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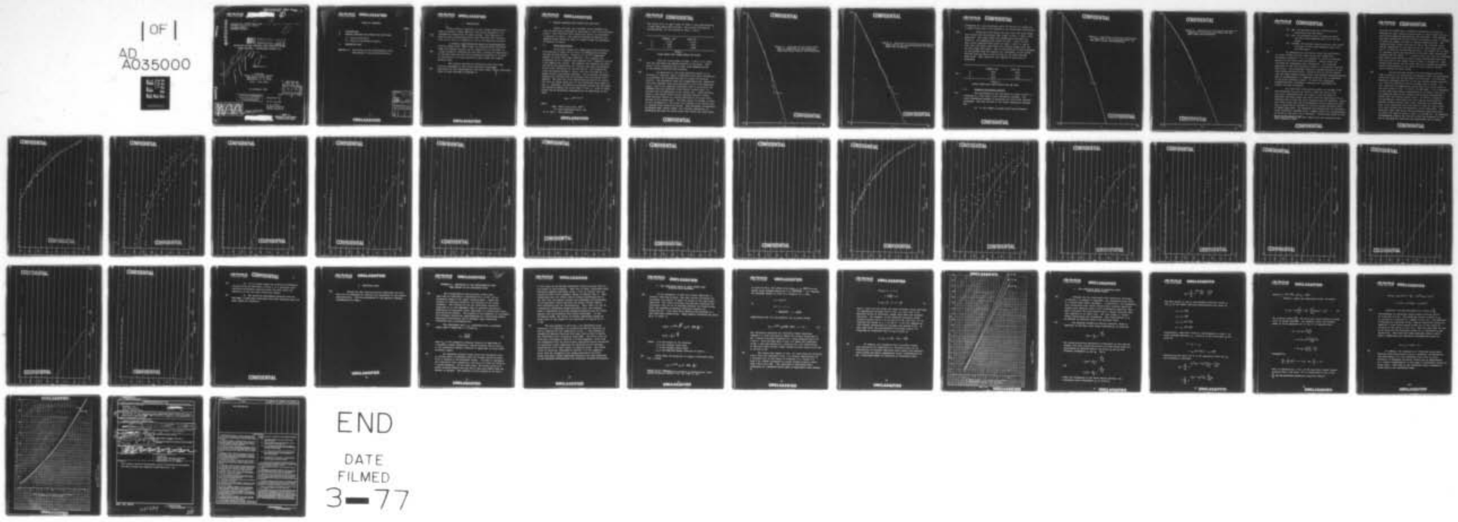

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Contract No. N00024-68-C-1238 - SECOND QUARTERLY PROGRESS REPORT
UNITECH Project No. 009-01
Document Number
UNITECH 68-035-C

VALIDATION OF THE COMPUTER AIDED DETECTION MODEL USING SEA DATA: PRELIMINARY RESULTS (U)

Submitted to:

Commander
Naval Ship Systems Command
Department of the Navy
Washington, D. C. 20360

Attn: Code OOV1C

16 December 1968

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SECOND QUARTERLY REPORT

TABLE OF CONTENTS

1. INTRODUCTION

(U) The classical approach to sonar target detection has been to provide a sonar operator with visual displays of the information received by the sonar system. This approach is known to have deficiencies which have motivated the investigation of the use of a computer to aid in the detection process.

(U) A computer-aided detection model was developed under Contract NObsr-93352. This model is currently being validated under the subject contract by the application of the model to a large volume of recorded sea test data. A detailed description of the data base and the data processing procedures to be used is contained in the first quarterly report under the subject contract date.

(U) The results obtained by processing twelve sea test runs are presented in this second quarterly report. A derivation of the transformation from peak height to log likelihood ratio is also included in Appendix A.

2. RESULTS OBTAINED FROM TWELVE SEA TEST RUNS

(U) Twelve sea test runs recorded during TECHEVAL sea trip two have been processed as described in the first quarterly report. The resulting false alarm rate curves are presented in Section 2.1 below. The results obtained by applying the computer-aided detection model to target tracks are presented in Section 2.2 below.

2.1 False Alarm Rates

(U) To provide a basis for comparison of CAD effects on reverberation a large set of noise was generated and passed through the CAD process. Initially 4.2 x 10^6 independent samples of Gauss noise were obtained. This sequence was considered to be a sampled time sequence with a sampling rate of 1,000 samples per second. The sampled time sequence was bandlimited by the application of a digital 5th order Butterworth filter with 3 dB points at 100 and 200 Hz. The bandlimited noise was passed through a linear rectifier followed by a 10 sample finite time perfect averager. The resulting "envelope" sequence was divided into 396 sections each containing 10752 samples. The data was first thresholded and sorted to obtain the curve of false alarm rate vs log likelihood ratio shown in Fig. 1. Secondly, the data was processed through the CAD model and sorted to obtain the curve shown in Fig. 2. Each of these curves can be accurately represented by an expression of the form;

$$\text{FAR} = e^{A+B\cdot L+C\cdot L^2} , \qquad (1)$$

where

FAR = False alarm rate, SEC^{-1},
L = Log likelihood ratio, and
A, B, and C are constants.

The values of A, B, and C shown in Table I were determined by a least mean square bit process. The results obtained by evaluating Eq. (1) are plotted on Figs. 1 and 2.

(C)

	WITHOUT CAD	WITH CAD
A	1.9276	2.0273
B	- .5560	- .6623
C	- .0317	- .0065

TABLE I

FALSE ALARM RATE COEFFICIENTS FOR NOISE

(U) From the curves shown in Figs. 1 and 2 it is clear that the CAD model has adverse effects on the noise. This result is not unexpected and is more than compensated for by the benefits derived from tracking.

(C) As described in the first quarterly report it is necessary to separate signal information from noise information in processing the recorded sea data to obtain the desired results. The procedures used for accomplishing this separation have been expanded from those described in the first quarterly report Due to the sampling techniques used in digitizing the TECHEVAL data the submarine track usually occurs about 1.5 seconds from the beginning of the cursor gate. Often multiple paths to the target exist causing multiple parallel tracks. These multiple tracks are usually confined to the first five seconds of the cursor gate. For this reason no attempt is made to use information in the first five seconds of the cursor gate to develop false alarm rate curves. This procedure successfully eliminates most target tracks. As a further precaution, in processing the data for false alarm rate curves any track which

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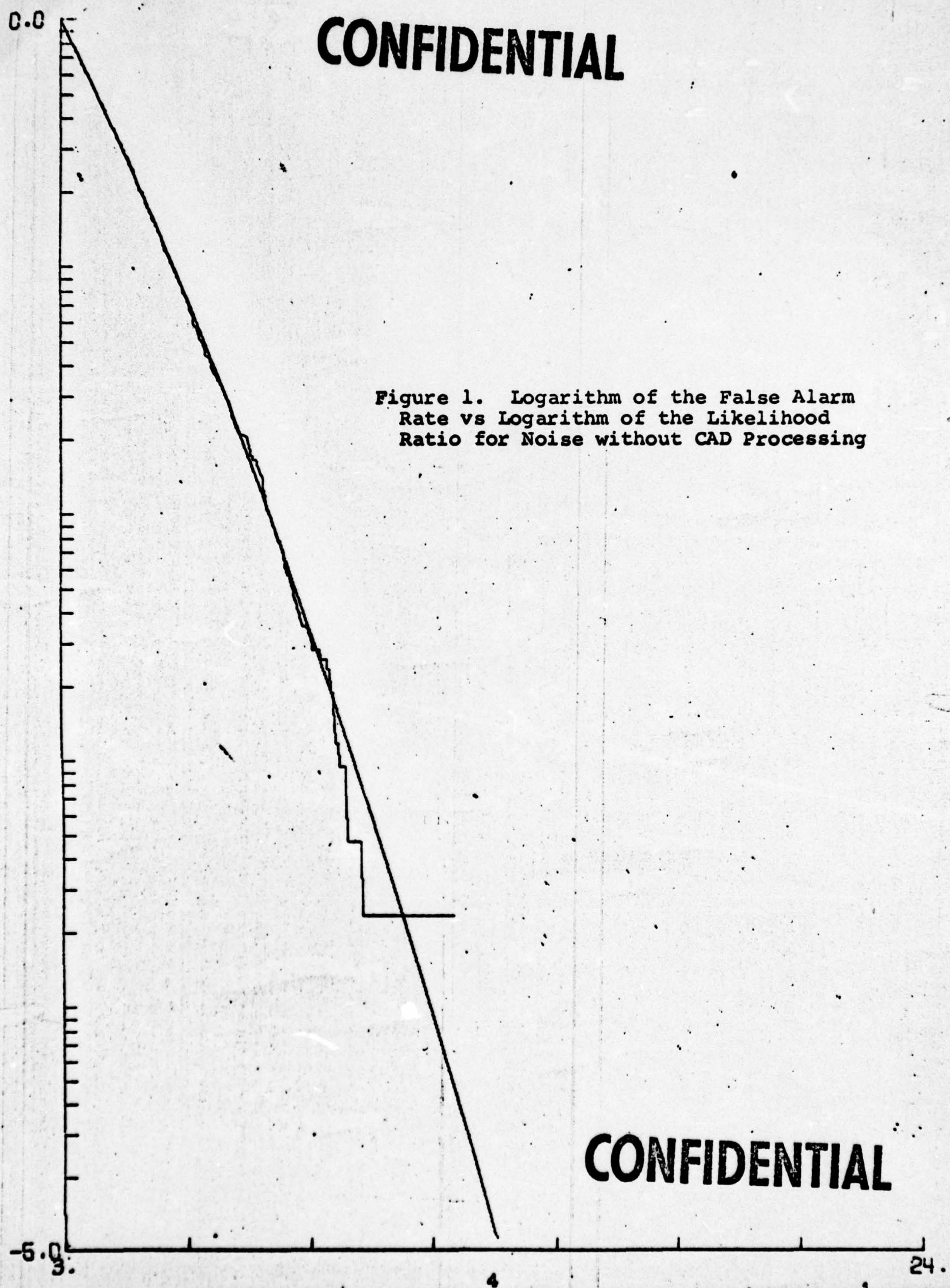

