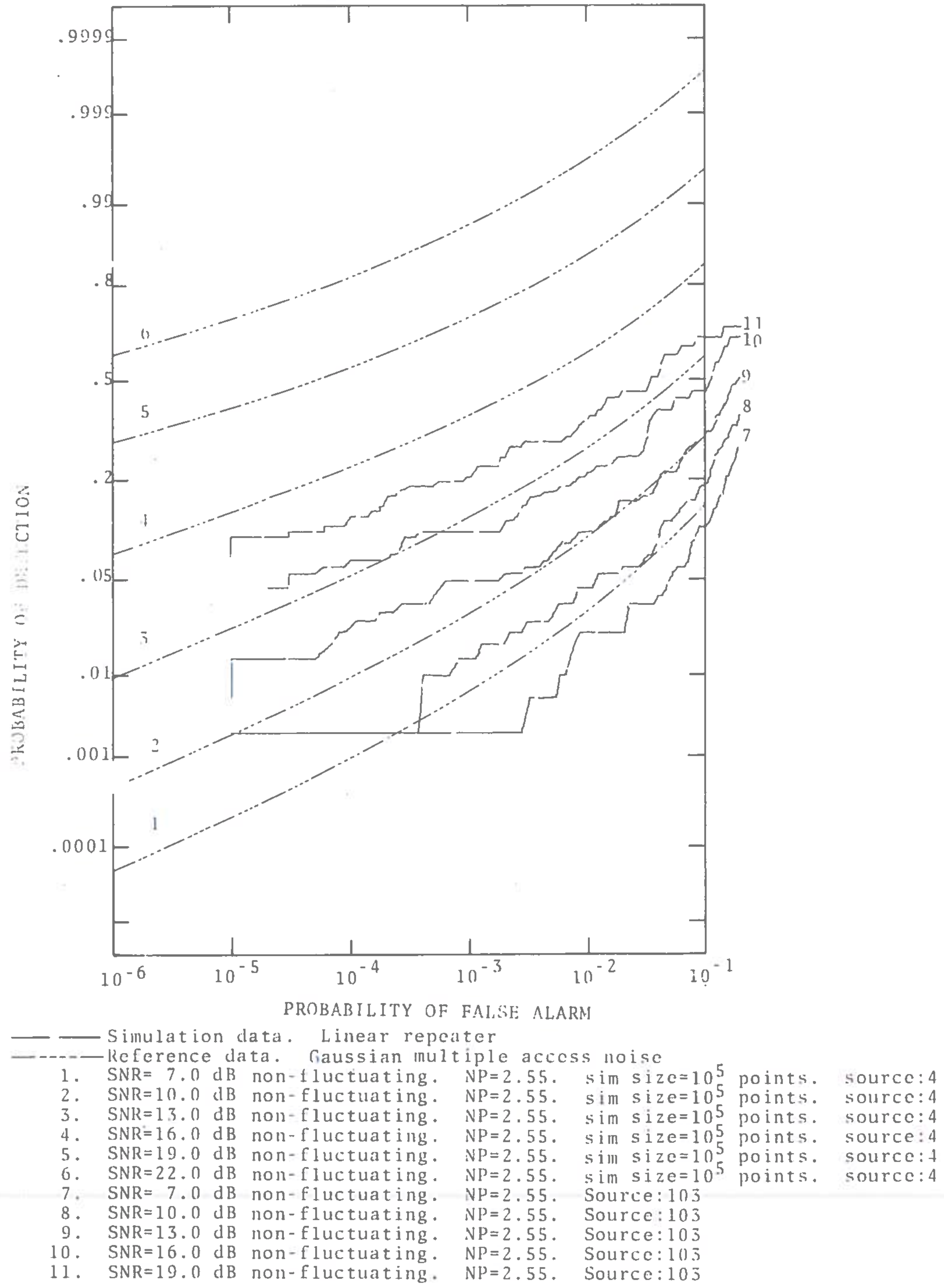


Figure 21. ROC With Signal-To-Noise Ratio as a Parameter -- Receiver Output Sampled Once per Range/Time Cell

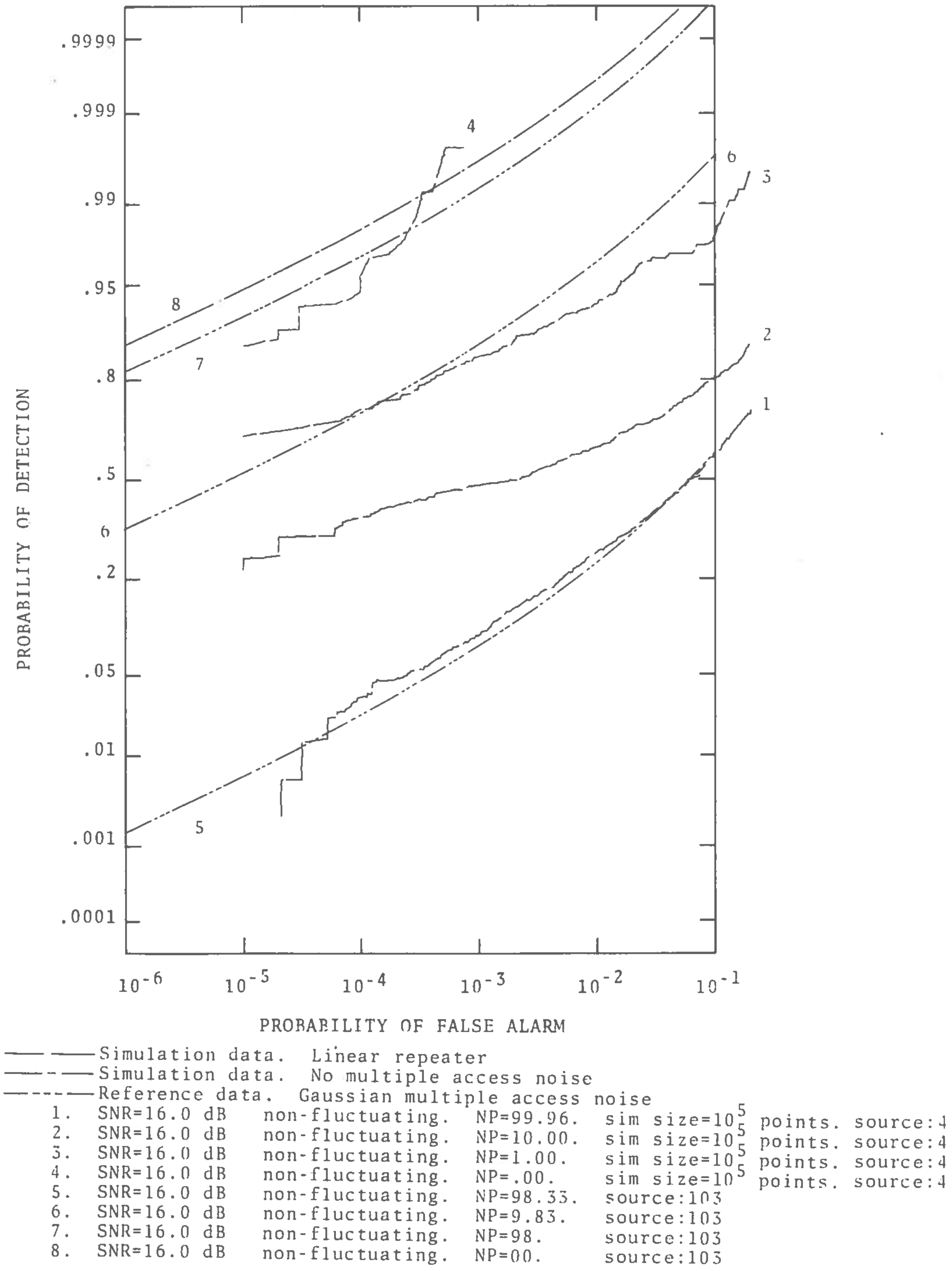
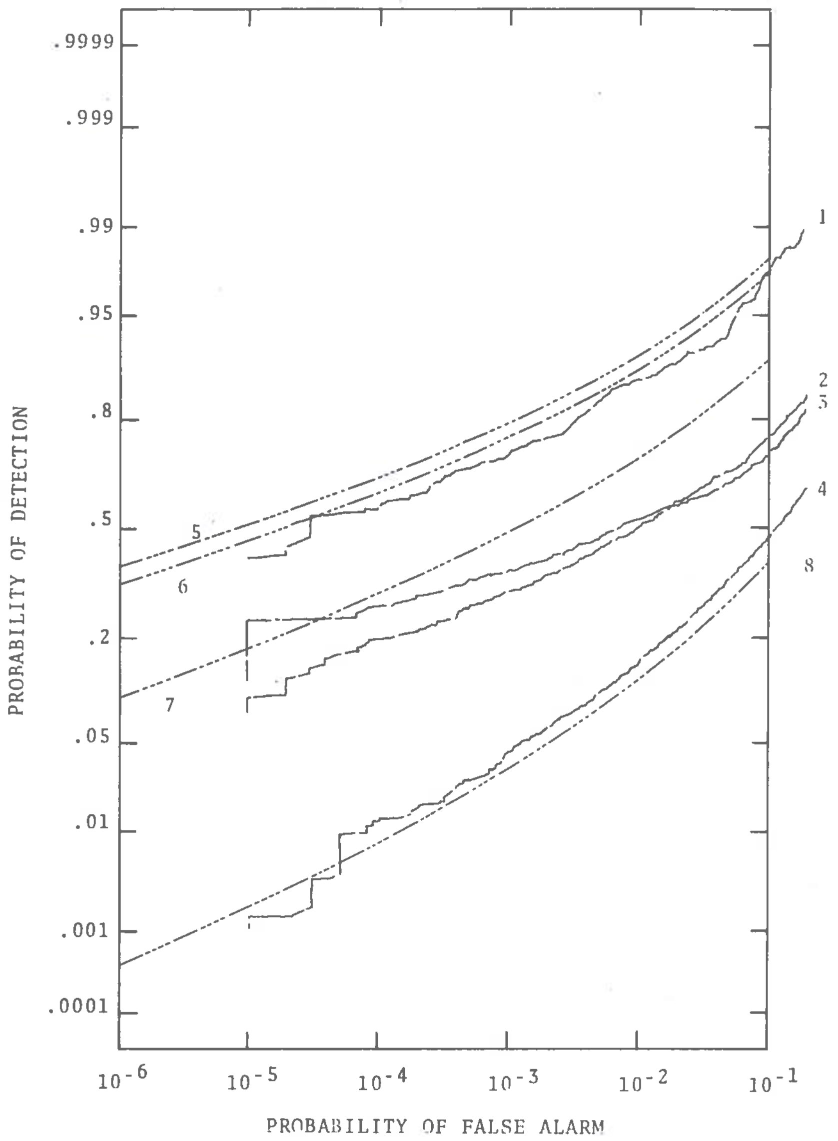


Figure 22. ROC With Number of Overlapping Pulses as a Parameter -- Continuously Sampled Receiver Output



1. SNR=16.0 dB non-fluctuating. points. source:4 NP=00. Sample period=1.000 sim size=10^5
2. SNR=16.0 dB non-fluctuating. points. source:4 NP=1.02. Sample period=1.000. sim=10^5
3. SNR=16.0 dB non-fluctuating points. source:4 NP=10.04. Sample period=1.000. sim size=10^5
4. SNR=16.0 dB non-fluctuating. points. source:4 NP=99.96. Sample period=1.000. sim size=10^5
5. SNR=16.0 dB non-fluctuating. NP=00. Sample period=1.000. source:103
6. SNR=16.0 dB non-fluctuating. NP=1.00. Sample period=1.000. source:103
7. SNR=16.0 dB non-fluctuating. NP=10.04. Sample period=1.000. source:103
8. SNR=16.0 dB non-fluctuating. NP=99.96. Sample period=1.000. source:103

Figure 23. ROC With Number of Overlapping Pulses as a Parameter - Receiver Output Sampled Once Per Range/Time Cell

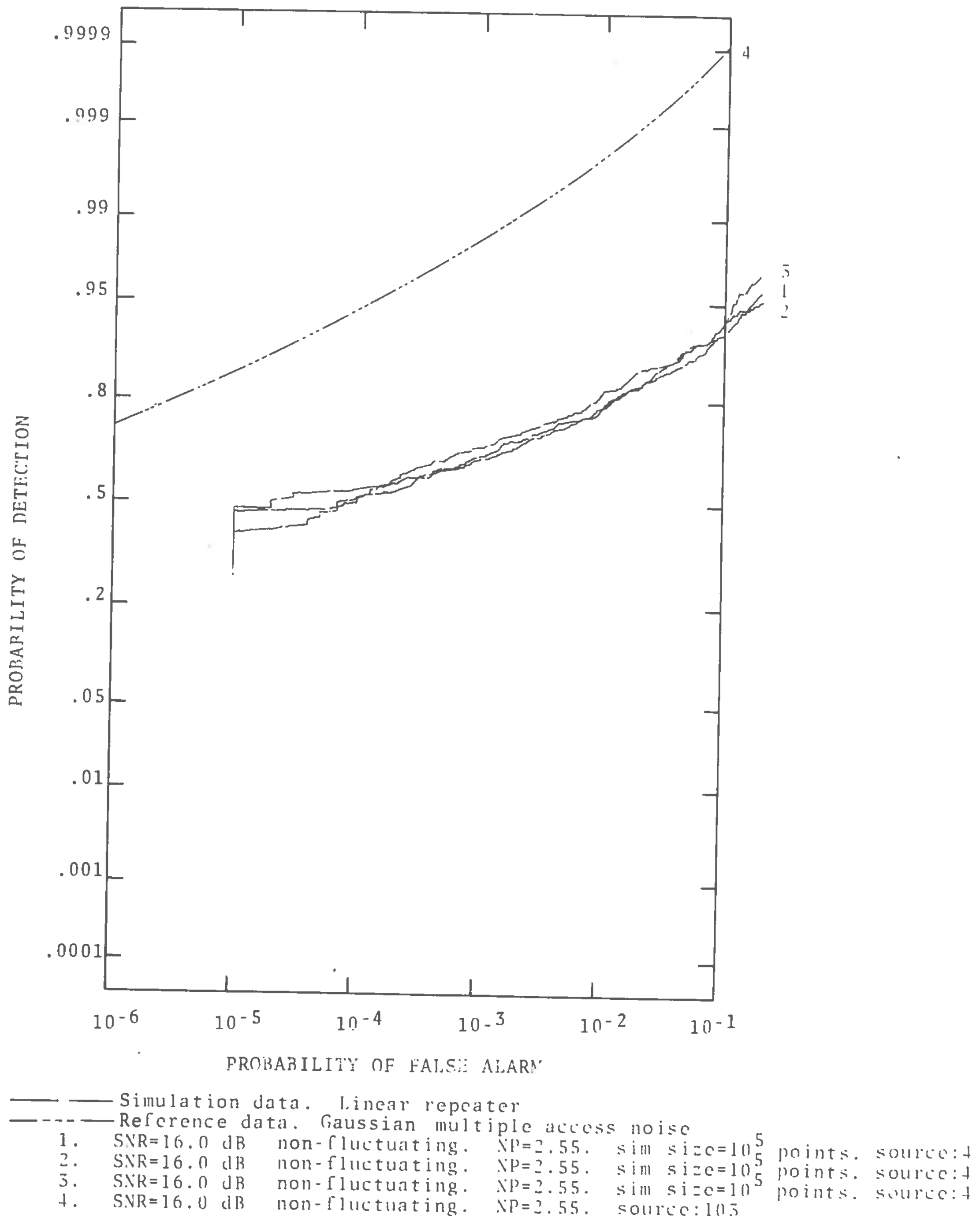
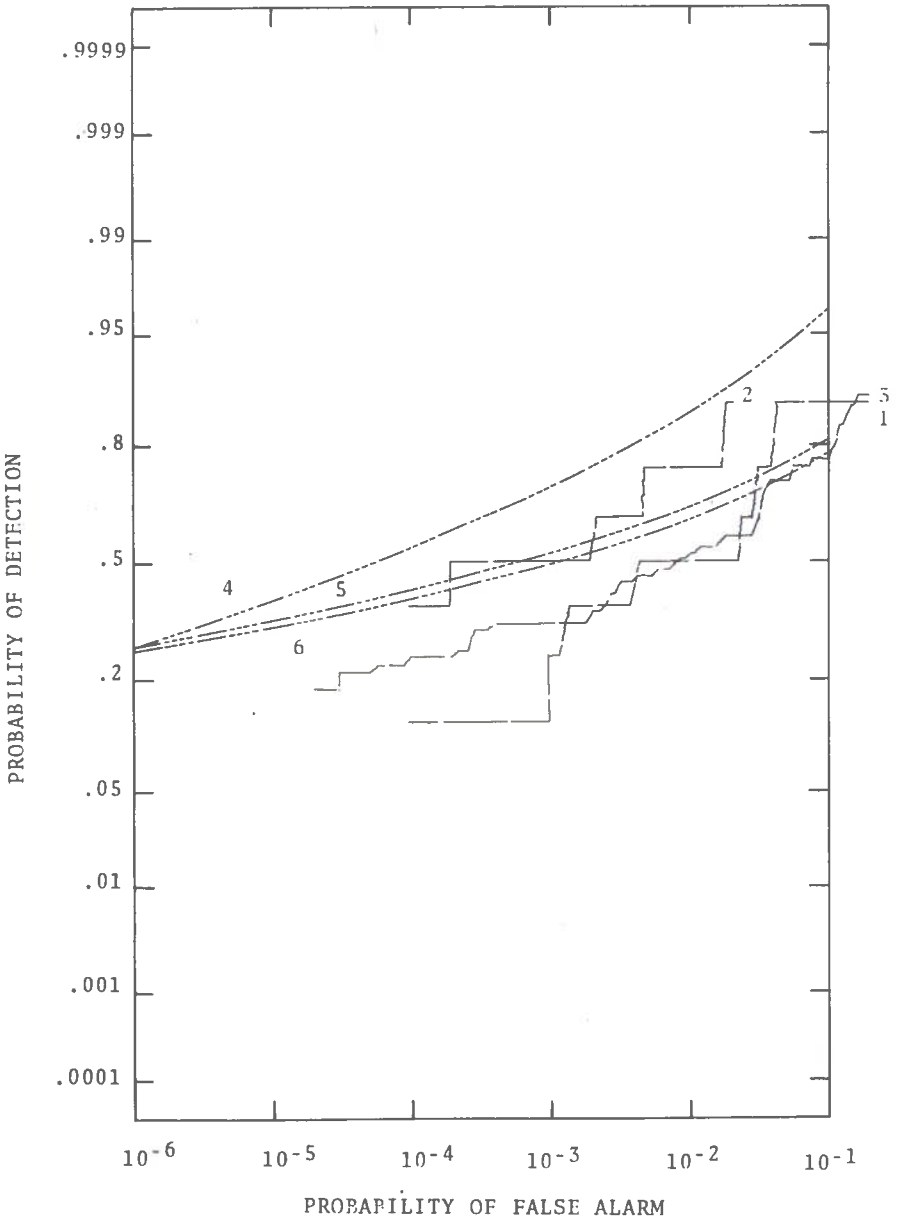


Figure 24. ROC For Three Code Sets -- Continuously Sampled Receiver Output



——— Simulation data. Linear repeater

—·—·— Reference data. Sampled. Gaussian multiple access noise

1. SNR=16.0 dB fluctuating. NP=2.55. sim size=10^4 points.
2. SNR-(13.0 dB non-fluctuating. 13. 0dB fluctuating). NP=2.55. sim size=10^4 points
3. SNR=16.0 dB non-fluctuating. NP=2.55. sim size=10^5 points.
4. SNR=16.0 dB non-fluctuating. NP=2.55. Sample period=1.000. source:103
5. SNR=(13.0 dB non-fluctuating. 13. 0dB fluctuating). NP=2.55. Sample period=1.000. source:103
6. SNR=16.0 dB fluctuating. NP=2.55. Sample period=1.000. source:103

Figure 25. ROC For Three Different Code Sets -- Receiver Output Sampled Once Per Range/Time Cell

The first plotted line is the ROC for the target-waveform set used in all of the other plots in this report. The second waveform is a different ML sequence from the set of 15 multiple-access noise sequences used for all of the other plots in this report. The third line is from a random signal set. The random set was generated by selecting one target sequence and 15 multiple access noise sequences, each sequence with 128 randomly positioned ones and 127 minus ones.