Figure 1. Logarithm of the False Alarm Rate vs Logarithm of the Likelihood Ratio for Noise without CAD Processing

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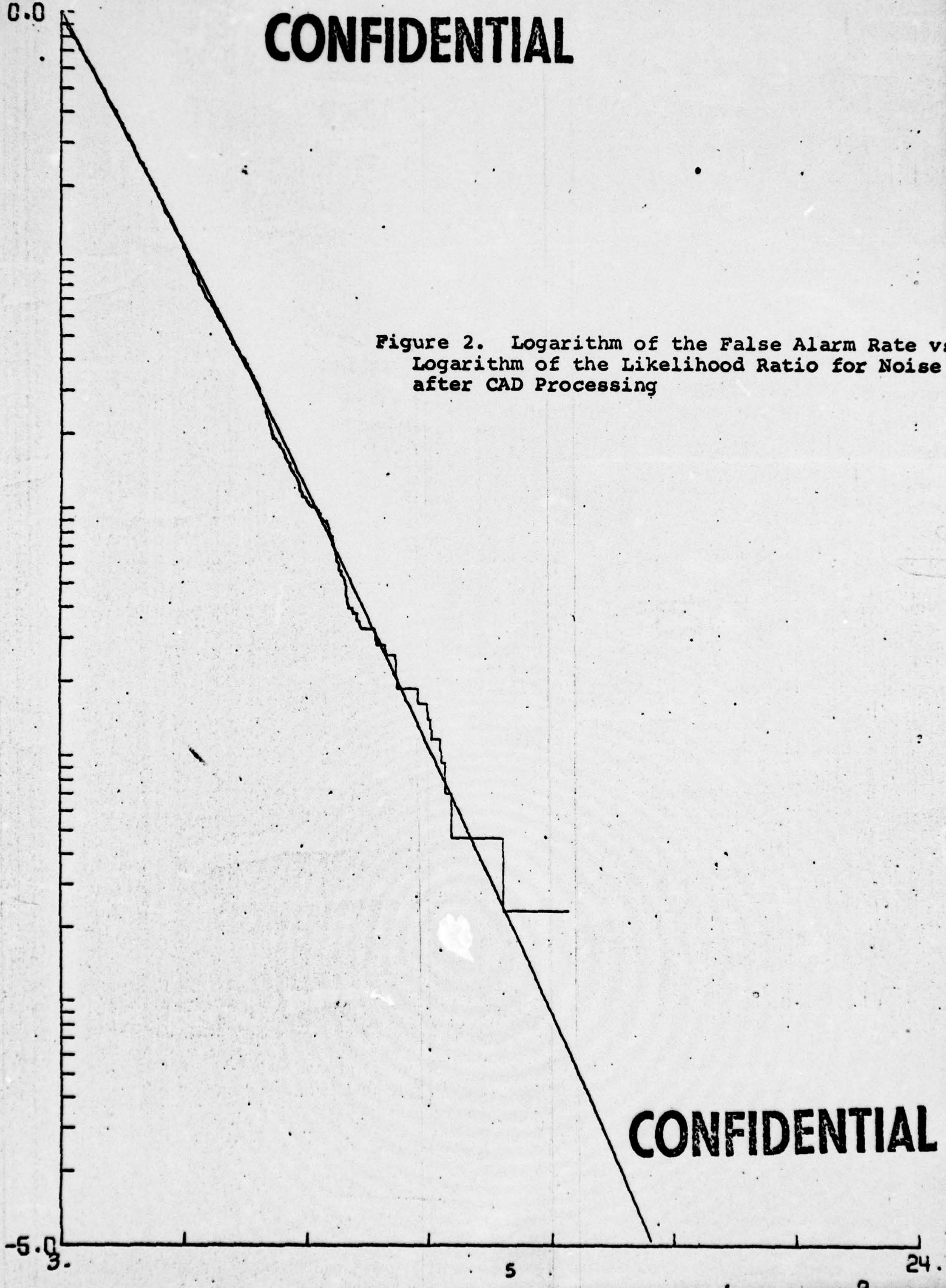

Figure 2. Logarithm of the False Alarm Rate vs Logarithm of the Likelihood Ratio for Noise after CAD Processing

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integrates to a log likelihood ratio of fourteen is called as a target track and is not counted in the false alarm statistics.

(C) Using data from twelve sea test runs the false alarm rate curves with and without CAD, shown in Figs. 3 and 4, were generated. The false alarm rate coefficients are given in Table II. By comparing the curves of Figs. 3 and 4 to the base curves (derived from noise) in Figs. 1 and 2 it can be seen that the false alarm rates are slightly higher with the sea data than with noise. Due to the quantity of data processed at the present time the quality (or confidence) of the curves derived from sea data is not as high as for those derived from noise. This condition will improve as more data is processed.

(C)

	WITHOUT CAD	WITH CAD
A	.8616	.9148
B	- .2675	- .3342
C	- .0345	- .0208

TABLE II

FALSE ALARM RATE COEFFICIENTS FOR SEA DATA

2.2 Absolute Performance Measure

(U) The performance of the CAD model on target tracks is condensed to a four entry track information package. One track information package is generated for each track sequence processed. The four entries in the track information package are,