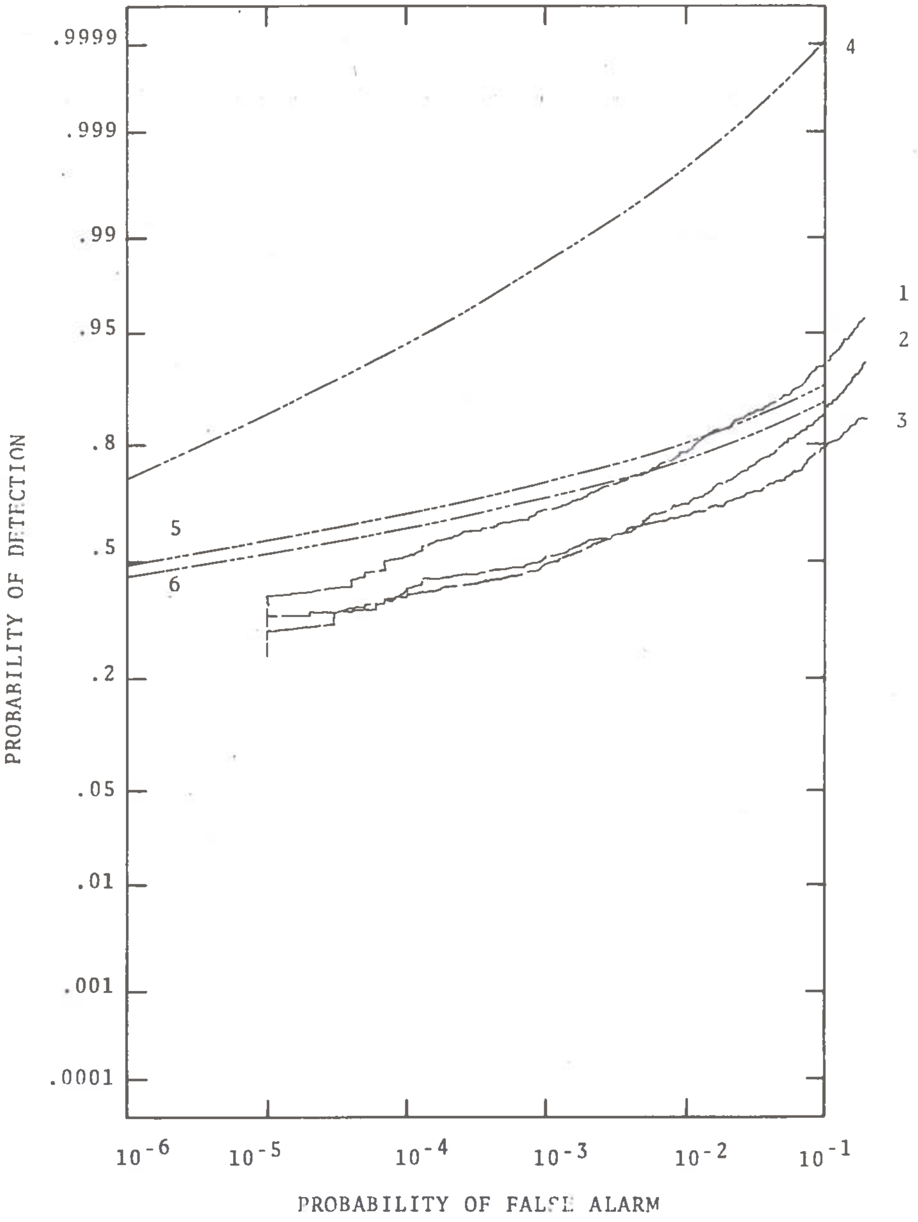
This plot is interesting because all three lines are so close together.

7.3.1.4 Performance as a Function of Target Fading Characteristics - Figures 26 and 27 show ROC's for three different types of target-amplitude fluctuation. One ROC is the conventional non-fluctuating point target, a second ROC is for a Rayleigh fading-point target. The third line is for a target with Rician-amplitude probability density with fading parameters selected half-way between the two previous lines.

Figure 26 is for a continuously sampled receiver output. Figure 27 is for the discretely sampled receiver output. In Figure 27 lines 1 and 2 cross in several places. This Figure was generated using an older form of the simulation program than the form used to generate Figure 26 and it has lower statistical significance in the probability of detection dimension.

7.3.1.5 Effects of Non-Linear Receiver on Performance - In all of the plots presented in this section the non-linear receiver is identical to the matched filter-envelope detector receiver, except that a hard limiter proceeds the receiver.

Figures 28 and 29 show the same set of simulation conditions as in section 7.3.1 and Figures 20 and 21. The reference curves have been removed for readability. These curves are interesting because of the relatively minor performance degradation introduced by the limiter for the equal target amplitude, non-fluctuating target model.



— —— Simulation data. Linear repeater

------ Reference data. Gaussian multiple access noise

1. SNR=16.0 dB non-fluctuating. NP=2.55. sim size=10^5 points. source:4
2. SNR=(13.0 dB non-fluctuating. 13. 0dB fluctuating). NP=2.55. sim size = 10^5 points. source:4
3. SNR=16.0 dB fluctuating. NP=2.55. sim size=10^5 points. source:4
4. SNR=16.0 dB non-fluctuating. NP=2.55. source:103
5. SNR=(13.0 dB non-fluctuating. 13. 0dB fluctuating). NP=2.55. source:103
6. SNR=16.0 dB fluctuating. NP=2.55. source:103

Figure 26. ROC For Different Target Fading Models -- Continuously Sampled Receiver Output

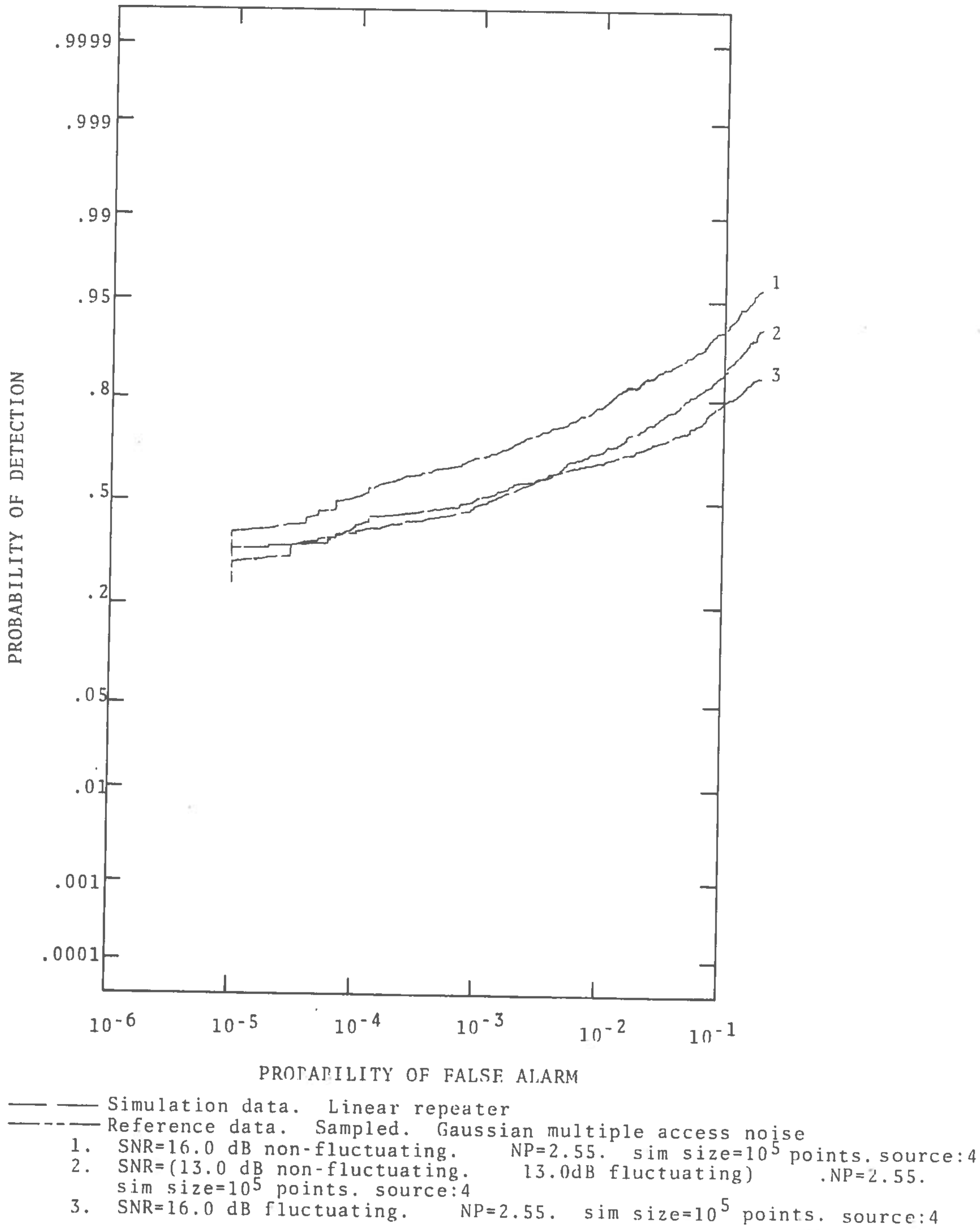


Figure 27. ROC For Different Target Fading Models -- Receivers Output Sampled Once Per Range/Time Cell

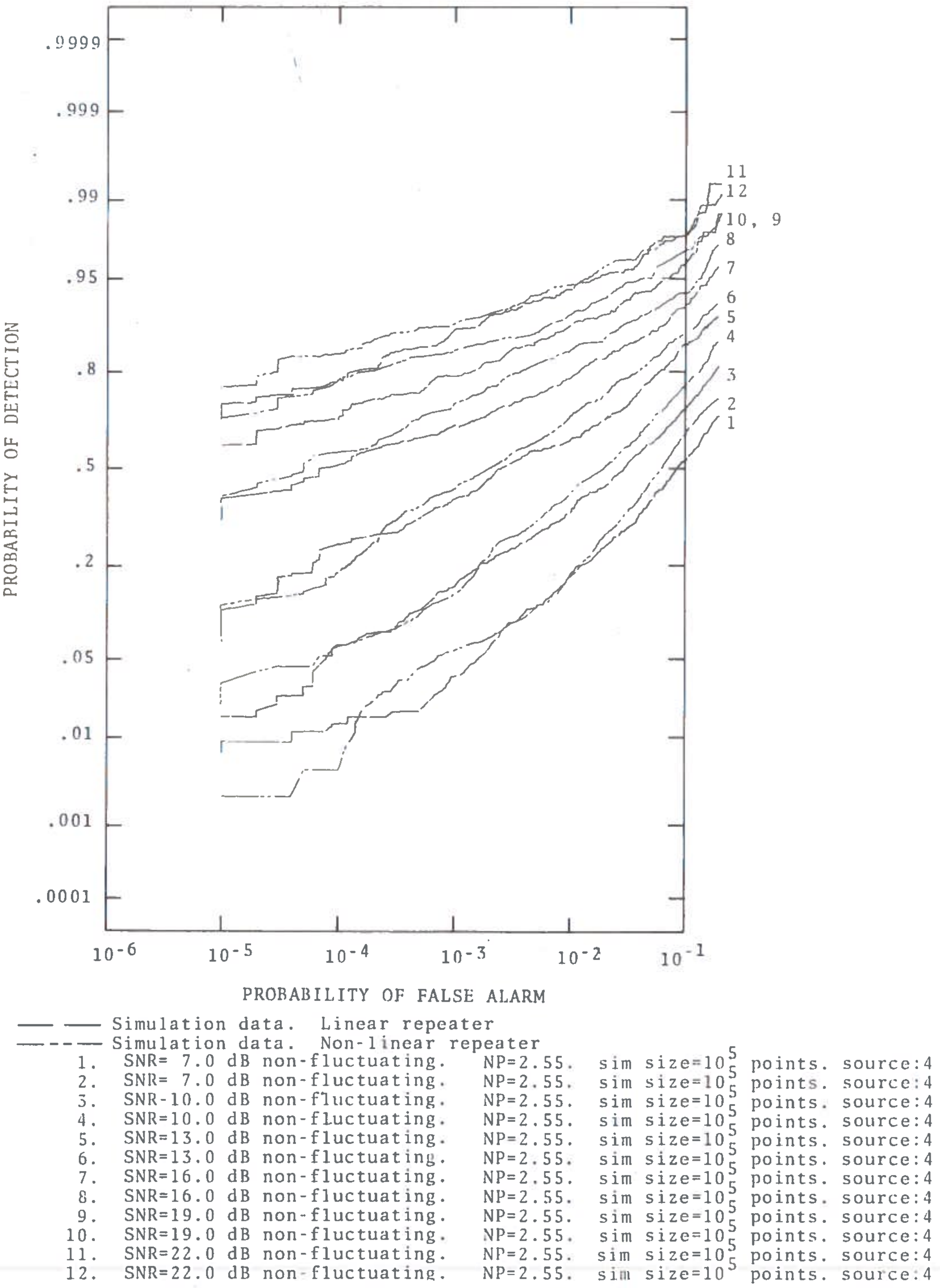


Figure 28. ROC For Linear and Non-Linear Receivers -- With SNR as a Parameter -- Continuously Sampled Receiver Output

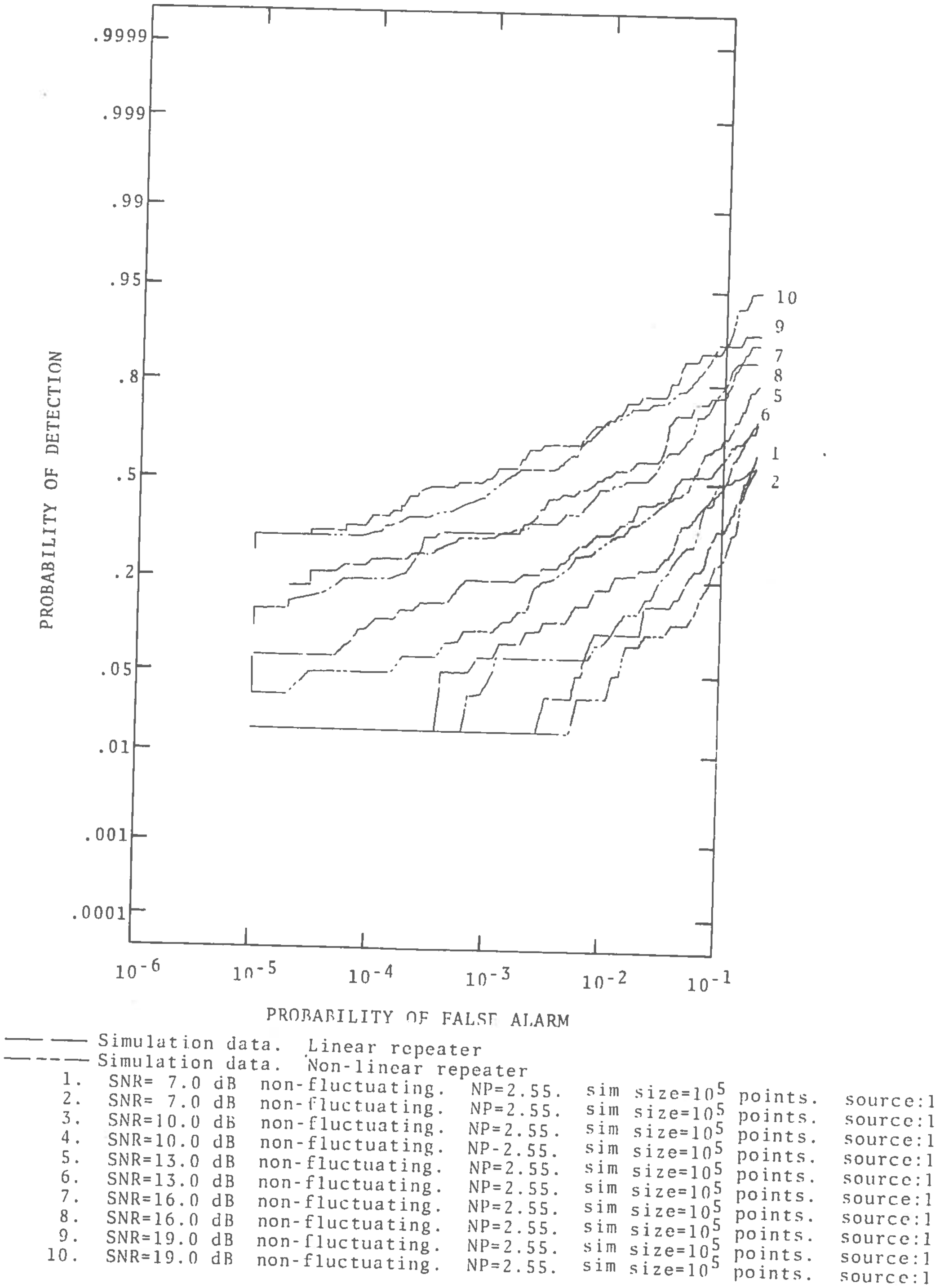


Figure 29. ROC For Linear and Non-Linear Receivers -- With SNR as a Parameter -- Receiver Output Sampled Once Per Range/Time Cell

Figures 30 and 31 show the linear and non-linear receiver ROC's for the condition described in Section 7.3.1.4 and Figures 26 and 27. In this case, as should be expected, the fluctuating target-performance with non-linear receiver show a greater performance-degradation relative to the fluctuating target with linear receiver than the non-fluctuating model generated.

7.3.1.6 Effects of Sampling on Performance - Figure 32 shows the effect of sampling rate on the ROC. The data in this figure is redundant but the form of presentation makes the sampling loss somewhat easier to see.

7.4 COMPUTER SIMULATION MODELS

Figure 33 shows a block diagram of the system which is modeled by the simulation program. The separate parts of the block diagram are described below.

7.4.1 Signal

A large number of targets transmit one of K different signals. Each target transmits it signal asynchronously with respect to all other targets. Each of the K signals is a sequence of I chips, where each chip is an antipoduly phase-modulated simple-pulse of length t. The basic signal chip which is transmitted is:

$$C(t) = \begin{cases} e^{jw_c t} & o \le t < \tau \\ o & \text{elsewhere} \end{cases}$$

The K signals are defined by:

$$S_k(t) = \sum_{j=o}^{J-1} S_{kj}\, C\,(t-j\tau) \qquad 1 \le k < K \tag{1}$$

where the sequences S_{kj} are codewords which take on the value +1 or -1.

The targets transmit their waveforms independently and asynchronously. Target transmission times are modeled as being identical independent Poisson processes for each of the K waveform types.

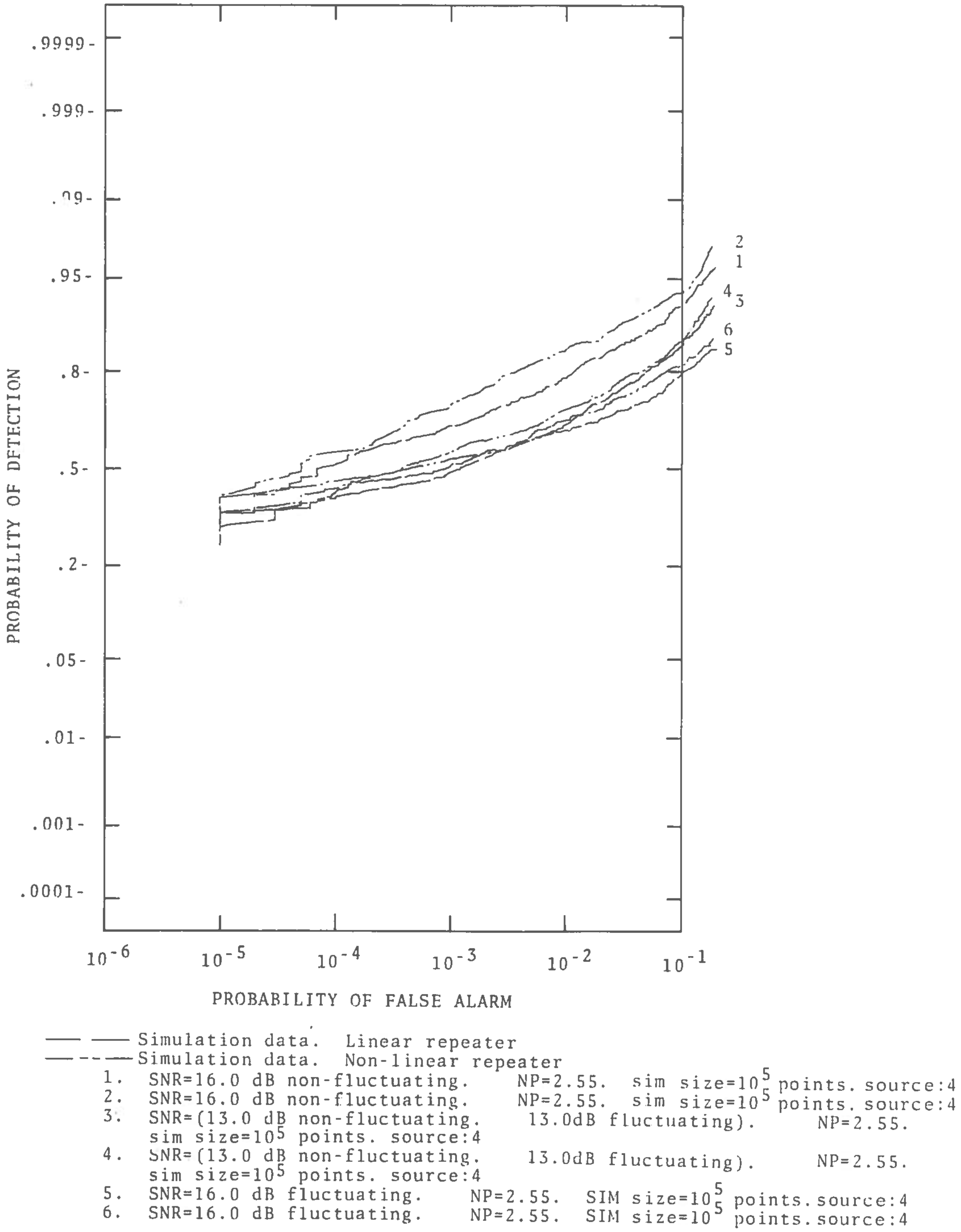


Figure 30. ROC For Linear and Non-Linear Receivers -- Three Different Target Fading Models -- Continuously Sampled Receiver Output

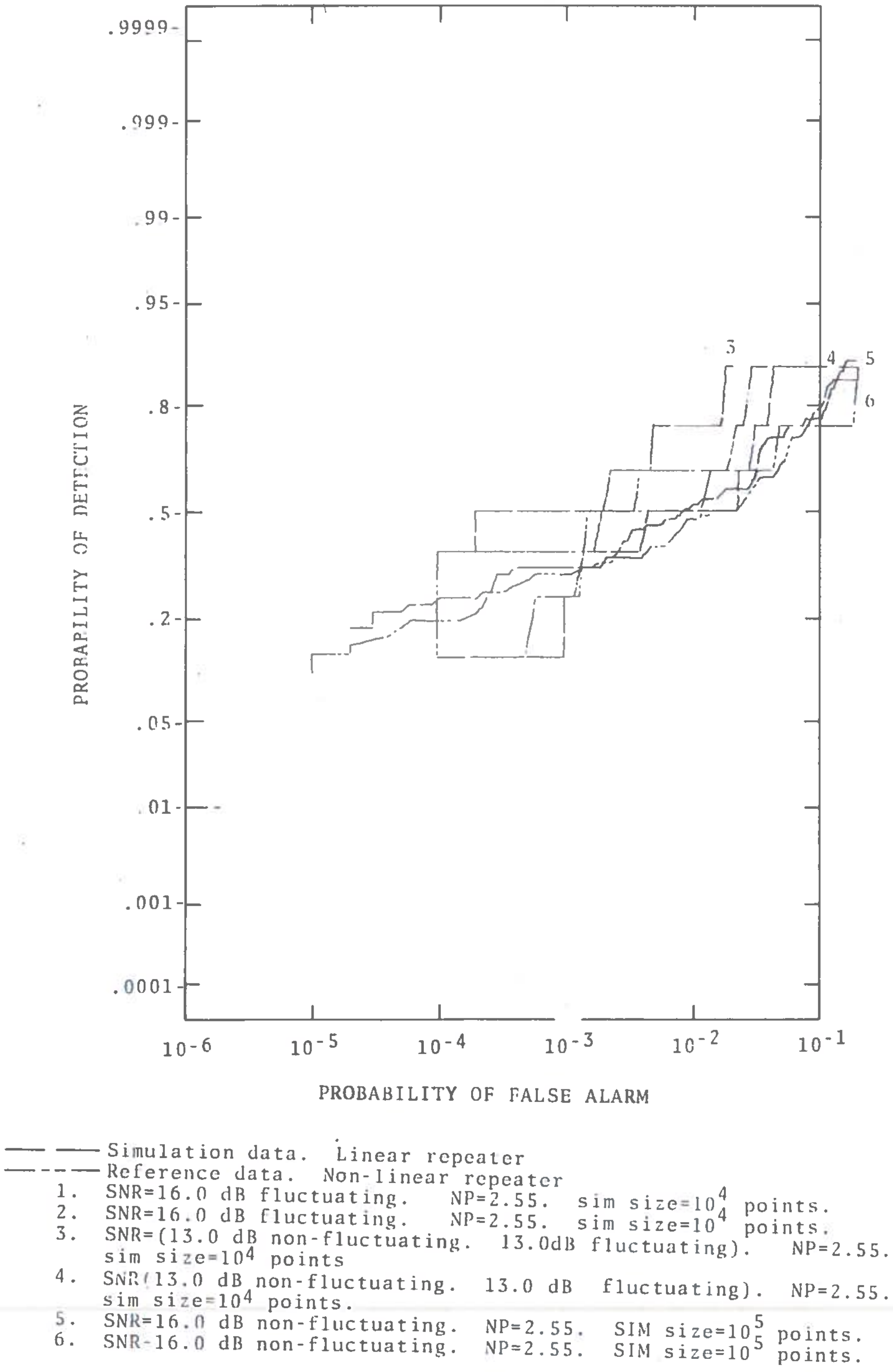


Figure 31. ROC For Linear and Non-Linear Receivers -- Three Different Target Fluctuation Models -- Receiver Output Sampled Once Per Range/Time Cell

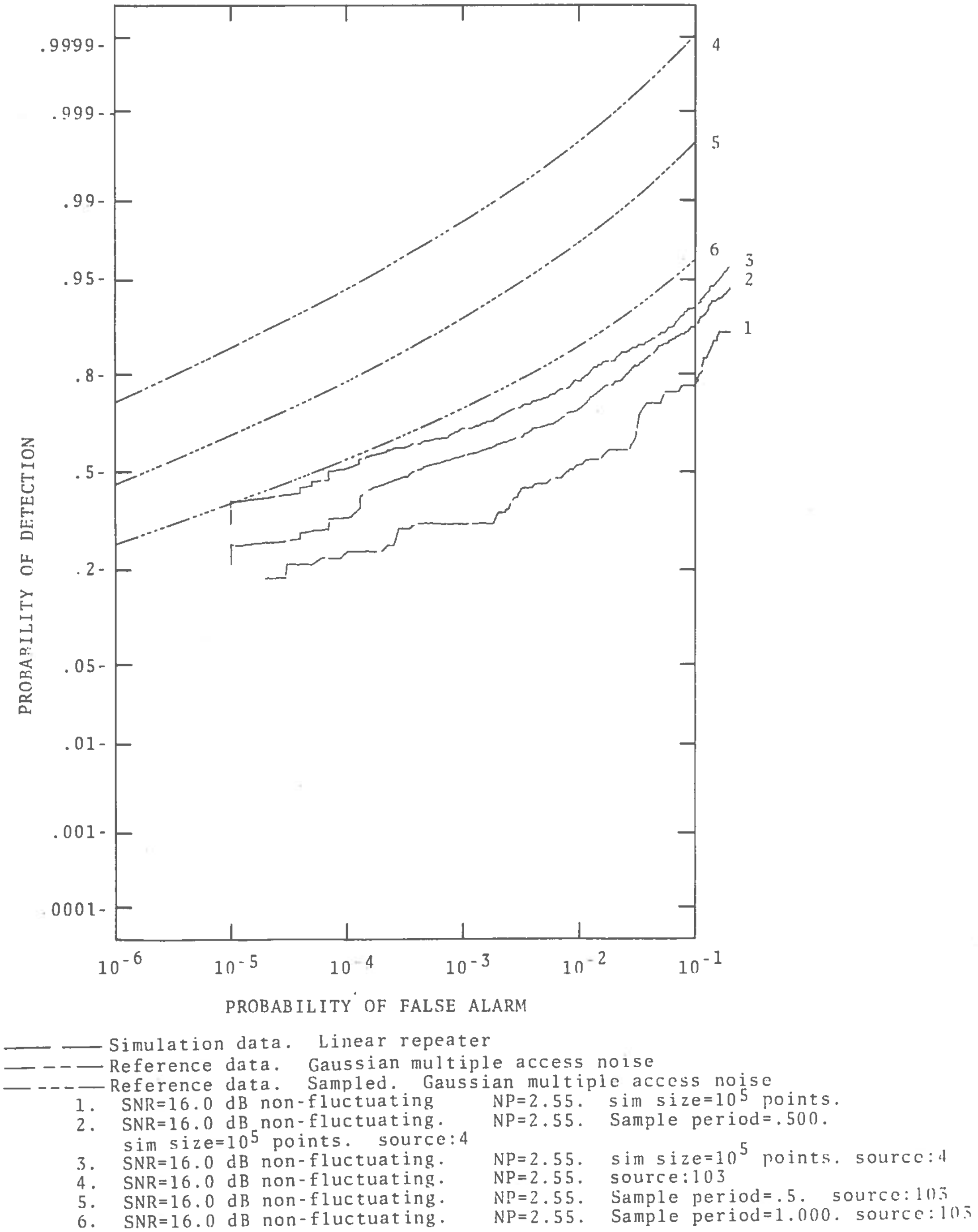


Figure 32. ROC For Three Different Receiver Sampling Rates

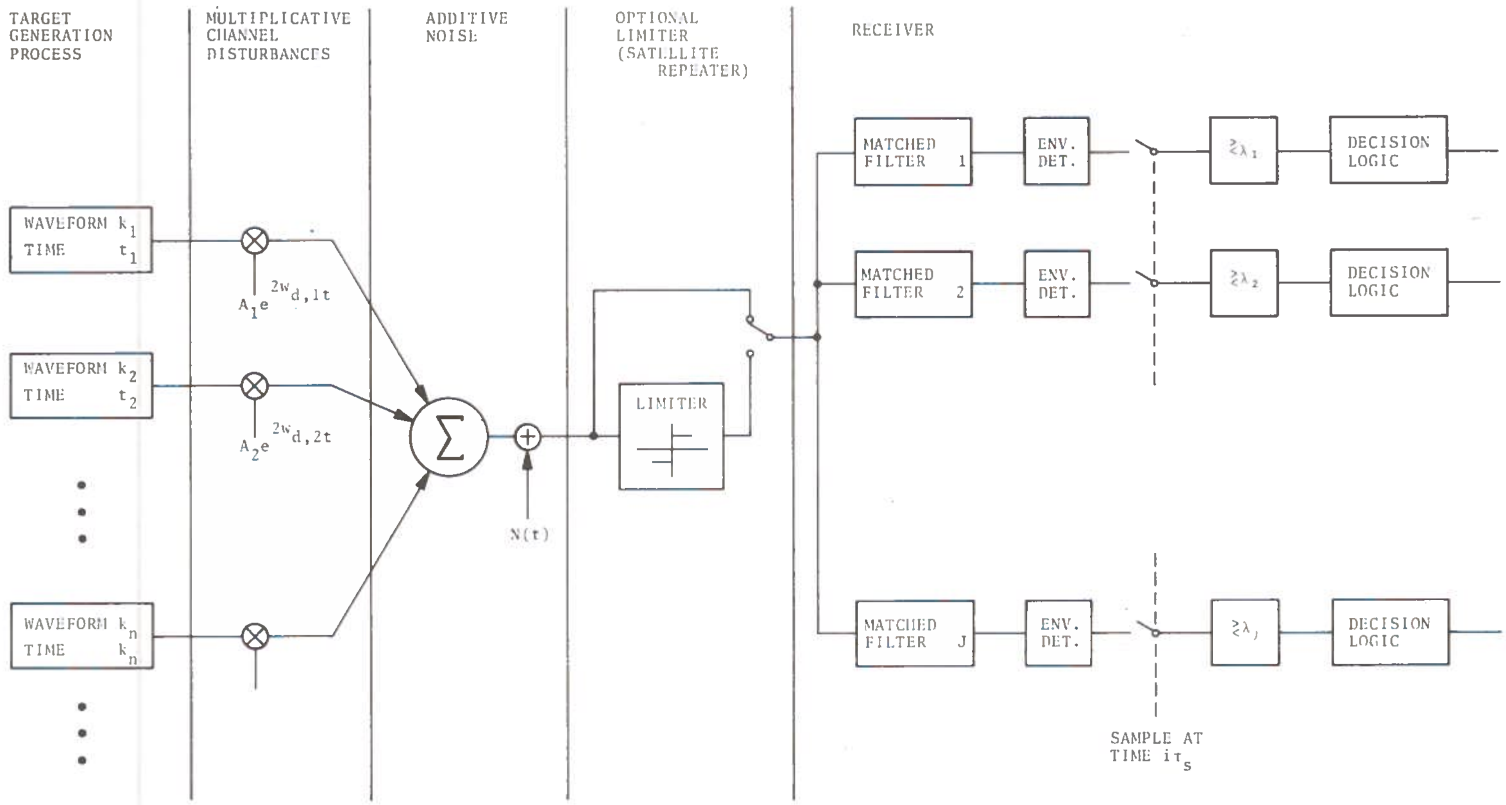


Figure 33. System Which is Modeled by Simulation Program

Unique target identities are not maintained for individual targets, only transmission times are simulated. This is not a restriction on the accuracy of the simulation for large numbers of targets, which is the situation of interest in this program.

7.4.2 Radio Channel Model

The radio channel is modeled as generating a random phase-shift, uniformly distributed between 0 and 2π, a Rician Probability Density for the received signal envelope amplitude, a Gaussian distributed doppler shift, and adding white Gaussian noise. When the transmitted signal is S_R (t) and no other signals are transmitted the received signal is described by:

$$r_k(t) = A\, e^{jw_d t}\, S_k(t) + n(t) \qquad (2)$$

A is a complex random variable with Rician amplitude. The probability density for the magnitude of A is:

$$P_A(x) = \frac{X}{\sqrt{E_R/2}}\; I_o\left(x\sqrt{\frac{2E_S}{E_R}}\right)\; \exp\left(-\;\frac{X^2 + E_S}{E_R}\right) \qquad X \geq 0 \qquad (3)$$

when E_R equals zero this reduces to: $\delta(\sqrt{E_S})$, when E_S equals zero it reduces to the Rayleigh distribution:

$$P_A(x) = \frac{X}{\sqrt{E_R/2}}\; \exp\left(-\,\frac{X^2}{E_R}\right) \qquad X \geq 0 \qquad (4)$$

For any values of E_R and E_S the mean square value of A is given by:

$$\overline{A^2} = E_R + E_S\ .$$

This model is used to describe the varation of received signal energy caused by aircraft motion with relatively complex antenna patterns, and scintillation.