(1) N, the number of pings which were processed

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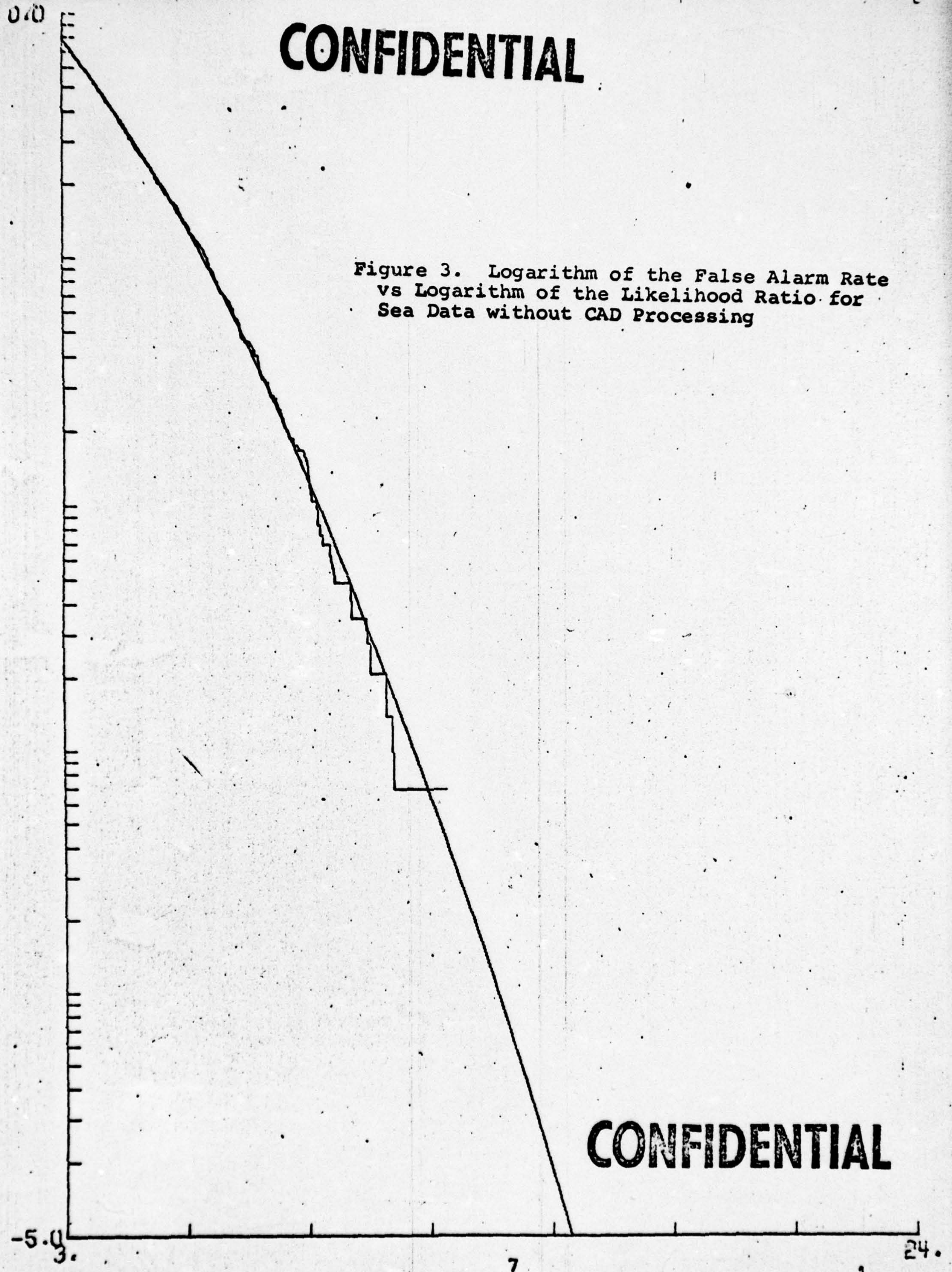

Figure 3. Logarithm of the False Alarm Rate vs Logarithm of the Likelihood Ratio for Sea Data without CAD Processing

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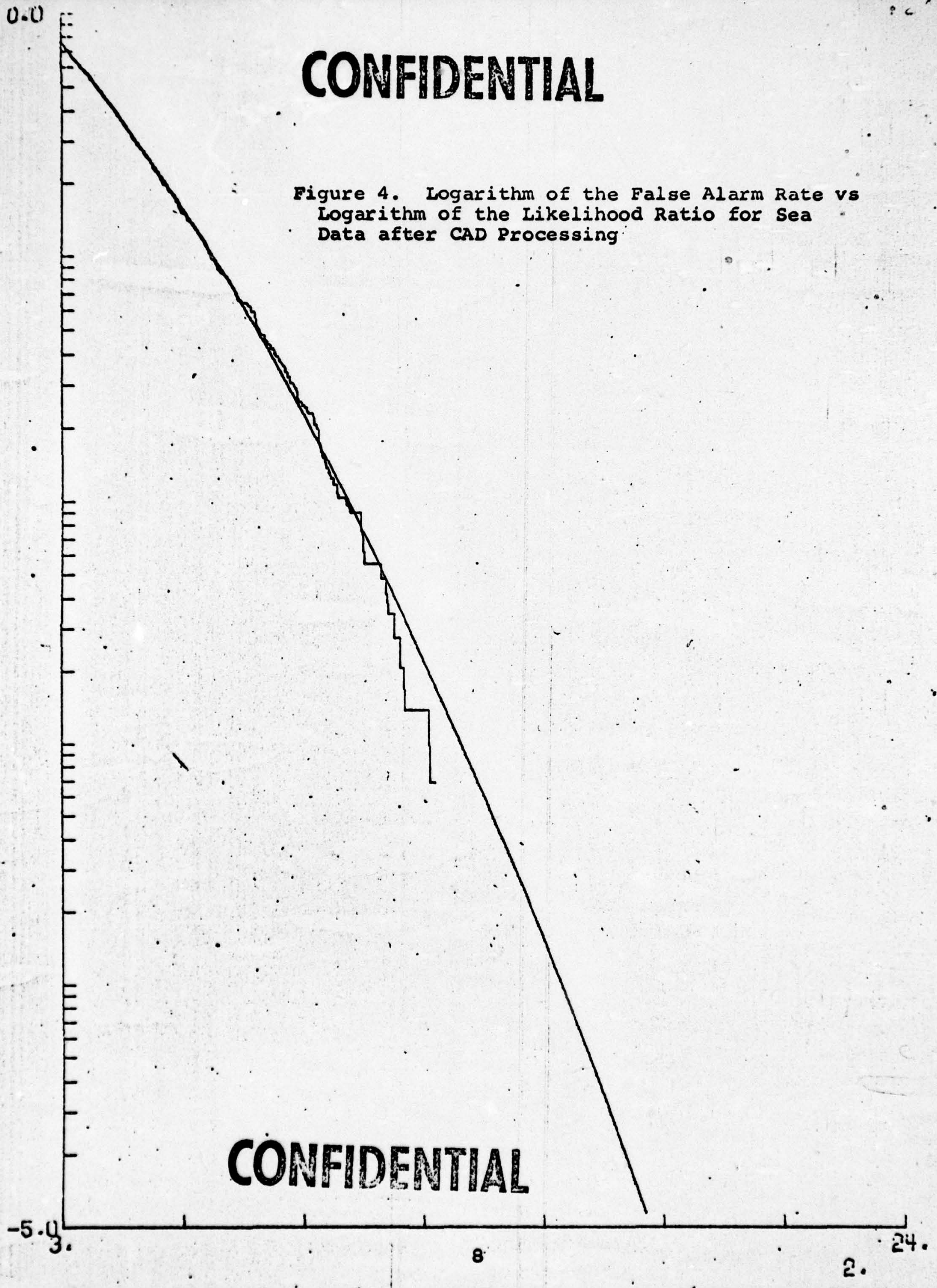

Figure 4. Logarithm of the False Alarm Rate vs Logarithm of the Likelihood Ratio for Sea Data after CAD Processing

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(2) LLR, the maximum track log likelihood ratio obtained by the CAD model,

(3) S/N, the estimated value of signal-to-noise for the N ping sequence going into the CAD model,

(4) S/N;MAX, the maximum signal-to-noise ratio which occurred in the N ping sequence going into the CAD model.*

(U) By combining the information about CAD performance on target tracks with the false alarm rate information described in Section 2.1 it is possible to obtain an absolute measure of the total model performance. Several means are available for displaying this information. One technique described in the first quarterly report is to generate modified ROC curves. This technique requires a parameterization of the input signal-to-noise ratio. Since we have no direct control over the input signal-to-noise ratio the required parameterization must be accomplished in a somewhat arbitrary way as described in the first quarterly report. To avoid this arbitrary parameterization a different technique for displaying the results has been developed.