If the transmission time for the i-th target of type k is denoted by $t_{i,k}$ the entire received time function is given by:

$$r(t) = n(t) + \sum_{i,k} \left[A_{i,k} e^{jw_{d,i,k}(t-t_{i,k})} \sum_{j=o}^{N-1} S_{k,j} \, C(t-j\tau-t_{i,k}) \right] . \tag{5}$$

7.4.3 Receiver Model

The receiver is modeled as a bank of matched-filter envelope-detectors which is optionally proceeded by a limiter. The matched-filter for the k-th waveform has response:

$$h_k(t) = S_k(-t) = \sqrt{\frac{2}{N_o}} \sum_{j=0}^{J-1} S_{J-j,k} \, C(t-j\tau), \tag{6}$$

where $\frac{N_o}{2}$ is the noise variance. For the current implementation of the simulation program only one of the K-matched-filters is simulated. This was done because the simulation can be repeated with the same set of random numbers for different receiver filters and it generates a sample ROC with the maximum statistical significance for a fixed run time.

7.4.4 Detector

Two different detection procedures have been simulated. In the first procedure, the output of the matched-filter envelope-detector is sampled once every τ_s where $o \leq \tau_s \leq \tau$, and τ is the duration of one basic waveform chip. The following definitions are more or less trival but are specifically implemented in the simulation program. A detection is defined to occur if the voltage at the output of the sampler exceeds a threshold. A false alarm is defined to occur if a detection for waveform type k if the threshold is exceeded at a sample time which is not adjacent to the actual position of a simulated target. No false alarm occurs if two detections occur, one on each side of the target position. A target is missed only if there is no detection at either adjacent sample point.

For the second detection procedure only the receiver output at the sample time nearest to the target peak position is examined to determine the conditional probability density for signal amplitude given that a target is present.

7.4.5 Gaussian Multiple Access Noise Model

This model is used to generate reference data which are plotted on the same coordinates as the simulated data. The reference data allow convenient compairson of the two models.

7.4.5.1 Continuous Detector Output Sampling - When a target is present the receiver output voltage is described by:

$$P_R(r) = \frac{r}{\sqrt{\frac{N_0}{2} + \frac{N_P}{2}(E_R + E_S) + \frac{E_R}{2}}} \; I_0\left(\frac{r\sqrt{E_S}}{\sqrt{\frac{N_0}{2} + \frac{N_P}{2}(E_R + E_S) + \frac{E_R}{2}}}\right)$$

$$\exp\left(\frac{-r^2 - E_S}{N_0 + N_P(E_R + E_S) + E_R}\right) \quad r \geq 0 \qquad (7)$$

when no target is present the probability density is:

$$P_R(r) = \frac{r}{\sqrt{\frac{N_0}{2} + \frac{N_P}{2}(E_R + E_S)}} \; \exp\left(\frac{-r^2}{N_0 + N_P(E_R + E_S}\right) r \geq 0 \qquad (8)$$

In both cases;

$\frac{N_0}{2}$ is the amplitude of the white gaussian noise power spectral density

N_P is the average number of simultaneously transmitting targets

E_R is the fluctuating energy transmitted by one target

E_S is the non-fluctuating energy transmitted by one target.

For a threshold value λ the probability of detection is given by:

$$P_d(\lambda) = Q\left(\sqrt{\frac{E_S}{\frac{N_O}{2} + \frac{N_P}{2}(E_R + E_S) + \frac{E_R}{2}}}, \frac{\lambda}{\sqrt{\frac{N_O}{2} + \frac{N_P}{2}(E_R + E_S) + \frac{E_R}{2}}}\right) \quad (9)$$

where Q(A,B) is marcum's Q function, and is defined by

$$Q(A,B) \triangleq \int_{\beta}^{\infty} X \, I_o \, (AX) \, \exp \, -\left(\frac{A^2+X^2}{2}\right) \, dx \quad (10)$$

and the probability of false alarm is given by:

$$P_F(\lambda) = \exp\left(- \frac{\lambda^2}{N_O + N_P (E_R + E_S)}\right) \quad (11)$$

7.4.5.2 <u>Discrete Sampling of the Detector Output</u> - When the output of the matched-filter envelope-detector is sampled every τ_S second:

$$0 \leq \tau_S \leq \tau$$

the probability of false alarm at each sample point is as in Section 7.4.2.1. But the probability of detection is given by:

$$P_d(\lambda) = \frac{1}{\tau_S} \int_o^{\tau_S} Q\left(\sqrt{\frac{(1-\frac{x}{\tau}) \, E_S}{\frac{N_O}{2} + \frac{N_P}{2}(E_R + E_S) + \frac{E_R}{2}}}, \frac{\lambda}{\sqrt{\frac{N_O}{2} + \frac{N_P}{2}(E_R + E_S) + \frac{E_R}{2}}}\right) dx \quad (12)$$

APPENDIX A - SIMULATION PROGRAM ERROR ANALYSIS

The principal error-source in the simulation program is the Monte Carlo-type approximation to the actual ROC. For this program both the X and Y positions of one point on the ROC plot are subject to this type of error. The errors on one line are highly correlated.

For low false alarm rates and high or low detection probabilities the simulation is granular and has low significance. For example with a 10^5 point simulation 1 false alarm yields a false alarm rate of 10^{-5} and N false alarms yield a false alarm rate of $10^{-5}N$. The sample false-alarm and detection probability are Binomaly Distributed with mean at the actual probability and with variance:

$$\mathrm{Var}(P) = \frac{P(1-P)}{N}$$

where P is the probability being simulated and N is the number of points in the simulation. Whenever the simulation is not excessively granular the Binomial density can be approximated by a Normal Distribution to determine the two or three sigma confidence limits. Where the simulation is extremely granular, the confidence limits are determined easily by direct numerical evaluation of the probability of being at the grid points. In any case, this process does not yield results that are significantly different from the Normal Distribution approximation when the cofidence limit bounds are within the area which implies two or more events.

This analysis is relatively important since the results of the simulation will often be used to predict the performance of systems at low false alarm rates where the Monte Carlo-process provides relatively low significance.

For 10^5 point simulation sizes, the size used for all of the curves presented in this report, there are approximately 10^5 false alarms, and no less than 400 target detections. Typical error elipsoids are plotted in Figures 34. The P_F and P_D error bounds under the Normal Distribution approximation are shown in Figures 35 and 36. The scales of these plots allow direct comparison with the data presented in the report.

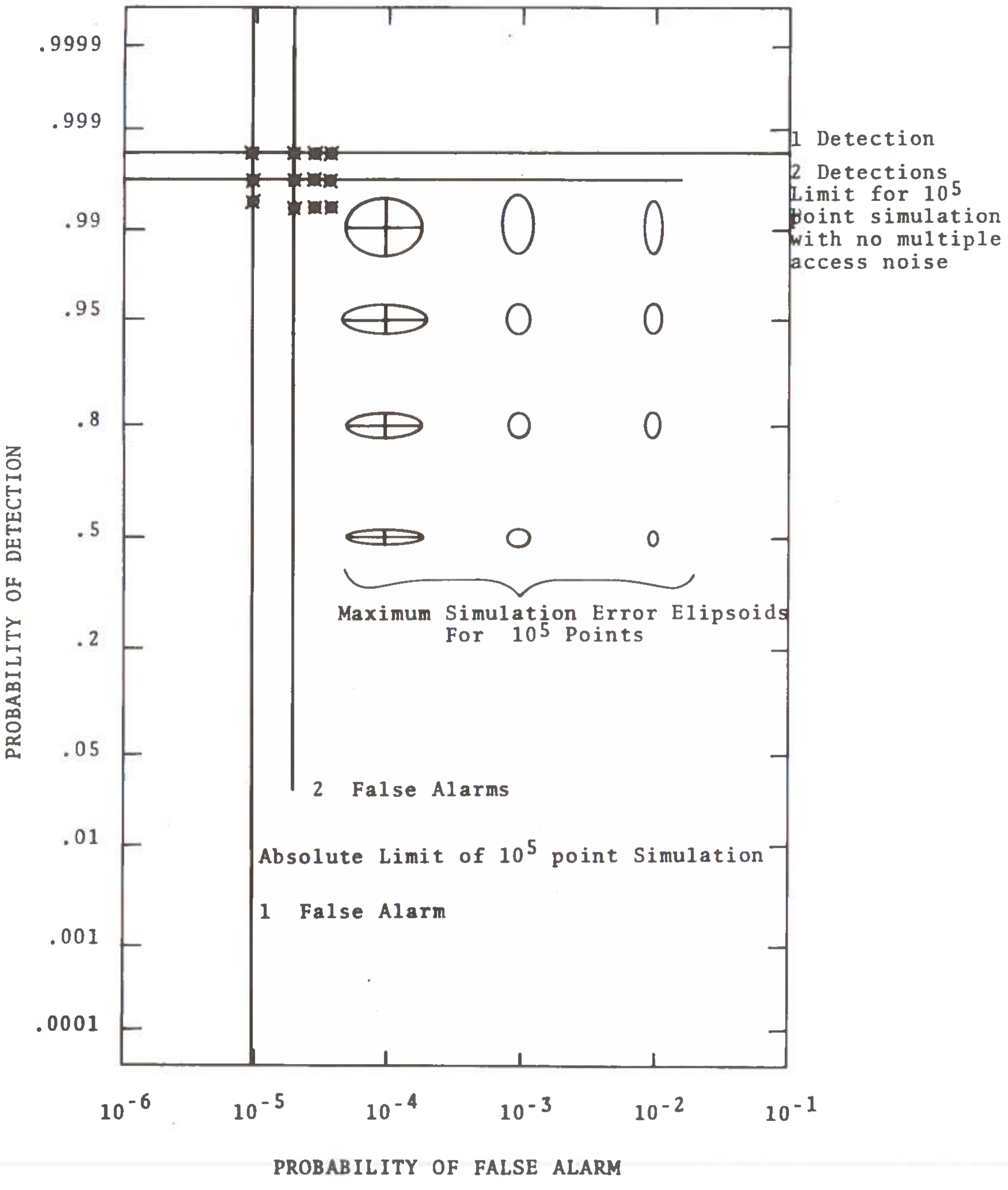


Figure 34. Typical Error Ellipsoids for a 10^5 Point Simulation

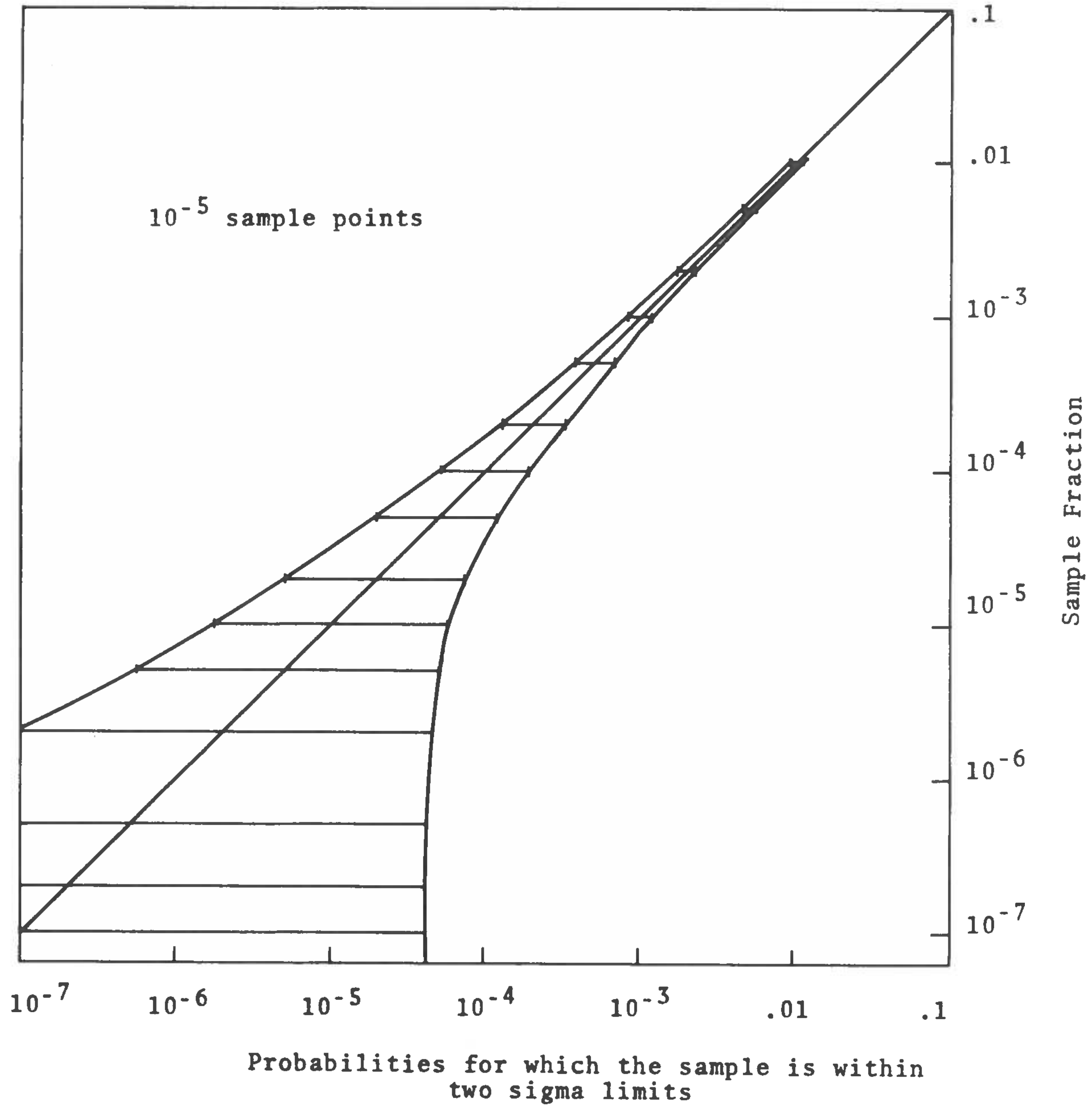


Figure 35. Two Sigma Probability of Detection Error Region -- For a Simulation Which Generates 40 or 400 Targets

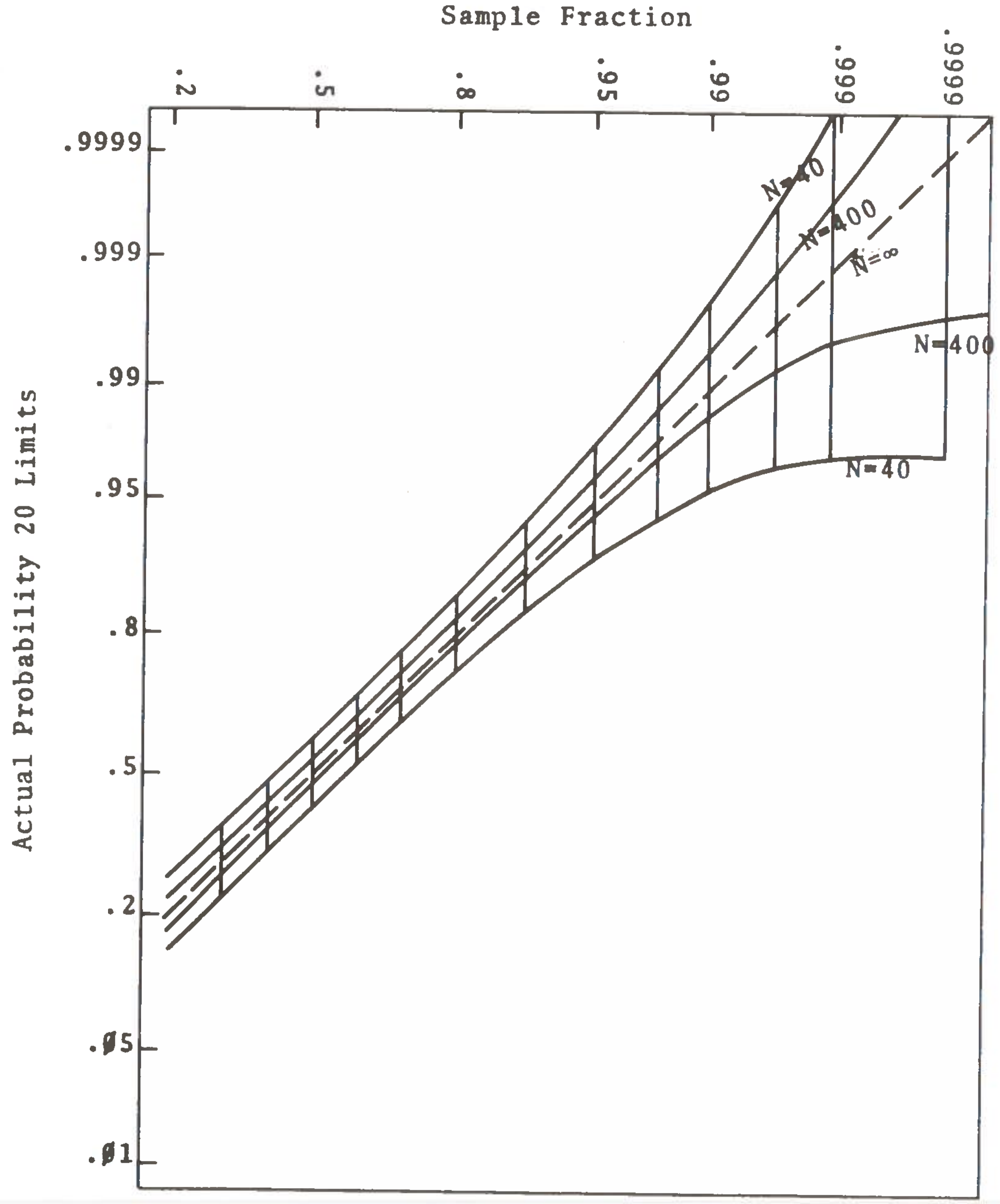


Figure 36. Two Sigma Probability of False Alarm Error Region for a 10^5 Point Simulation

APPENDIX B - SIMULATION PROGRAM

B.1 SIMULATION PROGRAM LOGIC

The simulation program listing is presented at the end of this appendix. The situation is a relatively straightforward simulation with the steps described in Section 7.4. The program simulates the complex envelope of the voltage on the radio channel and has a basic clock rate of one sample per waveform chip time. A flow chart of the program is in Figure 37A and B. The mathematical approximations described below are made.

B.1.1 Target Position

The Poisson process for target position is generated by using a random number generator to generate a target of each type in each cell with probability P. When P is small, as it is here, the total number generated is approximately Poisson. When a target is generated in a cell, a second random number is used to generate its actual offset within the cell. Because the time/autocorrelation function of the simple-pulse chip waveform is triangular, the target position is modeled by adding a fraction of the target signature to each of the two adjacent cells.