(C) For each track information package the maximum track log-likelihood ratio can be used to index the false alarm rate curve associated with the output of the CAD model to determine the false alarm rate which would be associated with a threshold set so that the track sequence would be detected. Using this false alarm rate and the estimated value of signal-to-noise ratio a point can be plotted on a grid of signal-to-noise ratio vs false alarm rate. By repeating this process for all available track information packages with a common value of N a distribution of points on the grid can be obtained. Finally the points on the

---

*This fourth quantity has been added since the writing of the first quarterly report.

grid may be fitted with a quadratic expression to obtain an estimate of input signal-to-noise ratio vs false alarm rate for each N ping sequence processed by the CAD model. This process has been carried out and the results are shown in Figs. 5 through 12 where the number of pings is varied parameterically. The signal-to-noise ratios are given in dB on the vertical scale and the logarithm (to the base 10) of the false alarm rate (in Sec^{-1}) is given on the horizontal scale. The symbol "X" is used to represent points derived directly from the track information packages and the symbol "·" is used to plot the curve fit function. Many large signal-to-noise ratio tracks yield points which are off the scale of the graphs shown in Figs. 5 through 12. Even though these points are not shown they are included in determining the coefficients of the curve fit since they do present valid information about trends.

(C) To provide some insight into the benefits derived from tracking it is interesting to determine what the performance would have been had the CAD model not been used. An alternate detection procedure would be to use the largest signal occurring in a track for detection with no attempt made to track. If this were done the appropriate false alarm rate curve would be the curve given in Fig. 3 without the CAD model. It is important to note that when several observations are allowed (such as 6) the expected value of the largest signal may be considerably larger than the average signal level. To obtain a display of the performance associated with this type of processing the maximum signal-to-noise ratio which occurred was transformed into a log likelihood ratio and used to index the false alarm rate curve without CAD to determine a false alarm rate. The resulting (FAR, S/N) pairs were processed as described above to obtain the results shown in Figs. 13 through 20. By comparing corresponding results for the use of CAD for detection vs the use of the peak for detection two conclusions can be drawn:

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S/N VS FALSE ALARM RATE USING CAD FOR DETECTION, N= 1,

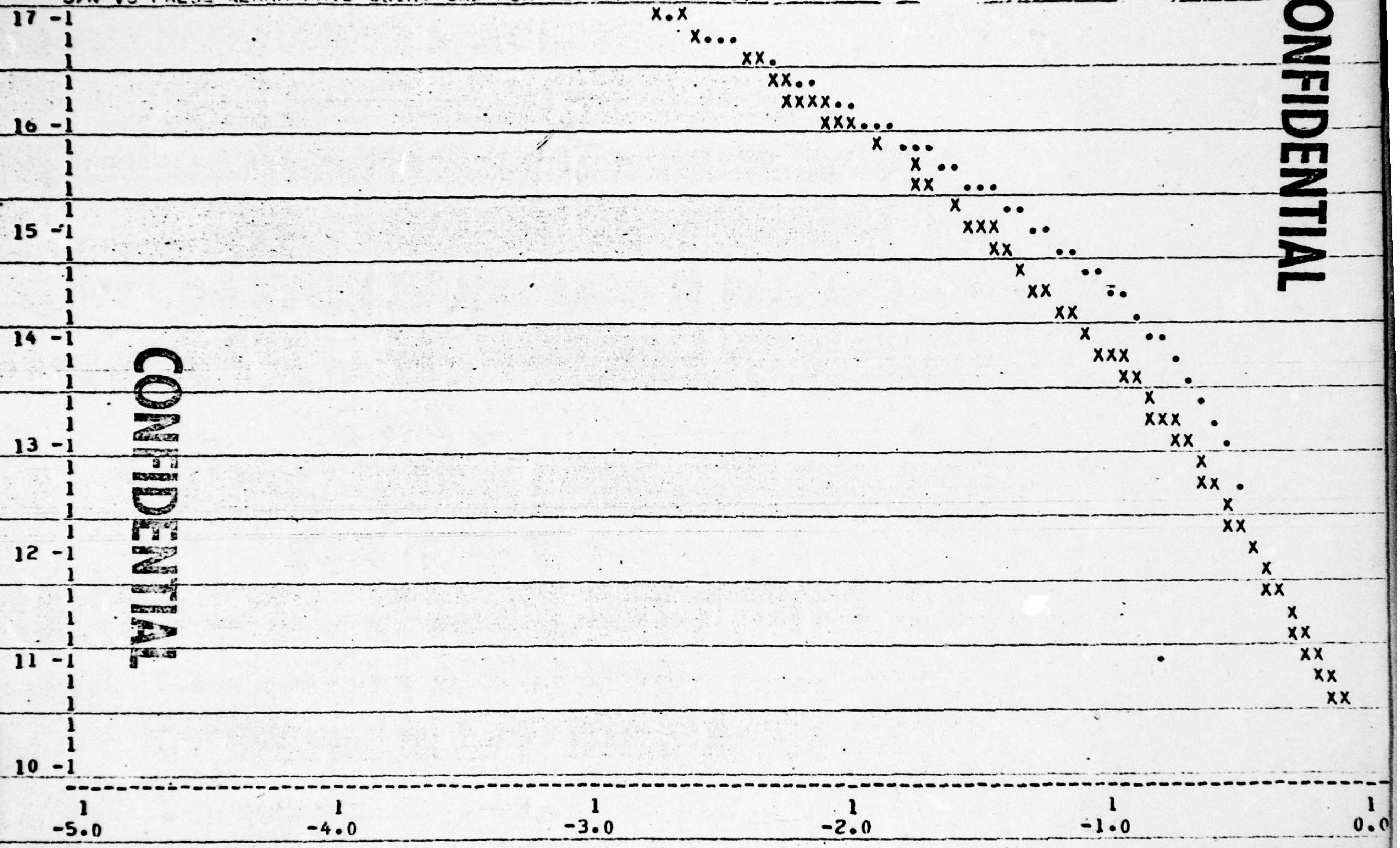

FIGURE 5

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S/N VS FALSE ALARM RATE USING CAD FOR DETECTION, N= 2,

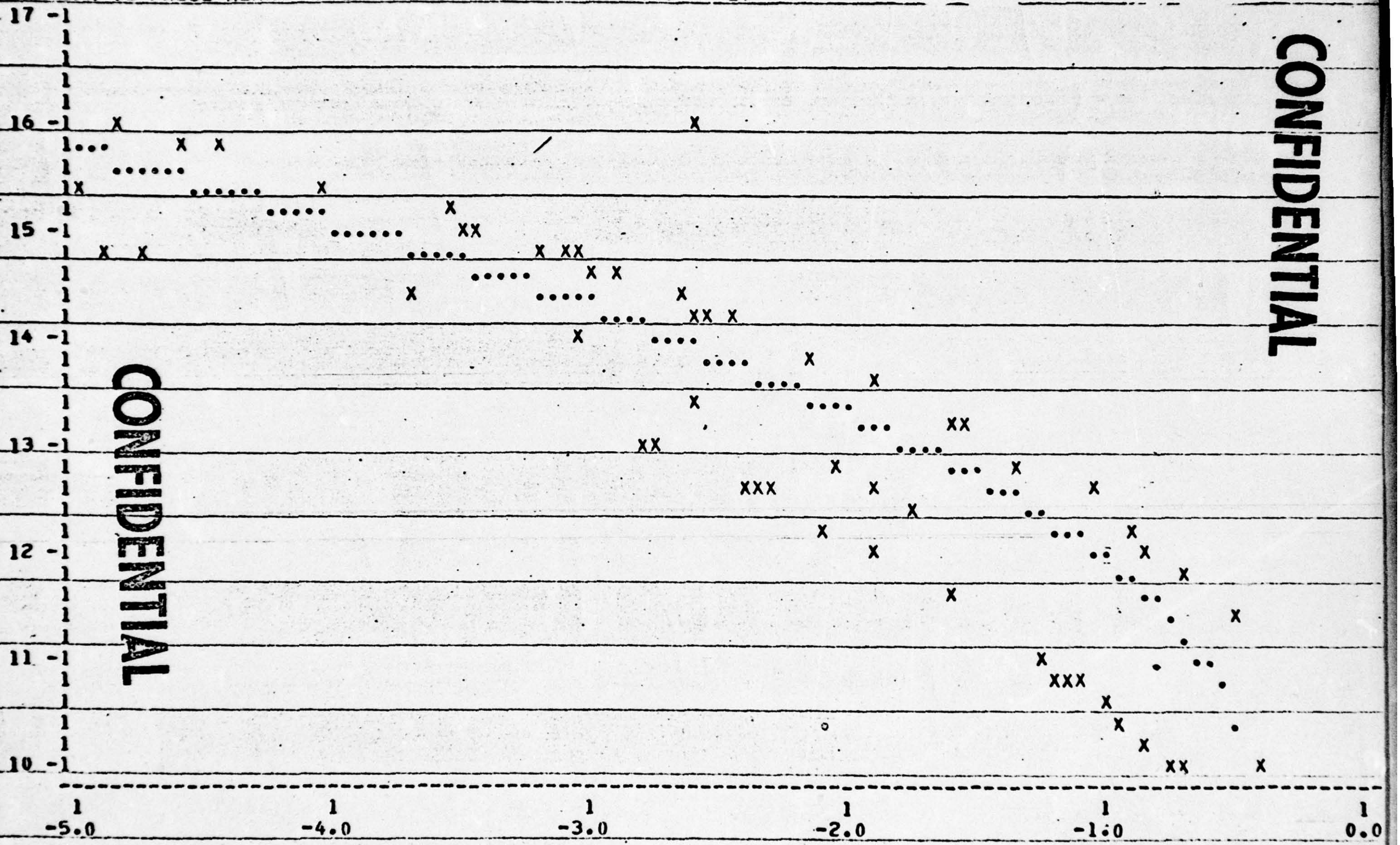

FIGURE 6

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S/N VS FALSE ALARM RATE USING CAD FOR DETECTION, N= 3,

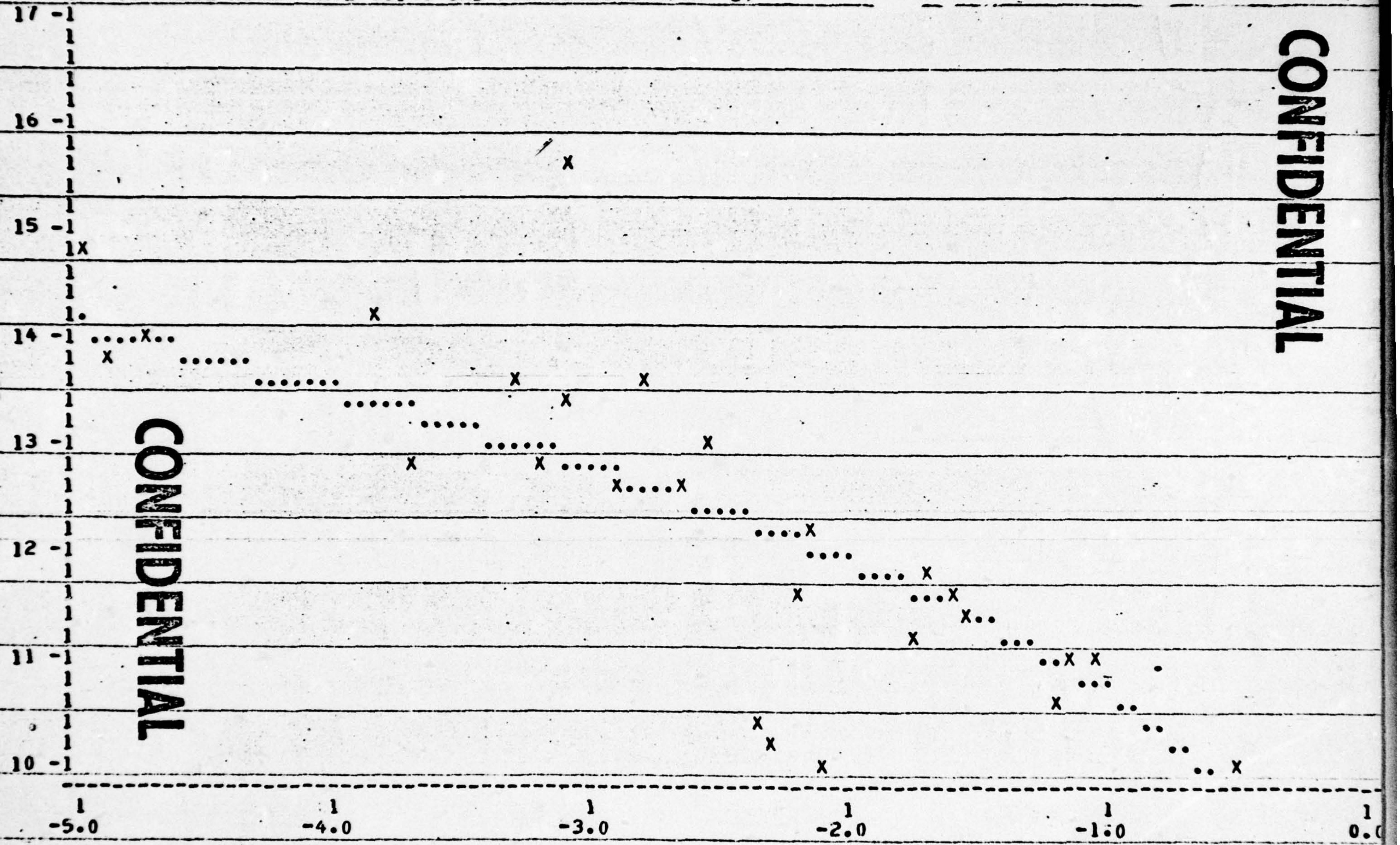

FIGURE 7

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S/N VS FALSE ALARM RATE USING CAD FOR DETECTION, N= 4,

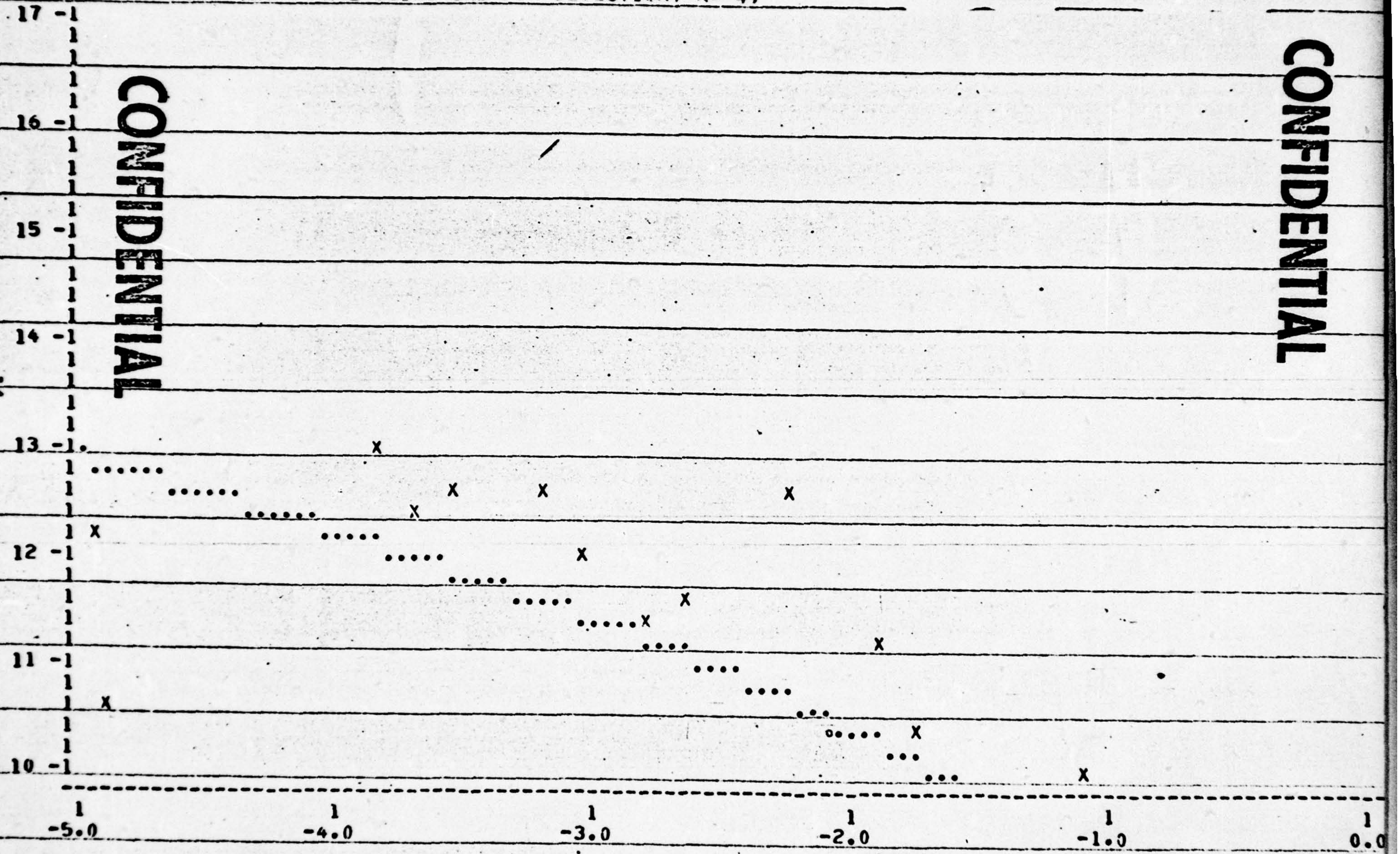

FIGURE 8

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S/N VS FALSE ALARM RATE USING CAD FOR DETECTION, N= 5,

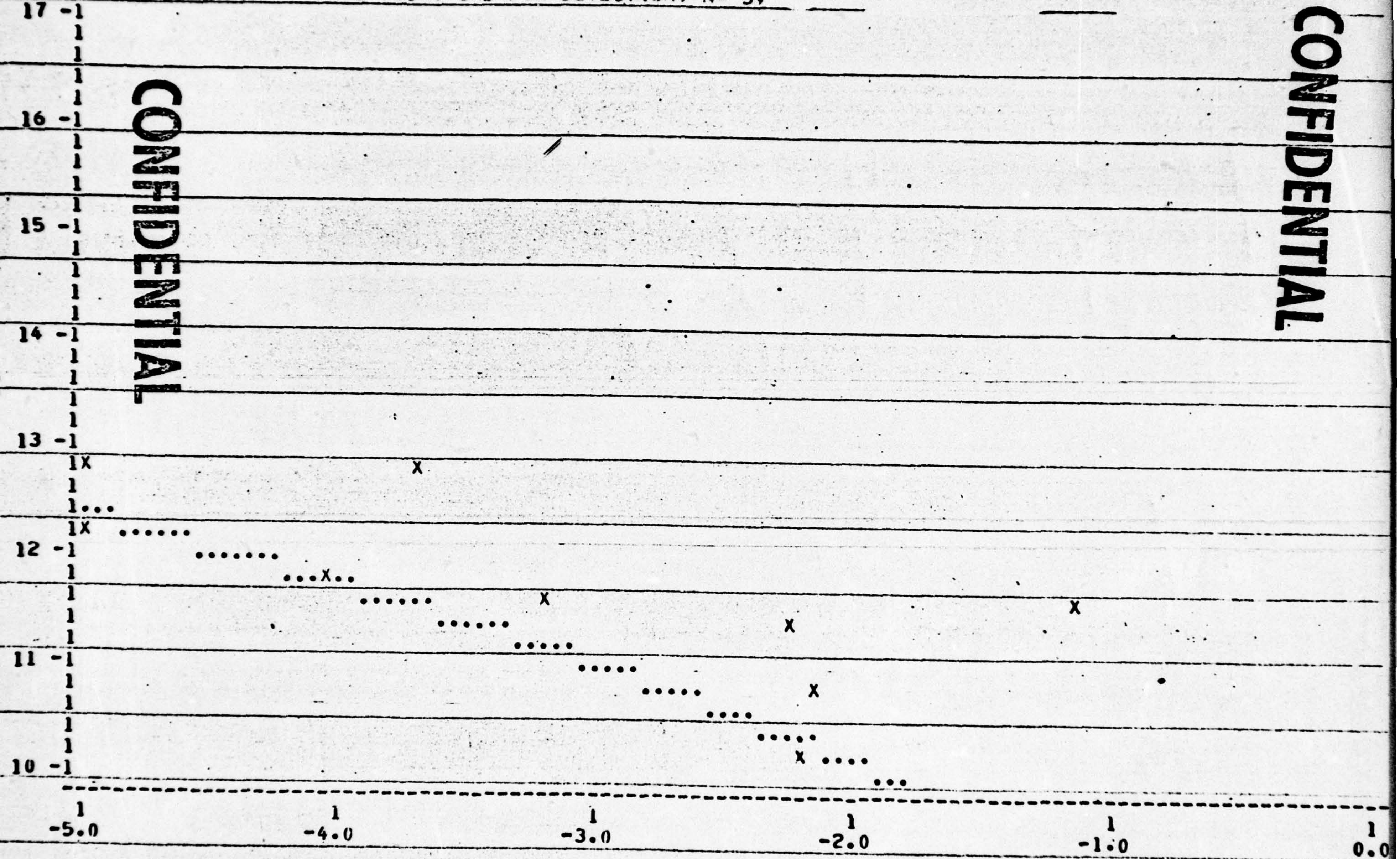

FIGURE 9