B.1.2 Target Phase and Amplitude

The following equation are used to generate the complex amplitude for each waveform bit

$$R_e(A) = \frac{1}{m}\sqrt{\frac{E_R}{2}} \sum_{i=1}^{12} X_i + \frac{1}{m} \sqrt{E_S} \cos (2\pi X_o),$$

$$I_m(A) = \frac{1}{m}\sqrt{\frac{E_R}{2}} \sum_{i=13}^{24} X_i + \frac{1}{m} \sqrt{E_S} \sin (2\pi X_o).$$

The X_i, $0 \le i \le 24$ are independent uniformly distributed random numbers:

$$P_{X_i}(x) = \begin{cases} 1 & -\frac{1}{2} \le X_i \le \frac{1}{2} \\ 0 & \text{elsewhere,} \end{cases}$$

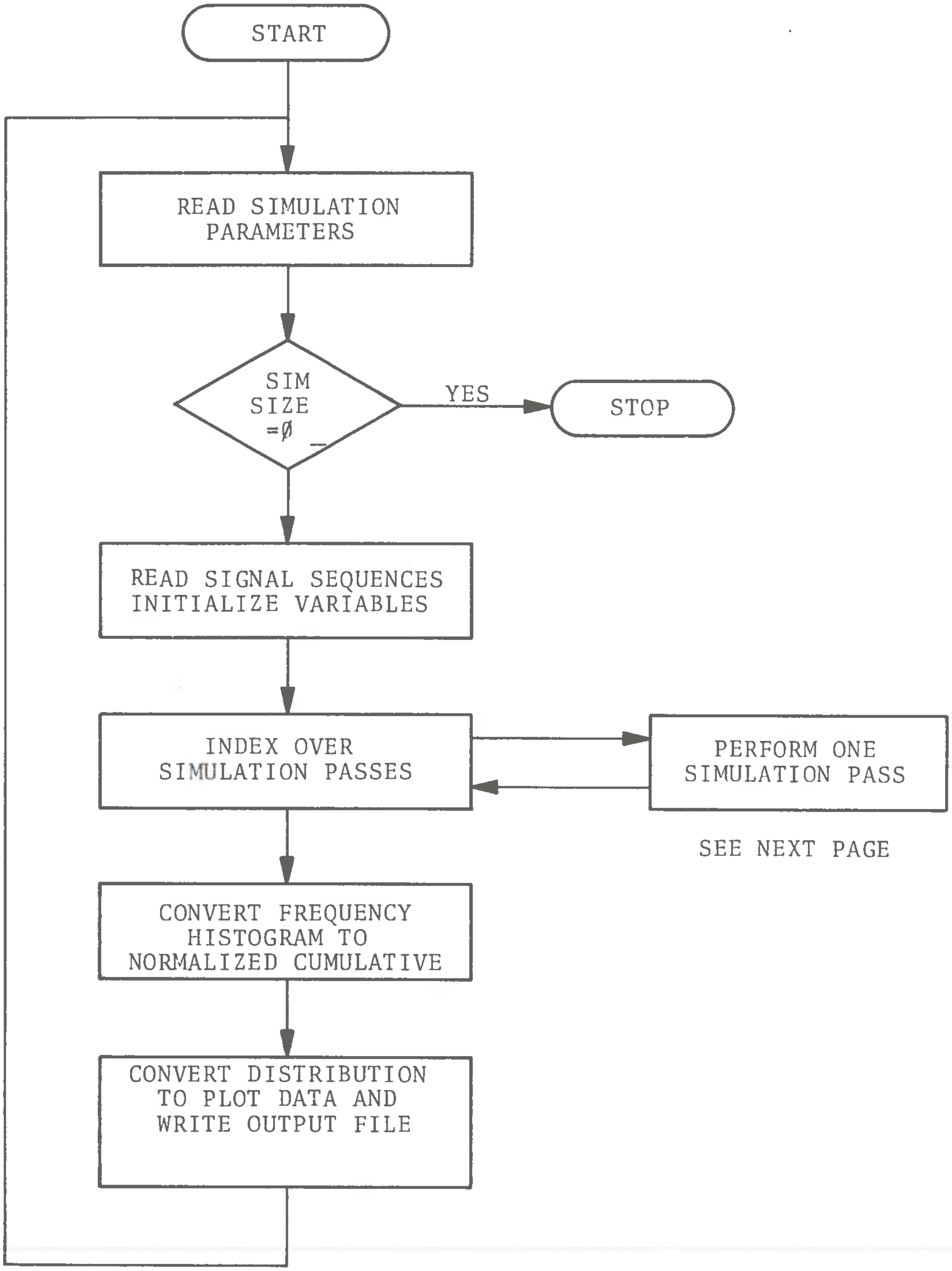


Figure 37A. Simulation Program Flow Chart

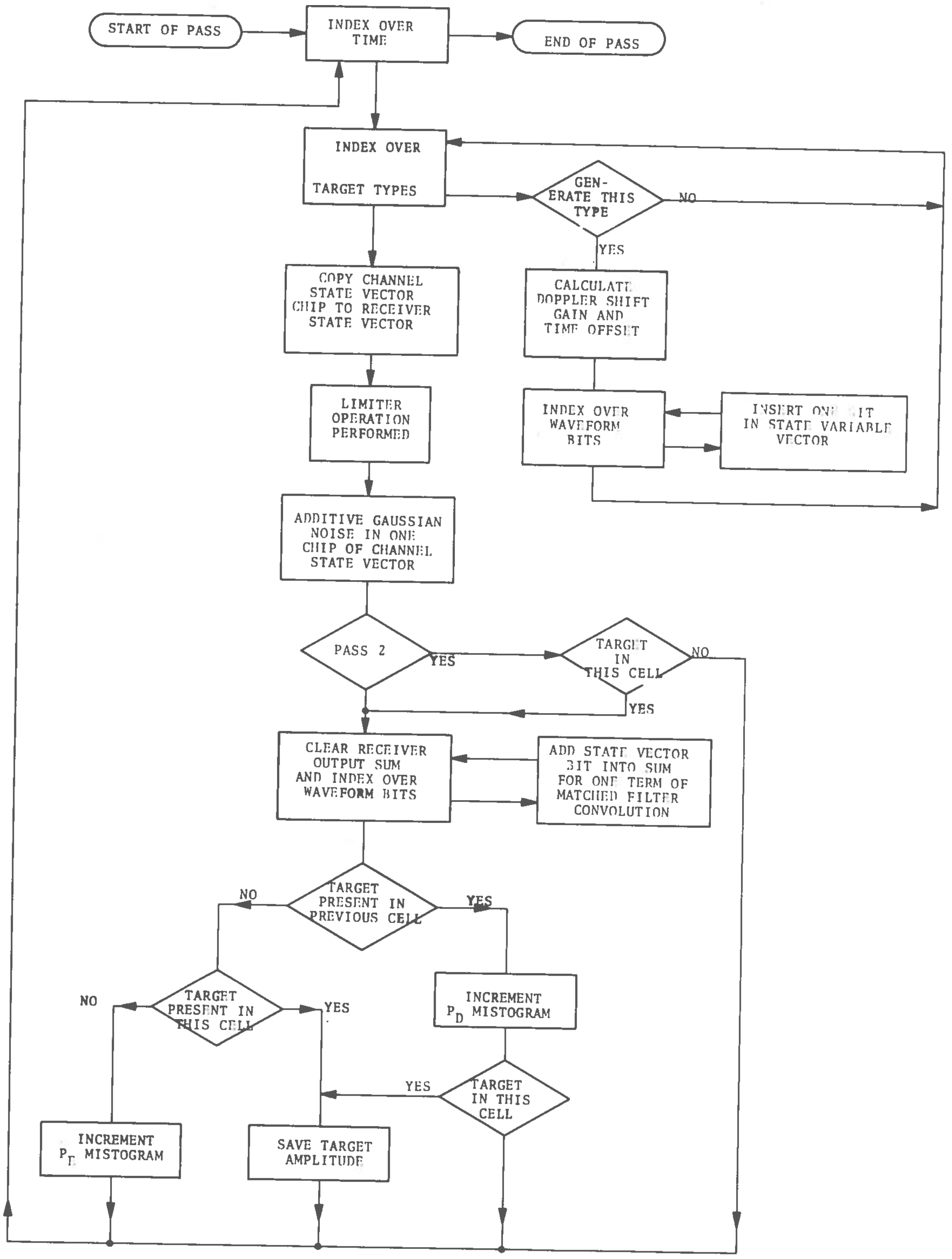


Figure 37B. Simulation Program Flow Chart and m is the length of a signal. The sums generate numbers which are approximately Gaussian with unit-variance and zero-mean.

B.1.3 Doppler Shift

A Gaussian random number is generated for the phase-shift between two successive bits. The complex channel gain is rotated through this phase-angle as each bit is generated so that the received signal is given by:

$$r(t) = \sum_{i=0}^{J-1} e^{jw_d i} S_i C(i).$$

When the phase-shift between two successive bits, w_d is small this is equivalent to equation 2.

B.1.4 Limiting Receiver

The limiting detector is generated by dividing the voltage on the channel by its magnitude. This maintains phase but destroys all amplitude information.

B.1.5 Matched Filter Receiver

The matched-filter is generated by filtering the time continuous channel data with a chip matched-filter. A process which is implicit in the target generation algorithm and then convolving the sampled output from the chip matched-filter output with the digital waveform sequence.

B.1.6 Sampler

The simulation runs at a τ clock rate but simulates targets samples generated at a τ_S, $0 \leq \tau_S \leq \tau$ rate. This is done by generating a subset of the targets at distance d, $0 \leq d \leq \tau_S/2$ from the clock points, rather than uniformly distributed over the interval. Only these targets are used for the probability of detection curve.

B.1.7 ROC Generation

Histograms of detection of flase-alarms count versus amplitude are generated each with identical histogram cell-sizes. When these histograms are converted to normalized cumulative sample probability distributions each P_d, P_f cell pair for a fixed amplitude contains one ROC point.

B.2 SPECIALIZATION OF THE PROGRAM

A perfectly general program for the type of simulation performed is inconsistent with maximum program efficiency. The main problem is in the receiver matched-filter simulator. This short segment of code accounts for most of the simulation time. If the signals are long, J greater than several hundred the convolution is most efficiently performed using a FFT based convolution algorithm.

For small signal lengths the convolution is more efficient when a direct summation is performed. If it is desired to extend the class of signals to allow non-binary phase-shifts the direct summation will require multiplications as well as the additions required for the binary signal-set. In this case the FFT will be more efficient except for extremely short signals.

The simulation program will be much larger when the FFT convolution is used because relatively large size FFT's are required for efficiency. When the computer billing algorithm includes size as well as run-time, the tradeoff becomes non-trival. The minimum core-direct summation-procedure presented here is the least expensive for the computer and signal-set which were used.

Signal-set dimensions have been compiled directly into the program in order to save run time.

APPENDIX C - PROGRAM USER'S GUIDES

The simulation consists of a set of three programs: the actual simulation program, a reference curve generator program, and a plot program. All three programs were written on the TSC PDP-10 computer. The Reference and Plot programs are fast and are most conveniently run as time-sharing programs. The simulation program takes roughly 5 minutes per 10,000 simulated time points and is run in the batch mode. The only useful output from the programs are the ROC plots produced by the plot program. The simulation and reference program produce intermediate files in a common form, which is plotted by the plot program. The intermediate files are printable and contain parameter values and plot coordinate points.

Operation of the three programs is described below.

C.1 SIMULATION PROGRAM OPERATION

Parameter input to this program is in one namelist read for each simulation runs. The meanings and default-values of the parameters are defined in the program-listing. The parameter IPTS in the namelist is used to specify the number of points to be simulated but stops the program if the value is 0. The commands are normally written in a file with the name "SIMCM.DAT" and this file has the following format.

```
 $PARMS IPTS=100000 ......... $
AAAAA.DAT
BBBBB.DAT
 $PARMS .......... $
CCCCC.DAT
DDDDD.DAT
 $PARMS IPTS=0 $
```

where "AAAAA.DAT" is the name of the file containing the signals to be used for the first program run, "CCCCC.DAT" contain the signals for the second run. The results of the two simulations are written on "BBBBB.DAT", and "DDDDD.DAT".

C.2 REFERENCE PROGRAM

All input to this program is by namelist input with parameters described in the program listing. The program requests a five-letter file name for its output with the prompt FILE.

C.3 PLOT PROGRAM

The plot program has several format options. The options are described in the listing. A minimal plot may be obtained from the command sequence.

```
0N0AAAAA.DAT
0N0BBBBB.DAT
...
...
000
```

where when N-9, the file on the current command line will be the first file plotted on a new page, when N=1, the current plot page will be used, and N=0 stops the program.

The commands are written is a file with the name "PPLCM.DAT". The plotter is a 36" bed Calcomp plotter.

APPENDIX D - WAVEFORMS

Two sets of waveforms have been used. A set of maximal length shift register sequences and a set of random codewords. The random codewords were constrained to have 128 ones and 127 minus ones. The listings for the programs and sequences which they, generated are at the end of this appendix. To make the signal printouts reasonably readable asterisks have been used to represent plus ones and dots minus one.

```
C SIMULATION PROGRAM -- MULTIPLE ACCESS NOISE
C
C VERSION 3 -- DOPPLER SHIFTS AND VARIABLE SAMPLING
C
C INPUT DATA:
C   ALL INPUT PARAMETERS ARE IN NAMELIST PARMS, VARIABLES ARE
C       SNRDB    SIGNAL TO NOISE RATIO IN DB
C       RFL      FRACTION OF SNR IN FLUCTUATING SNR
C       PROB     PROBABILITY OF GENERATING EACH TARGET TYPE
C                 IN ONE 100NS TIME PERIOD
C       BRAKP    BREAKPOINT FOR NONLINEAR REPEATER
C       IPTS     NUMBER OF 100NS TIME PERIODS TO BE SIMULATED
C                 IF IPTS=0 THE PROGRAM STOPS
C       IW5      NUMBER OF LOG FILE
C       IDENT    AN INTEGER WHICH IS PUT IN THE PLOT FILE LABEL
C                 USED TO INDICATE SIGNAL SET
C       DWL      DOPPLER STANDARD DEVIATION IN WAVEFORM SIN(F)/F UNITS
C       TSAMP    SAMPLE PERIOD IN WAVEFORM CHIP UNITS (100NS=1.)
C   SIMCM.DAT CONTAINS THE PARAMETER INPUT DATA
C   SIGNAL SEQUENCE FILE NAME IS AN INPUT PARAMETER
C   PLOT FILE NAME IS AN INPUT PARAMETER
C
C OUTPUT DATA:
C   PRIMARY OUTPUT IS THE PLOT DATA WRITTEN ON FILE(S) 21
C   LOG DATA FOR THE PROGRAM IS WRITTEN ON FILE IW5 WHICH IS TTY,
C       IF IW5 IS ASSIGNED TO SOME OTHER DEVICE THERE IS NO TTY OUTPUT
C
C SIGNAL SET:
C   ALL ARRAY DIMENSIONS ARE SET FOR A SET OF 16 SEQUENCES, EACH OF
C       LENGTH 255.  TO CHANGE THE NUMBER OF DIFFERENT SIGNALS CHANGE
C       THE NUMBER 16 IN ALL OF THE ARRAY DECLARATIONS TO THE NEW
C       NUMBER AND CHANGE 'DO 140 ITYPE=1,XX'.  CHANGING THE SIGNAL
C       LENGTH REQUIRES AS A MINIMUM CHANGING ALL OF THE 255'S IN THE
C       PROGRAM TO THE NEW SIZE, CHANGING THE 260'S TO THE NEW SIZE
C       PLUS 4 OR 5.  IF THE NEW SIZE IS MUCH LARGER THAN 255 THEN
C       A NEW FORM OF THE MATCHED FILTER, USING AN FFT FOR THE
C       CONVOLUTION, SHOULD BE CONSIDERED.  CLSZ SHOULD BE INCREASED
C       LINEARLY WITH SIGNAL LENGTH.
C
C
        LOGICAL        SIGNL(255,16),CSIGNL(255),ATPEAK,PASS1,DPSW
        INTEGER        MASK(16),ITGT(260),HLF(400),HLD(400),HHF(400)
        1             ,HHD(400),H(400,4)
        REAL           CSR(260),CSI(260),CLR(260),CLI(260),CHI(260)
        1             ,CHR(260),FH(400,4)
        EQUIVALENCE (HLF(1),H(1,1)),(HLD(1),H(1,2)),(HHF(1),H(1,3))
        1             ,(HHD(1),H(1,4)),(H(1,1),FH(1,1))
        2             ,(SIGNL(1,1),CSIGNL(1))
        NAMELIST      /PARMS/SNRDB,RFL,IPTS,BRAKP,PROB,IW5,IDENT,DWL,TSAMP
        DATA           PI2,AL10/6.28185307179885864,2.30258509299404568/
        1             ,ICDIM,ICORR/260,1/
        2             ,IPTS,SNRDB,RFL,NSDIM,NSIG/100000,16.,.00001,255,16/
        3             ,BRAKP,PROB,CLSZ/.01,.000625,1.5/
        4             ,DWL,TSAMP,IDENT,IW5/0.0,1.0,0,5/
        5             ,MASK/1,2,4,8,16,32,64,128,256,512,1024,2048,4096
        6             ,8192,16384,32768/
        7             ,I0,I9,F0,IX/0,9,0.0,0/
        8             ,IPGMID/4/
        CALL IFILE(22,'SIMCM')
C
C INITIALIZE FOR SIMULATION RUN
```

```
C
10        READ(22,PARMS)
          WRITE(IW5,12)SNRDB,RFL,IPTS,BRAKP,PROB,IDENT,DWL,TSAMP
12        FORMAT('  $PARMS SNRDB=',F5.1,' RFL=',F4.1,' IPTS=',I9
          1 ,' BRAKP=',F6.1,' PROB=',F8.5,' IDENT=',I5,' DWL=',F6.3
          2 ,' TSAMP=',F6.3,'$')
          IF(IPTS.EQ.0)GO TO 17
C GET NAMES OF SIGNAL FILE AND PLOT OUTPUT FILE
          READ(22,14)FN1,T,U
14        FORMAT(1A5,1A1,1A3)
          IF(FN1.EQ.'SAME')GO TO 21
          IF(T.EQ.'.'.AND.U.EQ.'DAT')GO TO 16
18        WRITE(IW5,15)FN1,T,U,FN2,V,W
15        FORMAT(' ** BAD FILE NAME ',(A5,A1,A5))
17        STOP
16        CALL IFILE(20,FN1)
          READ(20)SIGNL
          END FILE 20
21        READ(22,14)FN2,V,W
          IF(V.NE.'.'.OR.W.NE.'DAT')GO TO 18
          CALL OFILE(21,FN2)
          WRITE(IW5,19)FN1,T,U,FN2,V,W
19        FORMAT(' SIGNAL=',A5,A1,A3,2X,' PLOT=',A5,A1,A3)
C    SNR PARAMETERS ARE NOW INPUT EXPLICITLY
          SNR=10.**(.1*SNRDB)
          ER=RFL*SNR
          ES=(1.-RFL)*SNR
C VR & VS ARE GAIN PARAMETERS FOR TARGET GENERATOR
          VR=SQRT(ER/FLOAT(NSDIM*2))
          VS=SQRT(ES/FLOAT(NSDIM))
C ER & ES ARE SNR IN DB USED ONLY FOR OUTPUT
          ER=20.*ALOG10(SQRT(FLOAT(NSDIM*2))*VR)
          ES=20.*ALOG10(SQRT(FLOAT(NSDIM))*VS)
C SET DOPPLER SHIFT PARAMETERS
          DPSI=DWL.EQ.0.0
          DPLSCL=DWL*PI2/FLOAT(NSDIM*2)
          IGRPS=2+IPTS/ICDIM
C CLEAR HISTOGRAMS
          DO 3 I=1,4
            DO 2 J=1,400
2               H(J,I)=0
3           CONTINUE
          ATPEAK=.FALSE.
C RESET THE RANDOM NUMBER GENERATOR
          CALL SETRAN(0)
C CLEAR THE STATE VARIABLE VECTOR BEFORE SIMULATION STARTS
          DO 7 I=1,ICDIM
            T=-6.0
            U=-6.0
            V=-6.0
            W=-6.0
            DO 4 I2=1,12
              T=T+RAN(IX)
              U=U+RAN(IX)
              V=V+RAN(IX)
              W=W+RAN(IX)
4             CONTINUE
            CSR(I)=U
            CSI(I)=T
            CLR(I)=V
            CLI(I)=W
```

```
              T=SQRT(CLR(I)*CLR(I)+CLI(I)*CLI(I))
              IF(T.LT.BRAKP)T=BRAKP
              T=1./T
              CHR(I)=T*CLR(I)
              CHI(I)=T*CLI(I)
  7           ITGT(I)=0
  C WRITE DATA HEADER FOR PLOT PGM
            T=ALOG10(FLOAT(IPTS))
            WRITE(21,517)I0,ER,ES,PROB,BRAKP,T,DWL,TSAMP,IDENT,IPGMID
  C
  C ACTUAL SIMULATION LOOP
  C
  C TWO PASS SIMULATION, PASS1 FOR PFA, PASS2 TO INCREASE
  C      ACCURACY OF PD IF REQUIRED
            DO 420 IPASS=1,2
            PASS1=IPASS.EQ.1
            IF(.NOT.PASS1)WRITE(IW5,102)
  102       FORMAT(' PASS 2')
  C EACH PASS THROUGH NEXT LOOP IS 260 SIMULATION TIME CELLS
            DO 410 IGRP=1,IGRPS
            IF(MOD(IGRP,20).EQ.1)WRITE(IW5,103)IGRP
  103       FORMAT(' IG=',I6)
            DO 400 ITIME=1,ICDIM
  C  TARGET GENERATION LOOP
              DO 140 ITYPE=1,16
               IF(PASS1)GO TO 112
               IF(ITIME.NE.1)GO TO 112
               ATPEAK=.FALSE.
               IF(ITYPE.EQ.1)GO TO 114
  112          IF(RAN(IX).GT.PROB)GO TO 140
  C GENERATE TARGET PHASE,AMPLITUDE, AND TIME OFFSET
  114          U=-6.0
               V=U
               DSR=V
               DO 117 I1=1,12
                 U=U+RAN(IX)
                 V=V+RAN(IX)
                 IF(.NOT.DPSW)DSR=DSR+RAN(IX)
  117            CONTINUE
               W=PI2*RAN(IX)
               CGR0=VR*U+VS*COS(W)
               CGI0=VR*V+VS*SIN(W)
               T=RAN(IX)
               IF(ITYPE.EQ.1)T=T*TSAMP
               U=1.-T
               CGR1=T*CGR0
               CGI1=T*CGI0
               CGR0=U*CGR0
               CGI0=U*CGI0
               IF(DPSW)GO TO 119
               U=T/U
               DSR=DSR*DPLSCL
               DSI=DSR*(1.-DSR*DSR*0.16666666667)
               DSR=SQRT(1.-DSI*DSI)
  119          IP=ITIME
  C INSERT TARGET WAVEFORM IN STATE VARIABLE VECTOR
               DO 130 J=1,255
                 IF(DPSW)GO TO 121
                 T=CGR0*DSR-CGI0*DSI
                 CGI0=CGR0*DSI+CGI0*DSR
                 CGR0=T
```

```
          CGR1=U*CGR0
          CGI1=U*CGI0
121       IF(SIGNL(J,ITYPE))GO TO 123
          CSR(IP)=CSR(IP)-CGR0
          CSI(IP)=CSI(IP)-CGI0
          IP=IP+1
          IF(IP.GT.ICDIM)IP=1
          CSR(IP)=CSR(IP)-CGR1
          CSI(IP)=CSI(IP)-CGI1
          GO TO 130
123       CSR(IP)=CSR(IP)+CGR0
          CSI(IP)=CSR(IP)+CGI0
          IP=IP+1
          IF(IP.GT.ICDIM)IP=1
          CSR(IP)=CSR(IP)+CGR1
          CSI(IP)=CSI(IP)+CGI1
130       CONTINUE
C MARK TARGET PRESENT SO CORRECT HISTOGRAM CAN BE SELECTED LATER
        IP=IP-1
        IF(IP.EQ.0)IP=ICDIM
        ITGT(IP)=ITGT(IP).OR.MASK(ITYPE)
140     CONTINUE
C
C END OF TARGET GENERATION
C GENERATE RECEIVED DATA
C
        U=CSR(ITIME)
        V=CSI(ITIME)
        CLR(ITIME)=U
        CLI(ITIME)=V
C CALCULATE LIMITING REPEATER OUTPUT
        T=SQRT(U*U+V*V)
        IF(T.LT.BRAKP)T=BRAKP
        CHR(ITIME)=U/T
        CHI(ITIME)=V/T
C CLEAR CHANNEL SIGNAL DATA AND ADD IN NOISE FOR NEXT PASS
        U=-6.0
        V=-6.0
        DO 153 I2=1,12
          U=U+RAN(IX)
          V=V+RAN(IX)
153       CONTINUE
        CSR(ITIME)=V
        CSI(ITIME)=U
C MATCHED FILTER
        IF(PASS1)GO TO 160
        IF(ITIME.LT.255)GO TO 240
        IF(ITIME.GT.256)GO TO 240
160     IP=ITIME
          SLR=0.
          SLI=0.
          SHR=0.
          SHI=0.
        DO 180 I=255,1,-1
          IF(CSIGNL(I))GO TO 173
            SLR=SLR+CLR(IP)
            SLI=SLI+CLI(IP)
            SHI=SHI+CHI(IP)
            SHR=SHR+CHR(IP)
          GO TO 178
173         SLR=SLR-CLR(IP)
```

```
                     SLI=SLI-CLI(IP)
                     SHR=SHR-CHR(IP)
                     SHI=SHI-CHI(IP)
178                IP=IP-1
                   IF(IP.EQ.0)IP=ICDIM
180                CONTINUE
C
C RECEIVER FILTER DONE
C START DETECTION PROCESS
C
C FIND HISTOGRAM CELL INDEX
                KL=SQRT(SLR*SLR+SLI*SLI)*CLSZ
                IF(KL.GT.400)KL=400
                IF(KL.LT.1)KL=1
                KH=SQRT(SHR*SHR+SHI*SHI)*CLSZ
                IF(KH.GT.400)KH=400
                IF(KH.LT.1)KH=1
                IF((ITGT(ITIME).AND.MASK(ICORR)).NE.0)GO TO 220
C NO NEW TARGETS IN THIS CELL
                IF(ATPEAK)GO TO 210
C NO TGT IN PROCESS,NO NEW TARGET
                HHF(KH)=HHF(KH)+1
                HLF(KL)=HLF(KL)+1
                GO TO 240
C NO NEW TARGET, TGT IN PROCESS
210             ATPEAK=.FALSE.
C TGT IN PROCESS, AND NEW TGT
215             IF(KL.GT.KLSV)KLSV=KL
                IF(KH.GT.KHSV)KHSV=KH
                HLD(KLSV)=HLD(KLSV)+1
                HHD(KHSV)=HHD(KHSV)+1
                GO TO 240
C NEW TGT FOUND
220             IF(ATPEAK)GO TO 215
C NEW TGT, NO TGT IN PROCESS
                KLSV=KL
                KHSV=KH
                ATPEAK=.TRUE.
                GO TO 240
C
240             ITGT(ITIME)=0
C
C END OF SIMULATION LOOP
C
400           CONTINUE
410           CONTINUE
420         CONTINUE
CD
CD PRINT HISTOGRAM CONTENTS
CD
D           DO 431 I2=0,396,4
D             WRITE(IW5,429)I2,((H(I2+I3,I4),I3=1,4),I4=1,4)
D429          FORMAT(I4,4(I5,3I3))
D431        CONTINUE
C
C CONVERT HISTOGRAMS TO DISTRIBUTIONS
C
            DO 510 I=1,4
              DO 505 J=2,400
505             H(J,I)=H(J-1,I)+H(J,I)
              T=H(400,I)
```

```
               IF(T.GT.0)T=1./T
               DO 510 J=1,400
509              FH(J,I)=FLOAT(H(400,I)-H(J,I))*T
510            CONTINUE
C
C GENERATE PLOT COORDINATE DATA
C
             DO 520 I=1,3,2
                 IPTCT=0
               DO 518 J=2,399
                 T=FH(J,I)
                 U=FH(J,I+1)
C CHECK IF DATA ON PLOT PAGE
                 IF(T.EQ.0.0)T=1.0E-35
                 T=ALOG10(T)+6.0
                 U=ERFINV(U)
                 IF(T.LT.-0.3)GO TO 518
                 IF(T.GT.5.3)GO TO 518
                 IF(U.LT.-4.3)GO TO 518
                 IF(U.GT.4.3)GO TO 518
                 IPTCT=IPTCT+1
                 WRITE(21,517)I,T,U
C THIS FORMAT IS USED FOR ALL PLOT DATA FILE RECORDS
C  THE FIRST FIELD DESCRIBES THE RECORD TYPE
517              FORMAT(' ',I2,7E12.3,2I5)
518              CONTINUE
             WRITE(IW5,519)IPTCT
519          FORMAT(' HIST SZ=',I4)
520            CONTINUE
C
C END OF ONE SIMULATION
C
C WRITE END OF LINE RECORD IN PLOT DATA FILE
             WRITE(21,517)I0,F0,F0
600          CONTINUE
610          CONTINUE
             WRITE(IW5,620)FN2
620          FORMAT(' END FILE, FN=',1A5)
C END OF FILE RECORD FOR PLOT DATA FILE
             WRITE(21,517)I9,F0,F0,F0,F0,F0,F0,F0,I0,IPGMID
             END FILE 21
             GO TO 10
             END
C
C INVERSE OF ERFC*  MODIFIED FORM OF SSP SUBR NDTRI
C
C
             FUNCTION ERFINV(PA)
             DATA A1,A2,A3/2.515517,0.802853,0.010328/
             1    ,A4,A5,A6/1.432788,0.189269,0.001308/
C
             P=PA
             IF(P.LE.0.)GO TO 2
             IF(P.GE.1.)GO TO 3
             IF(P.GT.0.5)P=1.-P
             T2=-2.*ALOG(P)
             T=SQRT(T2)
             X=T-(A1+A2*T+A3*T2)/(1.+A4*T+A5*T2+A6*T*T2)
             IF(PA.LT.0.5)X=-X
             ERFINV=X
1            RETURN

2            ERFINV=-999.
             GO TO 1
3            ERFINV=999.
             GO TO 1
             END
```

```
C  CHANNEL SIMULATOR REFFERENCE ROC GENERATOR
C VERSION 2 -- VARIABLE SAMPLING RATE
C
C MODES:
C        I=0 WRITE EOF LABEL AND STOP
C        I=1 NEW FILE
C        I=2 NO MULTIPLE ACCESS NOISE CONTINUOUS SAMPLING
C        I=4 GAUSSIAN MULTIPLE ACCESS NOISE, CONTINUOUS SAMPLING
C        I=5 GAUSSIAN MULTIPLE ACCESS NOISE, DISCRETE SAMPLING
C        I=6 CHERNOV UPPER BOUND *NOT YET IMPLEMENTED*
C        I=7 CHERNOV LOWER BOUND *NOT YET IMPLEMENTED*
C        ILLEGAL I VALUES ARE THE SAME AS 4
C
         REAL      AI(10),BXI(10)
         NAMELIST  /X/SNR,R,PR,I,TS
         DATA      SNR,R,PR,I/16.,0.0001,.000625,4/
         1        ,I0,I9,F0/0,9,0./
         2        ,IDENT,TS,IPGMID/0,1.0,103/
C
         GO TO 60
58       WRITE(21,5)I9,F0,F0,F0,F0,F0,F0,F0,IDENT,IPGMID
         END FILE 21
         IF(I.EQ.0)STOP
60       WRITE(5,61)
61       FORMAT(' FILE-'/)
         READ(5,62)FNAME
62       FORMAT(A5)
         CALL OFILE(21,FNAME)
20       WRITE(5,21)SNR,R,PR,I,TS
21       FORMAT(' SNR=',F5.1,' R=',F5.2,' PR=',F8.5,' I=',I2,