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S/N VS FALSE ALARM RATE USING CAD FOR DETECTION, N= 6,

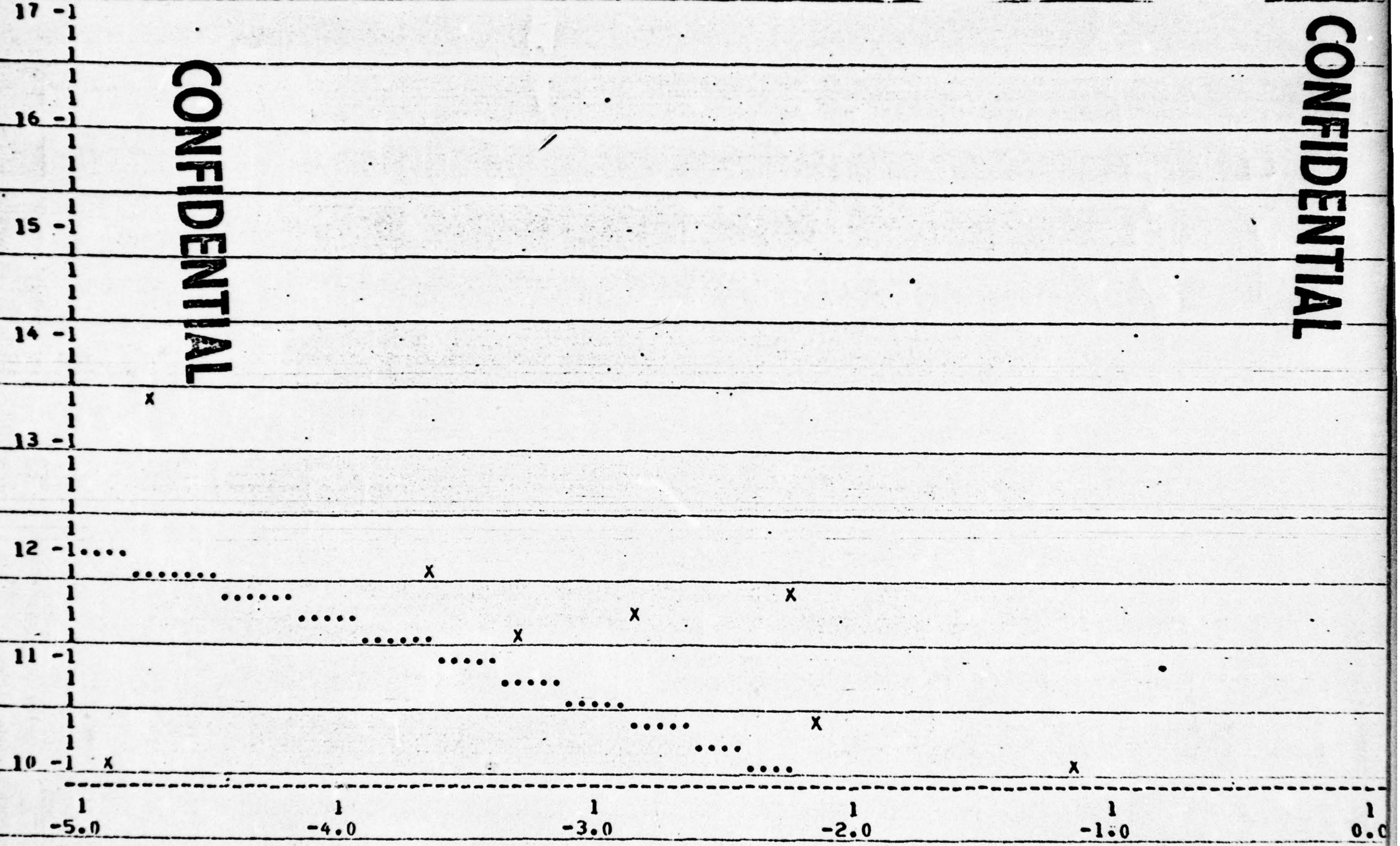

FIGURE 10

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S/N VS FALSE ALARM RATE USING CAD FOR DETECTION, N= 8,

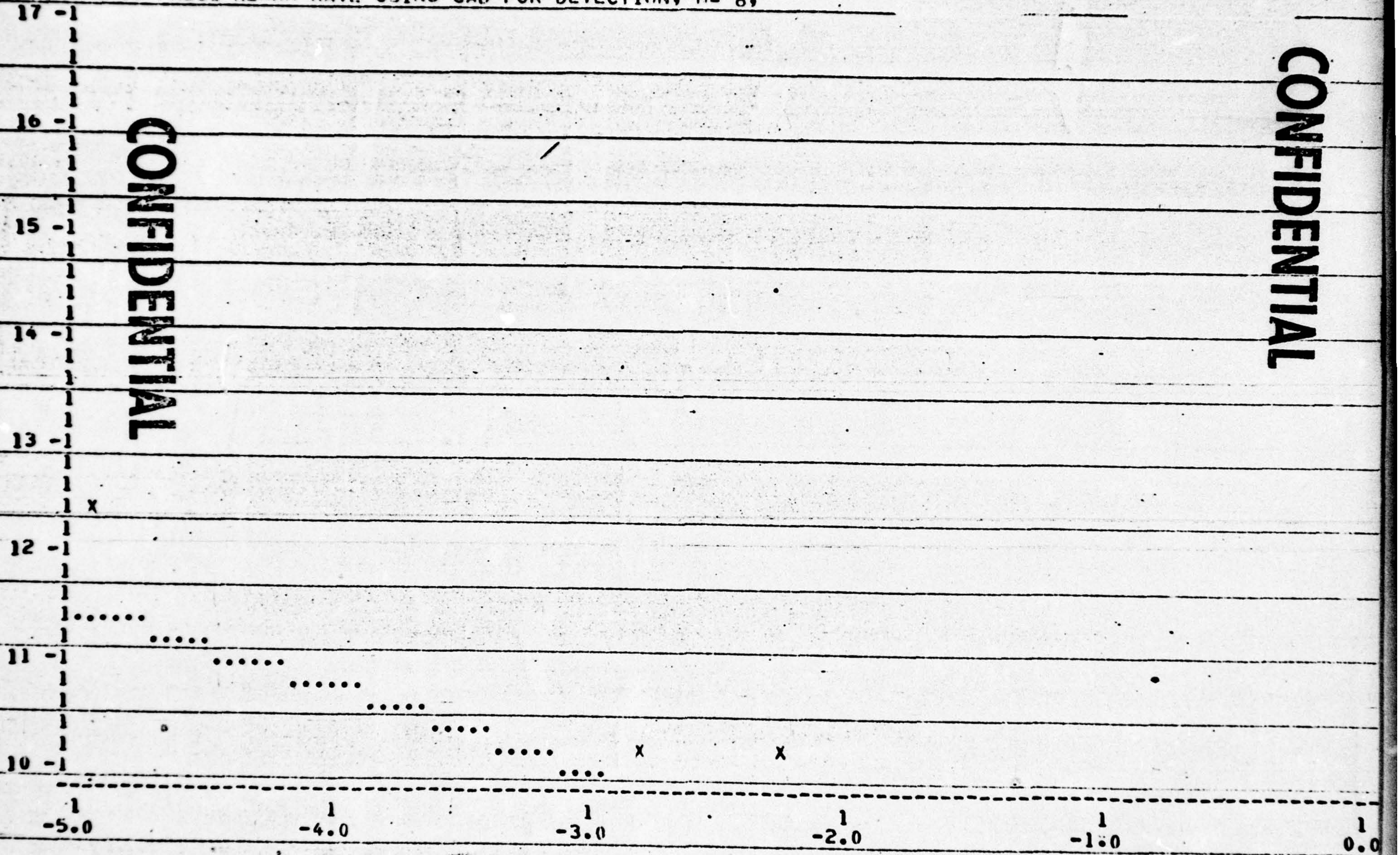

FIGURE 11

S/N VS FALSE ALARM RATE USING CAD FOR DETECTION, N=12,

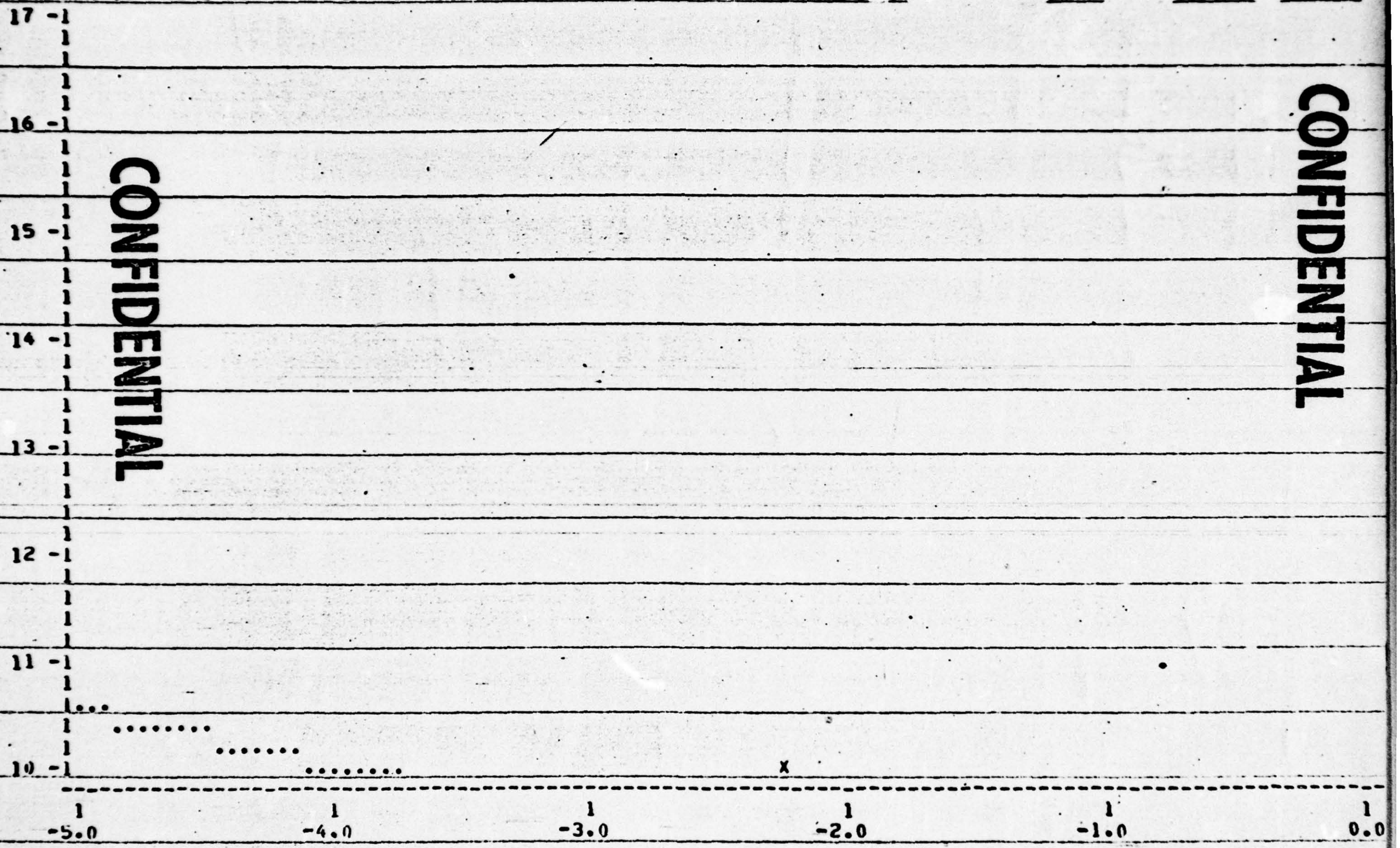

FIGURE 12