         1  ' TS=',F5.3,' $X'/)
         READ(5,X)
         IF(I.LE.1)GO TO 58
         ER=R*(10.**(.1*SNR))
         ES=(1.-R)*(10.**(.1*SNR))
         ERDB=10.*ALOG10(ER)
         ESDB=10.*ALOG10(ES)
         PR1=PR
         IF(I.EQ.2)PR1=0.
         TS1=0.
         IF(I.EQ.5)TS1=TS
         WRITE(21,5)I0,ERDB,ESDB,PR1,F0,F0,F0,TS1,IDENT,IPGMID
5        FORMAT(I3,7E12.3,2I5)
         ENZ=1.
         IF(I.NE.2)ENZ=1.+PR*16.*(.5*ER+.5*ES)
         BY=1./SQRT(ENZ)
         AL102E=-2.0*ALOG(10.)*ENZ
         BX=1./SQRT(.5*ER+ENZ)
         A=SQRT(ES)*BX
         IF(I.NE.5)GO TO 27
         W=SQRT(ES)
         DV=.05*TS
         V=1.-11.*DV
         DO 25 JA=1,10
         V=V+DV
         BXI(JA)=1./SQRT(ENZ+.5*ER*V*V)
         AI(JA)=W*BXI(JA)*V
25       CONTINUE
27       DO 30 K=1,251
         T=-6.0+FLOAT(K-1)*.02
         B=SQRT(AL102E*T)
```

```
          PF=GQF(0.,B*BY,1,1.E-8)
          PD=GQF(A,B*BX,1,1.E-8)
          IF(I.NE.5)GO TO 29
          DO 28 JA=2,10
 28       PD=PD+2.*GQF(AI(JA),B*BXI(JA),1,1.E-8)
          PD=(PD+GQF(AI(1),B*BXI(1),1,1.E-8))*.05
 29       CONTINUE
          PF=ALOG10(PF)+6.0
          PD=ERFINV(PD)
          IF(PD.GT.4.05)GO TO 31
          IF(PD.LT.-4.3)GO TO 30
          WRITE(21,5)I,PF,PD
 30       CONTINUE
 31       WRITE(21,5)I0,F0,F0
          GO TO 20
          END
 C
 C INVERSE OF ERFC*  MODIFIED FORM OF SSP SUBR NDTRI
 C
 C
          FUNCTION ERFINV(PA)
          DATA A1,A2,A3/2.515517,0.802853,0.010328/
          1    ,A4,A5,A6/1.432788,0.189269,0.001308/
 C
          P=PA
          IF(P.LE.0.)GO TO 2
          IF(P.GE.1.)GO TO 3
          IF(P.GT.0.5)P=1.-P
          T2=-2.*ALOG(P)
          T=SQRT(T2)
          X=T-(A1+A2*T+A3*T2)/(1.+A4*T+A5*T2+A6*T*T2)
          IF(PA.LT.0.5)X=-X
          ERFINV=X
 1        RETURN
 2        ERFINV=-999.
          GO TO 1
 3        ERFINV=999.
          GO TO 1
          END

 C  GENERALIZED Q FUNCTION
 C
          FUNCTION GQF(A,B,N,ACC)
 C
          AA=A*A*0.5
          BB=B*B*0.5
          IF(AA+BB.GT.170.)GO TO 8
          DEXPA=EXP(-0.5*AA)
          DGAMA=EXP(-0.5*BB)
          SCALE=DEXPA*DGAMA
          FK=N-1
          FKM=0.0
          GAMA=DGAMA
          TQF=0.0
          GO TO 2
 1        FKM=FKM+1.0
          DGAMA=DGAMA*BB/FKM
          GAMA=GAMA+DGAMA
 2        IF(FKM.LT.FK)GO TO 1
          FK=0.0
```

```
      GO TO 4
 3    FK=FK+1.0
      IF(FK.GT.2000.0)GO TO 8
      FKM=FKM+1.0
      DGAMA=DGAMA*BB/FKM
      GAMA=GAMA+DGAMA
      DEXPA=DEXPA*AA/FK
 4    DQF=DEXPA*GAMA
      TQF=TQF+DQF
      IF(DQF.GT.ACC*TQF)GO TO 3
      TQF=TQF*SCALE
      IF(TQF.GT.1.0-10.0*ACC)GO TO 8
      IF(TQF.LT.0.0)TQF=0.0
      GQF=TQF
 5    RETURN
 8    D=ABS(A-B)
      IF(D.LT.3.0)GO TO 11
      TQF=-.9189385332+(FLOAT(N)-.5)*(ALOG(B)-ALOG(A))-.5*D*D-ALOG(D)
      IF(-87.0.GT.TQF)GO TO 10
      TQF=EXP(TQF)
 9    IF(B.LT.A)TQF=1.0-TQF
      GQF=TQF
      GO TO 5
 10   TQF=0.0
      GO TO 9
 11   T=ABS(D)
      T=1.0/(1.0+0.2316419*T)
      Z=0.3989423*EXP(-D*D*0.5)
      TQF=1.-Z*T*((((1.330274*T-1.821256)*T+1.781478)*T-.3565638)*T+
     1   0.3193815)
      IF(D.GT.0.0)TQF=1.0-TQF
      GO TO 9
      END
```

```
C MULTIPLE ACCESS NOISE SIMULATION -- PLOT PROGRAM
C VERSION 3
C
C I0: COMMAND LINE TYPE
C   0-PLOT FROM NEW FILE
C   1-PLOT OPTIONS
C   2-PLOT LINE TYPE MASK
C   3-CAPTION LINE
C I1: 0-STOP
C   1-PLOT ON CURRENT AXES
C   2-PLOT ON A NEW SET OF AXES
C   9-NEW AXES, OLD PLOT PARAMETERS
C I2: 0-NO LINE CAPTION
C   N-STARTING POSITION OF LINE CAPTION
C I4: 0-NO AXIS LABELS
C   1-AXIS LABELS
C I5: 0-NO HEADING CAPTION
C   N-HEADING CAPTION POSITION
C I6: N-SPACE BETWEEN HEADING AND PARAMETER LABELS
C I7: LINE TYPE HEADING
C   0-NONE
C   1-SHORT
C   2-LONG
C I8: DOTTED LINE PATTERNS FOR PLOTTED DATA
C   0-NO DOTS
C   1-INDICATE LINE TYPE
C   2-INDICATE LINE INDEX
C I9: PARAMETER LABELS
C   0-NONE
C   1-SHORT
C   2-LONG
C
        INTEGER M(10)
        COMMON /DACOM/MASK(10),ER,ES,PR,BP,FP,DW,TS,ID,IP,DE
        1 /PLCOM/S,D,B,XS,YS,ZS,IPAGE
        DATA I4,I5,I6,I7,I8,I9/0,0,0,0,2,1/
        1   ,M/1,0,0,1,1,1,1,0,0,0/
        DO 1 I00=1,10
1       MASK(I00)=M(I00)
        S=2.
        D=.03
        B=.5
        ZS=S*.08
        IPAGE=0
        CALL IFILE(20,'PPLCM')
C COMMANDS READ FROM 'PPLCM.DAT'
C
10      READ(20,15)I0,I1,I2,NAME,IT
15      FORMAT(3I1,A5,A4)
        IF(I0.EQ.0)GO TO 20
C COMMAND LINE IN UNEXPECTED PLACE
16      WRITE(5,17)I0
17      FORMAT(' ** COMMAND SYNC ',I1)
        GO TO 24
20      IF(I1.EQ.0)GO TO 24
        IF(IT.EQ.'.DAT')GO TO 25
        WRITE(5,21)I0,I1,I2,NAME,IT
21      FORMAT(' ** FILE NAME ',3I1,2A5)
24      CALL PLOT(12.*S,0.,999)
        STOP
C APPARENTLY GOOD TYPE 0 COMMAND LINE
```

```
 25       IF(I1.EQ.1)GO TO 50
          IF(I1.EQ.9)GO TO 34
          READ(20,32)I0,I4,I5,I6,I7,I8,I9
 32       FORMAT(72I1)
          IF(I0.NE.1)GO TO 16
          READ(20,32)I0,MASK
          IF(I0.NE.2)GO TO 16
 34       CALL PROBAX(I4)
          YS=-4.7*S
          IF(I4.EQ.0)YS=YS+.4*S
          IF(I5.NE.0)CALL COPY(I5)
          IF(I7.NE.0)CALL LINETP(I7)
          YS=YS-FLOAT(2*I6)*S
          INDEX=0
C PLOT ALL LINES IN NEXT FILE
 50       CALL IFILE(21,NAME)
          IF(I2.NE.0)CALL COPY(I2)
          CALL LINPLT(I8,I9,INDEX)
          END FILE 21
          WRITE(5,52)NAME
 52       FORMAT(' END ',A5,'.DAT')
          GO TO 10
          END

C PLOT DATA IN ONE SOURCE FILE
C
          SUBROUTINE LINPLT(I8,I9,INDEX)
          COMMON /DACOM/MASK(10),ER,ES,PR,BP,FP,DW,TS,ID,IP,DE
          1 /PLCOM/S,D,B,XS,YS,ZS,IPAGE
C
10        READ(21,12)I0,ER,ES,PR,BP,FP,DW,TS,ID,IP
12        FORMAT(I3,7E12.3,2I5)
          IF(I0.EQ.0)GO TO 15
          IF(I0.EQ.9)RETURN
13        WRITE(5,12)I0,ER,ES,PR,BP,FP,DW,TS,ID,IP
          WRITE(5,14)
14        FORMAT(' ** LINE SYNC LINPLT, RETURN')
          RETURN
15        READ(21,12)J,PF,PD
          IF(J.EQ.0)GO TO 10
          IF(J.GT.10)J=10
          IF(J.LT.1)J=10
          IF(J.NE.I0)GO TO 19
C THIS IS ANOTHER POINT ON THE CURRENT LINE
          IF(I8-1)16,17,18
16        CALL PLOT(PF*S,PD*S,2)
          GO TO 15
17        CALL DOTLIN(PF,PD,I0,2)
          GO TO 15
18        CALL DOTLIN(PF,PD,INDEX,2)
          GO TO 15
C THIS IS ANOTHER PLOT LINE -- SET HEADING
19        IF(MASK(J).EQ.0)GO TO 15
          I0=J
          INDEX=INDEX+1
          IF(I9.EQ.0)GO TO 20
          XS=-ZS
          YS=YS-1.7*ZS
          CALL NUMBER(-4.*ZS,YS,ZS,FLOAT(INDEX),0.,0)
          DE=PR*16.*255.
          IF(I9.EQ.1)CALL PARMS1(I8,J)
```

```
      IF(I9.EQ.2)CALL PARMS2(I8,J)
20    IF(PF.GT.2.5)TX=PF*S+.2*ZS
      IF(PF.LE.2.5)TX=PF*S-1.2*ZS
      CALL NUMBER(TX,PD*S-.5*ZS,ZS,FLOAT(INDEX),0.,-1)
      IF(I8-1)23,24,25
23    CALL PLOT(PF*S,PD*S,3)
      GO TO 15
24    CALL DOTLIN(PF,PD,I0,3)
      GO TO 15
25    CALL DOTLIN(PF,PD,INDEX,3)
      GO TO 15
      END

C INSERT CAPTION LINE
C
      SUBROUTINE COPY(J)
      INTEGER STR(16)
      COMMON /PLCOM/S,D,B,XS,YS,ZS,IPAGE
C
      READ(20,7)I,K,STR
7     FORMAT(I1,I2,16A5)
      IF(I.EQ.3)GO TO 15
      WRITE(5,7)I,K,STR
      WRITE(5,9)
9     FORMAT(' ** CMD SYNC COPY, STOP')
      STOP
15    YS=YS-1.7*ZS
      XS=-S+2.*ZS*FLOAT(J)
      CALL SYMBOL(XS,YS,ZS,STR,0.,K)
      XS=XS+FLOAT(K+1)*ZS
      RETURN
      END
C PROBABILITY AXIS PLOT
C
C
      SUBROUTINE PROBAX(LBL)
      REAL YP(11),N(11)
      DATA    YP/-3.719,-3.091,-2.327,-1.6452,-.84146,0.
      2       ,.841456,1.6452,2.327,3.091,3.719/
      3       ,N/5H.0001,5H .001,5H  .01,5H  .05,5H   .2,5H   .5
      4       .5H   .8,5H  .95,5H  .99,5H .999,5H.9999/
      COMMON /PLCOM/SCLE,D00D,D00B,D00XS,D00YS,D00ZS,IPAGE
      IF(IPAGE.GE.1)GO TO 100
      CALL PLOTS(IA)
      IF(IA.EQ.0)GO TO 305
      WRITE(IW5,301)IA
301   FORMAT(' CANT OPEN PLT IA=',I5)
      STOP
305   CONTINUE
      CALL PLOT(0.5*SCLE,-13.0*SCLE,-3)
      CALL PLOT(1.0*SCLE,8.5*SCLE,-3)
      IPAGE=1
      IDIR=0
      GO TO 110
C
100   IDIR=IDIR+1
      IPAGE=IPAGE+1
      IF(IDIR.GE.4)IDIR=0
      IF(IDIR.EQ.0)CALL PLOT(11.*SCLE,0.,-3)
      IF(IDIR.EQ.1)CALL PLOT(0.,13.5*SCLE,-3)
      IF(IDIR.EQ.2)CALL PLOT(11.*SCLE,0.,-3)
```

```
      IF(IDIR.EQ.3)CALL PLOT(0.,-13.5*SCLE,-3)
110   CALL PLOT(0.0*SCLE,-4.0*SCLE,3)
      DO 120 J=1,11
        CALL PLOT(0.0*SCLE,YP(J)*SCLE,2)
        CALL PLOT(-.1*SCLE,YP(J)*SCLE,2)
        CALL PLOT(0.0*SCLE,YP(J)*SCLE,3)
120     CONTINUE
      CALL PLOT(0.0*SCLE,4.0*SCLE,2)
      DO 130 J=1,4
        CALL PLOT(FLOAT(J)*SCLE,4.0*SCLE,2)
        CALL PLOT(FLOAT(J)*SCLE,4.1*SCLE,2)
        CALL PLOT(FLOAT(J)*SCLE,4.0*SCLE,3)
130     CONTINUE
      CALL PLOT(5.0*SCLE,4.0*SCLE,2)
      DO 140 J=11,1,-1
        CALL PLOT(5.0*SCLE,YP(J)*SCLE,2)
        CALL PLOT(5.1*SCLE,YP(J)*SCLE,2)
        CALL PLOT(5.0*SCLE,YP(J)*SCLE,3)
140     CONTINUE
      CALL PLOT(5.0*SCLE,-4.0*SCLE,2)
      DO 150 J=4,1,-1
        CALL PLOT(FLOAT(J)*SCLE,-4.0*SCLE,2)
        CALL PLOT(FLOAT(J)*SCLE,-4.1*SCLE,2)
        CALL PLOT(FLOAT(J)*SCLE,-4.0*SCLE,3)
150     CONTINUE
      CALL PLOT(0.0*SCLE,-4.0*SCLE,2)
      IF(LBL.LT.2)GO TO 171
      CALL SYMBOL(-0,7*SCLE,-2.5*SCLE,.21*SCLE
      1    ,'PROBABILITY OF DETECTION',90.,24)
      DO 160 J=11,1,-1
      CALL SYMBOL(-.8*SCLE,(YP(J)-.07)*SCLE,.14*SCLE,N(J),0.0,5)
160   CONTINUE
      CALL SYMBOL(-0.21*SCLE,-4.63*SCLE,.21*SCLE,
      1       'PROBABILITY OF FALSE ALARM',0.,26)
      DO 170 J=1,6
        K=-J
        X=FLOAT(6-J)-.21
        CALL SYMBOL(X*SCLE,-4.3*SCLE,.14*SCLE,'10',0.,2)
        CALL NUMBER((X+.28)*SCLE,-4.2*SCLE,.07*SCLE,FLOAT(K),0.,-1)
170     CONTINUE
171   RETURN
      END
C PLOT A DOTTED LINE
C
C
      SUBROUTINE DOTLIN(XR,YR,IPATRN,IPEN)
      COMMON /PLCOM/SCLE,DOT,SIZE,D00X,D00Y,D00Z,I00P
C
      IF(IPEN.NE.3)GO TO 100
C PEN UP MOVE
C RESET PATTERN ALSO
      I00=(2.*DOT*FLOAT(IPATRN)+.001)/SIZE
      TSIZE=SIZE*FLOAT(I00+1)
      X=XR
      Y=YR
      CALL PLOT(X*SCLE,Y*SCLE,3)
C RESET PATTERN BLOCK
90    DISTOT=TSIZE-.00001
      DISLFT=TSIZE-FLOAT(IPATRN*2)*DOT
      ISTS=2
      DISTOT=DISTOT-DISLFT
```

```
C CONTINUE PLOTTING CURRENT LINE
100       XDIS=XR-X
          YDIS=YR-Y
          DISMOV=SQRT(XDIS*XDIS+YDIS*YDIS)
          IF(DISMOV.GT.DISLFT)GO TO 105
          DISLFT=DISLFT-DISMOV
          CALL PLOT(XR*SCLE,YR*SCLE,ISTS)
          X=XR
          Y=YR
          RETURN
C CURRENT STROKE DOES NOT REACH THE NEXT POINT
105       X=X+XDIS*DISLFT/DISMOV
          Y=Y+YDIS*DISLFT/DISMOV
          CALL PLOT(X*SCLE,Y*SCLE,ISTS)
          DISTOT=DISTOT-DOT
          IF(DISTOT.LT.0.)GO TO 90
          IF(ISTS.LE.2)ISTS=4
          ISTS=ISTS-1
          DISLFT=DOT
          GO TO 100
          END
C PARAMETER LABELS -- SHORT FORM
C
          SUBROUTINE PARMS1(I8,LTP)
          COMMON /DACOM/D0MASK(10),ER,ES,PR,BP,FP,DW,TS,ID,IP,DE
          1 /PLCOM/S,D,B,XS,YS,ZS,IPAGE
          IF(ES.LT.-19.)GO TO 10
          CALL SYM('ES=',-3)
          CALL NUM(ES,1)
10        IF(ER.LT.-19.)GO TO 20
          IF(ES.GT.-19.)CALL SYM(',',-1)
          CALL SYM('ER=',-3)
          CALL NUM(ER,1)
20        CALL SYM('NP=',3)
          CALL NUM(DE,2)
          IF(BP.LT.0.1)GO TO 30
          CALL SYM('BP=',3)
          CALL NUM(BP,2)
30        IF(FP.LT.1.5)GO TO 40
          CALL SYM('PTS=10',6)
          CALL NUMBER(XS,YS+.4*ZS,.8*ZS,FP,0.,-1)
          XS=XS+ZS
40        IF(IP.LT.3)GO TO 70
          IF(TS.LT.0.001)GO TO 50
          IF((LTP.EQ.2).OR.(LTP.EQ.4).OR.(LTP.GE.6))GO TO 50
          CALL SYM('TS=',3)
          CALL NUM(TS,3)
50        IF(DW.EQ.0.)GO TO 55
          CALL SYM('DW=',3)
          CALL NUM(DW,3)
55        IF(ID.LE.0)GO TO 60
          CALL SYM('ID:',3)
          CALL NUM(FLOAT(ID),-1)
60        IF(IP.LE.0)GO TO 70
          CALL SYM('IP:',3)
          CALL NUM(FLOAT(IP),-1)
70        IF(I8.EQ.1)GO TO 80
          CALL SYM('TY:',3)
          CALL NUM(FLOAT(LTP),-1)
80        RETURN
          END
```

```
C PARAMETER LABELS -- LONG FORM
C
        SUBROUTINE PARMS2(I8,LTP)
        COMMON /DACOM/MASK(10),ER,ES,PR,BP,FP,DW,TS,ID,IP,DE
      1 /PLCOM/S,D,B,XS,YS,ZS,IPAGE
        CALL SYM('SNR=',-4)
        IF(ES.LT.-19.)GO TO 10
        IF(ER.GT.-19.)CALL SYM('(',-1)
        CALL NUM(ES,1)
        CALL SYM('DB NON-FLUCTUATING',-18)
        IF(ER.GT.-19.)CALL SYM(',',-1)
10      IF(ER.LT.-19.)GO TO 15
        CALL NUM(ER,1)
        CALL SYM('DB FLUCTUATING',-14)
        IF(ES.GT.-19.)CALL SYM(')',-1)
15      CALL SYM('NP=',3)
        CALL NUM(DE,2)
        IF(BP.LT.0.1)GO TO 20
        CALL SYM('BREAKPOINT=',11)
        CALL NUM(BP,2)
20      IF(IP.LT.3)GO TO 30
        IF(DW.EQ.0.)GO TO 25
        CALL SYM('DOPPLER BW=',11)
        CALL NUM(DW,3)
25      IF(TS.LT.0.001)GO TO 30
        IF((LTP.EQ.2).OR.(LTP.EQ.4).OR.(LTP.GE.6))GO TO 30
        CALL SYM('SAMPLE PERIOD=',14)
        CALL NUM(TS,3)
30      IF(FP.LT.1.5)GO TO 32
        CALL SYM('SIM SIZE=10',11)
        CALL NUMBER(XS,YS+.4*ZS,.8*ZS,FP,0.,-1)
        XS=XS+.9*ZS
        CALL SYM('POINTS',-6)
32      IF(ID.EQ.0)GO TO 35
        CALL SYM('WAVEFORM:',9)
        CALL NUM(FLOAT(ID),-1)
35      IF(IP.EQ.0)GO TO 40
        CALL SYM('SOURCE:',7)
        CALL NUM(FLOAT(IP),-1)
40      IF(I8.EQ.1)GO TO 130
        IF((LTP.NE.1).AND.(LTP.NE.3))GO TO 110
        CALL SYM('SIMULATION: ',12)
        IF(LTP.EQ.3)CALL SYM('NON-',-4)
        CALL SYM('LINEAR ',-7)
        CALL SYM('REPEATER ',-9)
        GO TO 130
110     IF(LTP.GE.6)GO TO 120
        CALL SYM('REFERENCE: ',11)
        IF(LTP.EQ.2)CALL SYM('NO ',-3)
        IF(LTP.EQ.5)CALL SYM('SAMPLED, ',-9)
        IF(LTP.GE.4)CALL SYM('GAUSSIAN ',-9)
        CALL SYM('MULTIPLE ',-9)
        CALL SYM('ACCESS ',-7)
        CALL SYM('NOISE ',-6)
        GO TO 130
120     CALL SYM('CHERNOV ',8)
        IF(LTP.EQ.5)CALL SYM('LOWER ',-6)
        IF(LTP.EQ.6)CALL SYM('UPPER ',-6)
        CALL SYM('BOUND ',-6)
130     RETURN
        END
```

```
C PRINT SYMBOL IN LINE, KEEP TRACK OF POSITION
C
      SUBROUTINE SYM(STRING,K)
      INTEGER STRING(2)
      COMMON /PLCOM/S,D,B,XS,YS,ZS,IPAGE
      N=IABS(K)
      IF(K.LT.0)GO TO 10
      CALL SYMBOL(XS,YS,ZS,',',0.,1)
      XS=XS+ZS
 10   T=FLOAT(N)*ZS+XS
      IF(T.LT.4.8*S)GO TO 20
      XS=.2*S
      T=XS+FLOAT(N)*ZS
      YS=YS-1.7*ZS
 20   CALL SYMBOL(XS,YS,ZS,STRING,0.,N)
      XS=T
      RETURN
      END
C PRINT A NUMBER AND KEEP TRACK OF LINE POSITION
C
      SUBROUTINE NUM(F,N)
      COMMON /PLCOM/S,D,B,XS,YS,ZS,IPAGE
      U=ABS(F)
      V=ZS
      DO 10 I=1,20
        U=.1*U
        IF(U.LT.1.)GO TO 15
 10     V=V+ZS
 15   V=V+FLOAT(N+1)*ZS
      IF(XS+V.LT.5.6*S)GO TO 20
      XS=0.2*S
      YS=YS-1.7*ZS
 20   CALL NUMBER(XS,YS,ZS,F,0.,N)
      XS=XS+V
      RETURN
      END
C LINE TYPE LABELS
C
      SUBROUTINE LINETP(LVL)
      COMMON /PLCOM/S,D,B,XS,YS,ZS,IPAGE
     1 /DACOM/IMSK(10),ER,ES,PR,BP,FP,DW,TS,ID,IP,DE
      DO 20 I=1,7
      IF(IMSK(I).EQ.0)GO TO 20
      YS=YS-1.7*ZS
      CALL DOTLIN(-0.8,(YS+.5*ZS)/S,I,3)
      CALL DOTLIN(-0.2,(YS+.5*ZS)/S,I,2)
      XS=-.15*S
      IF(LVL.LT.2)GO TO 5
      IF((I.EQ.1).OR.(I.EQ.3))CALL SYM('SIMULATION DATA, ',-17)
      IF((I.EQ.2).OR.(I.EQ.4).OR.(I.EQ.5))
     1 CALL SYM('REFERENCE DATA, ',-16)
      IF((I.EQ.6).OR.(I.EQ.7))CALL SYM('CHERNOV ',-8)
 5    IF(I.EQ.1)CALL SYM('LINEAR',-6)
      IF(I.EQ.2)CALL SYM('NO',-2)
      IF(I.EQ.3)CALL SYM('NON-LINEAR',-10)
      IF(I.EQ.4)CALL SYM('GAUSSIAN',-8)
      IF(I.EQ.5)CALL SYM('SAMPLED, GAUSSIAN',-17)
      IF(I.EQ.6)CALL SYM('UPPER',-5)
      IF(I.EQ.7)CALL SYM('LOWER',-5)
      IF(LVL.LT.2)GO TO 20
      IF((I.EQ.1).OR.(I.EQ.3))CALL SYM(' REPEATER',-9)
```

```
          IF((I.EQ.2).OR.(I.EQ.4).OR.(I.EQ.5))
          1   CALL SYM(' MULTIPLE ACCESS NOISE',-22)
          IF((I.EQ.6).OR.(I.EQ.7))CALL SYM(' ROUND',-6)
   20     CONTINUE
          RETURN
          END
```

```
C MAXIMAL LENGTH SHIFT REGISTER SEQUENCE GENERATOR
C  FOR MULTIPLE ACCESS NOISE SIMULATION PROGRAM
C
      LOGICAL  ISIGNL(255,16),ICON(8)
      INTEGER  MCON(16,2),ITEST(8),ICELL(8)
      DATA     MCON/285,299,301,333,351,355,357,361,369
      1            ,391,397,425,451,463,487,501,16*1/
C DEFINE PN SEQ FILE NAME
      CALL OFILE(20,'PNQ01')
C LOOP TO SET 16 PN SEQ COEFFICIENT SETS
      DO 8 M=1,16
        N=MCON(M,1)
        ISTART=MCON(M,2)
C SET SHIFT REGISTER TAPS
        DO 2 I=1,8
          ICELL(I)=MOD(ISTART,2)
          ISTART=ISTART/2
          ITEST(I)=ICELL(I)
          ICON(I)=MOD(N,2).EQ.1
2         N=N/2
C GENERATE ML SHIFT REG SEQUENCE
        DO 4 I=1,255
          ISUM=ICELL(1)
          DO 3 J=2,8
            IF(ICON(J))ISUM=ISUM+ICELL(J)
3           ICELL(J-1)=ICELL(J)
          ICELL(8)=MOD(ISUM,2)
4         ISIGNL(I,M)=ICELL(8).EQ.1
C TEST SEQUENCE PERIOD WHEN FINISHED
        DO 5 J=1,8
          IF(ICELL(J).NE.ITEST(J))GO TO 6
5         CONTINUE
        GO TO 8
6       TYPE 7,M
7       FORMAT('PN SEQ PERIOD ERROR',I3)
8       CONTINUE
C WRITE OUT DATA ON FILE PNQ01.DAT
      WRITE(20)ISIGNL
      STOP
      END
```

```
CONTENTS OF PN001.DAT

SEQ=  1 WEIGHT= 128
*...***...*..*.* **......**..*..*  ..**.***..*..... *.*.**.**.*.**..
*.**....*****.** .****.*.***.*...  *....**.**...*** *..***..**...*.*
*.*..*...*.*..*. *.*..***.***.**.  .****.******.*.. **..**.*.*...**.
....***.*.*.*.** ***..*.*....*..*  *******....*.*** *...**.*........

SEQ=  2 WEIGHT= 128
*..*.********... **.*.*.*.****.**  ..**..*.*..*...* ...**...****....
*....*.*.....*** **..******.*.*..  .*.*.*..**....** ..***.*****.***.
*..*.*.**.*..*** ..**.**...*.***.  **.****..*.**.** .*.***..*..*..**
.*...***...*..** **.*....***.*.**  .....*.**..*.... ..**.***........

SEQ=  3 WEIGHT= 128
*..*.*..******** ...**...*.*.*.*.  ...*....**..**.. ...*****.***.***
***.*.*..*.**.*. *.**..***..*..**  ..*...*.***...*. ..****..*.****..
..*.*...**.*.*** **..****.**..*.*  .***.*.**.***..* *.*..**.**.*...*
..***.**.**....* **.*..*..*.....*  .**...***......* *.****.*........

SEQ=  4 WEIGHT= 128
*.*.**...**..*** ......*****.*..*  .*.*..*.....*... .***.******.**..
..**...*..**.... .**.*...*.*..**.  *.*....*.***..** **.*.*****...***
..*.*...****.... *..*..*.****..*.  ..*...**.**.***. ..*.**..**..*.**
.**..*..***.*.*. *.***.**.*.**.*.  .********..**.** **.***.*........

SEQ=  5 WEIGHT= 128
*.*..*.*.*.*...* .***.***.*.***..  *..***.**....*.* *...******.**.*.
**..**.**.***... .***...**.*.*..*  ****...*....**.. *.*......****.**
******..***..**. .****..*.**.*..*  *.*...***.*..*.. ...**.****.*.*.*
*.**..*...*..*.. *.*****.*....*..  **...*.*.****... ..*...**........

SEQ=  6 WEIGHT= 128
*.***...***.**** ...*.**..**.**..  ..****..***....* .*.********..*.*
***.*..*.*....** .***.**.*****.*.  ***.*.....**..*. *.*.*...**.*.**.
..**.....*..*.** .**.*.*..**.*..*  *****.***..**..* ***.**..*....*..
....***..*..*..* *...*..***.*.*.*  *.*...*...*.*..* ...*****........

SEQ=  7 WEIGHT= 128
*.***.****.**..* *******..*.**.*.  **.***.*.*.*.*** ..*..**.**.*..**
..**.*...***.**. **...*...*..****  .*..*..*....**** ...*.*..***...**
***.*.****..***. *....*.*.**..*.*  ...*.**.....**.. *...**....**.***
***.***....*.... .*..*.*.*..*.***  **......***..**. ..**.*.*........

SEQ=  8 WEIGHT= 128
*.****.**......* **...**.*.....*.  .*..*.***....**. **.***..*...*.**
.**..*.**..***.* *.*.***.*.*..**.  ****..*****.*.** ...*.*....****.*
..****...*...*** .*...*..**..*..*  **..**.*.*.**.*. .*.*.******.***.
*****.....**..** ....*....*.*.*.*  ...**...******** ..*.*..*........

SEQ=  9 WEIGHT= 128
*.**...****.*... .********..*....  *.*..*****.*.*.* .***.....**...*.
*.**..**..*.**** **.****..**.***.  ***..*.*.*..*.*. ..*..*.**.*...**
..***..****...** .**....*...*.***  .*.****.**.***** ....**.*..**.*.*
*.**.*.*.....*.. ***.**..*..*..**  ......***.*..*.. .***...*........

SEQ= 10 WEIGHT= 128
******..*.*..*.* *.*.*****...*.**  ..*....*.*...*.. *..*.*.*.*..**..
*.***.*...***.** ..*****.**.*....  ..*.....*.****.* **.****....*..**
*.*.**...****..* *.**.********.*.  *.***..***..*..* *.*.*....**.***.
....**....***... **..**...*...**.  *..****.*..*...* .*.**.**........
```

```
SEQ= 11 WEIGHT= 128
*****...*..*.*.. .*...*.**.*.*.**  *..*...**..*..*. .***......*....*
..**.****..**..* **.******..*.**.  .*.*.**.**.*..*. ....**...**.*.**
...*.*.*.*..**.. ...*.***.*.*****  .**.***.**....*. *..*.****.*..***
*****.*.*....*** ..****....**.**.  .**.*...****.*** ...***.*.......

SEQ= 12 WEIGHT= 128
***.**......*..* *.*.....**.*.***  ....*.****..*... ***...*.**..*..*
..***.*.**.**.*. .****.**.***.*..  .**.**..***..*.* *.*.*..*.***.***
**.***..**....** ..*.*.*...*.*.**  ****..*****..... *.*....*....****
...**...*...*..* .*..**..**.****.  *.*.*.**...***** ***.*..*.......

SEQ= 13 WEIGHT= 128
**.**.*.*...*..* .****..*.**...*.  ..**..**...***.. ..**.....***.**.
...*.*.**..*..** *..***.*.*.*****  ***.**.**..****. ..**.*.***..*...
.****.***.****.* .....*......*.**  .*****..**.***.. .*.***.*..**..*.
*.*.*..*..*...*. *....*..**.*...*  ****.*.**.*..*.* ..******.......

SEQ= 14 WEIGHT= 128
**.***.*..*...** ****.....***.*.*  ..**.*.**....**. ..**.*....****..
.***..****.***.. *..**..**.**.***  *..*.*.***.***** ***.**.*..***...
.*.*.*......*.** ..***.**..*.....  *....*..*****.*. ****.*...*.*..*.
***...*...*..*.. *.*...**..*.**.*  .*.*.**.**...*.* ****..**.......

SEQ= 15 WEIGHT= 128
**..*****.*...** .**.*.*.*.**.*..  **...*.*..*..*.. .*...***.*..*.*.
..*.****.*.***** ..*....*.....*..  **.***..**.*.... ..*.*.*....***..
*.**.********.** *.*.*..****.**.*  *..**..*..***.** **..***...****..
..*.**...**....* *.*.**..*.*.***.  ....******...*.. *.***.**.......

SEQ= 16 WEIGHT= 128
**...*.....****. *.*...**..*....*  .*****.*..*..*.. .*..**.**.*.*.**
**.**.....*..*.* **...*.**..*.**.  *..****..**..*** ..********.****.
.....*.*..**.... *...*****..*.*.*  *...***....***.* *.**..**.*.**.**
****...**.*....* *.***..*..***.*.  ***.***.*...*.*. *.*..*.*.......
```

```
C RANDOM SIGNALS FOR MULTIPLE ACCESS NOISE SIMULATOR
C  SUBSTITUTE FOR PN SEQUENCES
C
C OUTPUT IS ON FOR21.DAT, RENAME IT
        LOGICAL SEQ(4080)
        CALL SETRAN(0)
        P=.9999
10      S=.5*P
        DO 20 I=1,4080
12      T=RAN(0)
        IF(T.GT.P)GO TO 12
        SEQ(I)=T.GT.S
20      CONTINUE
        DO 40 I1=1,16
        IB=255*(I1-1)
31      J=0
        DO 32 K=1,255
        IF(SEQ(IB+K))J=J+1
32      CONTINUE
        IF(J.EQ.128)GO TO 40
        IR=IABS(J-128)
        DO 34 IA=1,IR
        K=1+IB+254.999*RAN(0)
        IF(J.LT.128)SEQ(K)=.TRUE.
        IF(J.GT.128)SEQ(K)=.FALSE.
34      CONTINUE
        GO TO 31
40      CONTINUE
        WRITE(21)SEQ
        STOP
        END
```

```
CONTENTS OF PN002.DAT

SEQ=  1 WEIGHT= 128
.**....**.*..**. *...*.....*...*.  *.....**..***.*. ....*..*..**.*..
.**..****.**..*. .**.**.**..*.*.*  *******.*.*.*.*. *.*.***....****.
..***.*..*..*..* *..*...*....*...  *..******..***** ***..*****..**..
*.**..*.*..*.**. *..***.***.**...  *...******..*.*. **..****.*....*

SEQ=  2 WEIGHT= 128
.*.*.*..***.**.* .*.*...**..*.*..  ..***..*..**..** ..*.*..*..**.*..
.**.**.*.***.*** .**..*........**  .**..*.*.*.*.*.* *.*..**.*...***.
..**.*.*.*.**... ...**..***.*....  **.*.*.**.**.**. .*.*****.*.*****
.*******..***... ****...*...*****  **..........*.** **.***..**.....

SEQ=  3 WEIGHT= 128
***.***.**.**.** ...****.**......  ...*..**..*..*.. **..*..******.**
*.**.*..*..*.**. .*....****...*..  ..*.**.*.**.***. ....****.*.**.*.
*...**.**.***... ****..*.***.*.*.  *..***.*..****.* ..*****.*...*..*
.**.........*..* .***.***.***...*  .......***.*.*.* *.***.*.*.....*

SEQ=  4 WEIGHT= 128
.**.*.*..*.**... .*.*.....*..*..*  **.*.*.*..*..*.. **.*.*...*.*****
..*.***..***.*** ..*...**.**.***.  **...***..*..*.* ....***..*.*.**.
***..***..*.**.. *..**..***.***.*  ....*...**...**. .**..**..*..**.*
...**..*...**..* **..****.*..**..  *****..*.***..*. *.*.**.*.***..*

SEQ=  5 WEIGHT= 128
..**.**..*..**.* ***.**.**.*...**  .*..**.*.**.*..* *..**.***.*.****
......****..**.. .*.**....*******  ....*.*...*.**.* .**..***...*.*.*
.*.*****.*..*.*. ..*.****.*..*..*  *****.****...*** ..*..*..*.*.*.*.
.*........*..**. *.****.*...*.*..  ...**.*.*.**...* **...**.**..*..

SEQ=  6 WEIGHT= 128
*****.*....**..* .*...**.*..**..*  *.**..**.*...*.. .*....**..**.*..
**.*.....*...**. *..*.*.*.*.****.  ****....****.*.. ...**.*....*..*.
.**.****.*.****. *..****.*..*...*  *.*...*.**.*.*.* .***.*.**..**...
*****..*.*.*..*. .***.*.**..*....  ****..******.... *.**..**..*.***

SEQ=  7 WEIGHT= 128
*****..*.*....** ****..**...**..*  .***.*.**.*..*** ..****....*....*
****.....*.*..*. .**.*.*..**..**.  *.....**.*....** ..**.***.***.*.*
*..***.*.*.**... .....*.**.**.*.*  .****.***....*.* ..*.*..**..**..*
..***.*.*...**** .*.*.****.**.*.*  ...*........*.*. *..**...*******

SEQ=  8 WEIGHT= 128
.**.*......****. .*..*****.*..*.*  ***.**....**.... ***....***.*..**
....*..*.*..*... ....*..*...*..*.  .**.*.**..*.*..* *.****...***..*.
*..*.****.***... ...*.***.*******  **.*.*..***..*** *.*.***.*.*..***
*..*.*.*..*.*..* .*.**.*..*.**.*.  .*****...***.... *.*.*.*.***.*..

SEQ=  9 WEIGHT= 128
..*..*.....***.. .****....*...*.*  **.*...**.*..*.. *****.*.**..*.**
...*.*****..*.** *****...**.*..*.  ....*****...*.** *.**.*..........
..*.*..**..*...* **...*.*.*..*..*  *......**.*.**.. *...*********.**
.***.****.*.**** *****.*...**.*..  ***.*..**...**.. .*****...*.*..*

SEQ= 10 WEIGHT= 128
*.**..*.****...* ..**.**.*.****..  .****...*******. **...*..*.....*.
.****.*..*....*. *.*.**.**....*.*  *...**.*.*****.* *.*..*..****..*.
...**.*.**.***.. ..****.**.....*.  ....****...**... *..**.*..***.*..
*.*...**..**..** ..*....*.**.**.*  .*...*...****.*. ***.**..**.***.
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SEQ= 11 WEIGHT= 128
.*.*.*.*..**.*.* **.***.*.*..*.*.  **..***.....**.* ***.*.**...*....
**...*.....*..*. .*.***.*.**..*.*  **.**.**...***** *....*..*.***...
...**..***.**... *..*.*...*.****.  *..***...*....** *.*.....*..****.
..*************. .****.**..****..  ***..**.*..*.*.. .*...*.*.*..*..

SEQ= 12 WEIGHT= 128
**....**.*...**. .*..***...*.*...  .******....*.*** *.*.**..*.*...**
..*..*....****.* .*.**.**..*.****  **...*.*.*..*..* .*.*.**....*.**.
** ******....... *...*.***.***.*.  *.**...***.***.* *..*.**...*....*
**.*..*...***... .**.*...*.****.*  *.*..*.****..*.. *****..***....*

SEQ= 13 WEIGHT= 128
*.**...*.*...*** *.*.**.*..*.*.*.  ***....****..**. *.*.*..***.*.*..
*...***....****. ..**..*...*.**..  ...*.*.*.****.*. ***..**..***...*
***.**.**.*.*... **...*...****.**  ..***..*..*.***. *..*.......**.*.
*...*...*.**.*.* ***.....*...*.**  *****..***.*.*** .*..*..****..*.

SEQ= 14 WEIGHT= 128
*.*...*..*.*.*.. ****.**.*......*  ***..*.*....***. .*.*.*...***....
**.*..**.*...*.* *..****......*.*  ...*.**...***.** .**.*.*.*****.*.
...*****.**.*... .***...*..***.*.  .*.*..**..*.*..* **.*..****.*....
*.**..***.***.*. *..*****.*.***.*  ***.....**.***.. ..***.*...*..**

SEQ= 15 WEIGHT= 128
*..******.***..* *.**..**..*.****  .......****..*.. ..**.***.***....
.**......**..**. ..*.*...**.**..*  ..***.****..**** **...*.*....*.*.
****..*.*.....*. *..**.*..****.*.  ***.*...*..*.*** .**..*..***....*
**.****..*..*.** *.*.*.*..**.**..  .****.*.*..***.* ...*...*.*..*..

SEQ= 16 WEIGHT= 128
*...*.**.*.*.**. ***..*..*.*.*...  .***.*.**.**..*. *.**..**..**.*..
*****..*...*.**. ..**..***..*.*..  *.***.*.*..*..*. **.*.*.*...**.*.
*.**.*...*.****. **...*.******...  .**.*.*.**.*..** **.*.*........*.
.*.**.*..*..**.* ..*.******..*.*.  ...*..*.*******. *....*.*..*.*.*
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