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S/N VS FALSE ALARM RATE USING PEAK FOR DETECTION, N= 1,

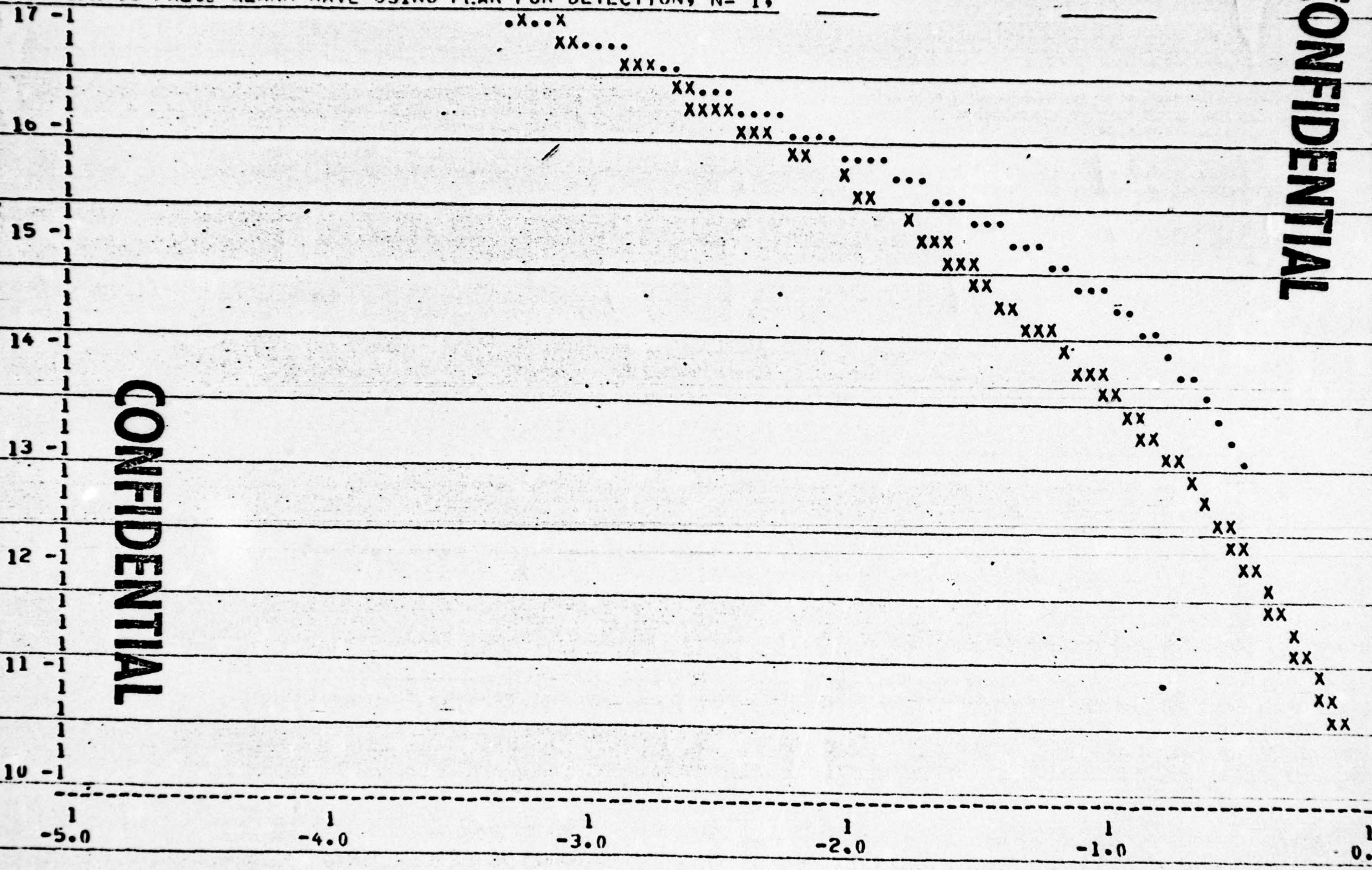

FIGURE 13

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S/N VS FALSE ALARM RATE USING PEAK FOR DETECTION, N= 2,

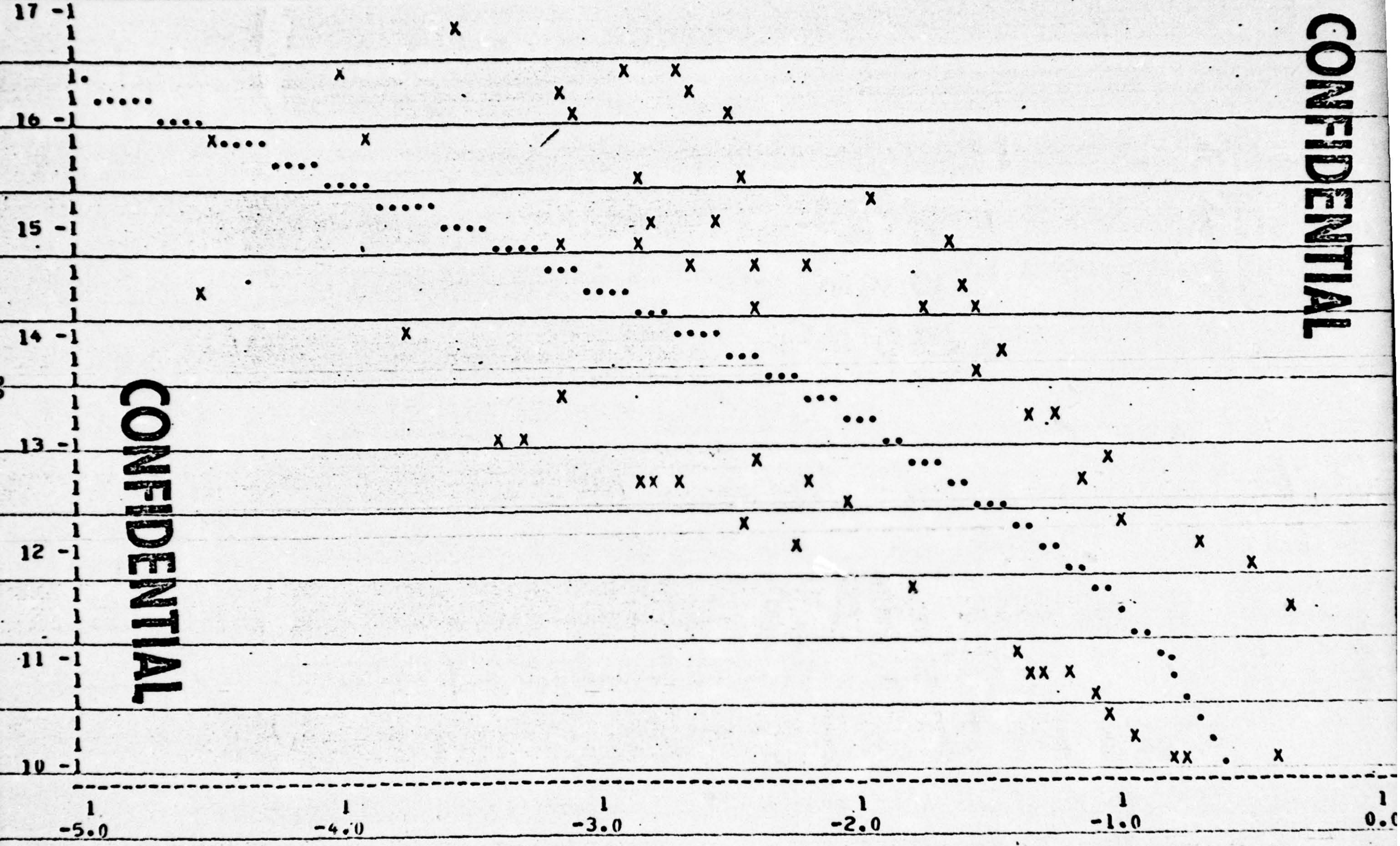

FIGURE 14

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S/N VS FALSE ALARM RATE USING PEAK FOR DETECTION, N= 3, A= -12.889254, B= 2.946107, C=

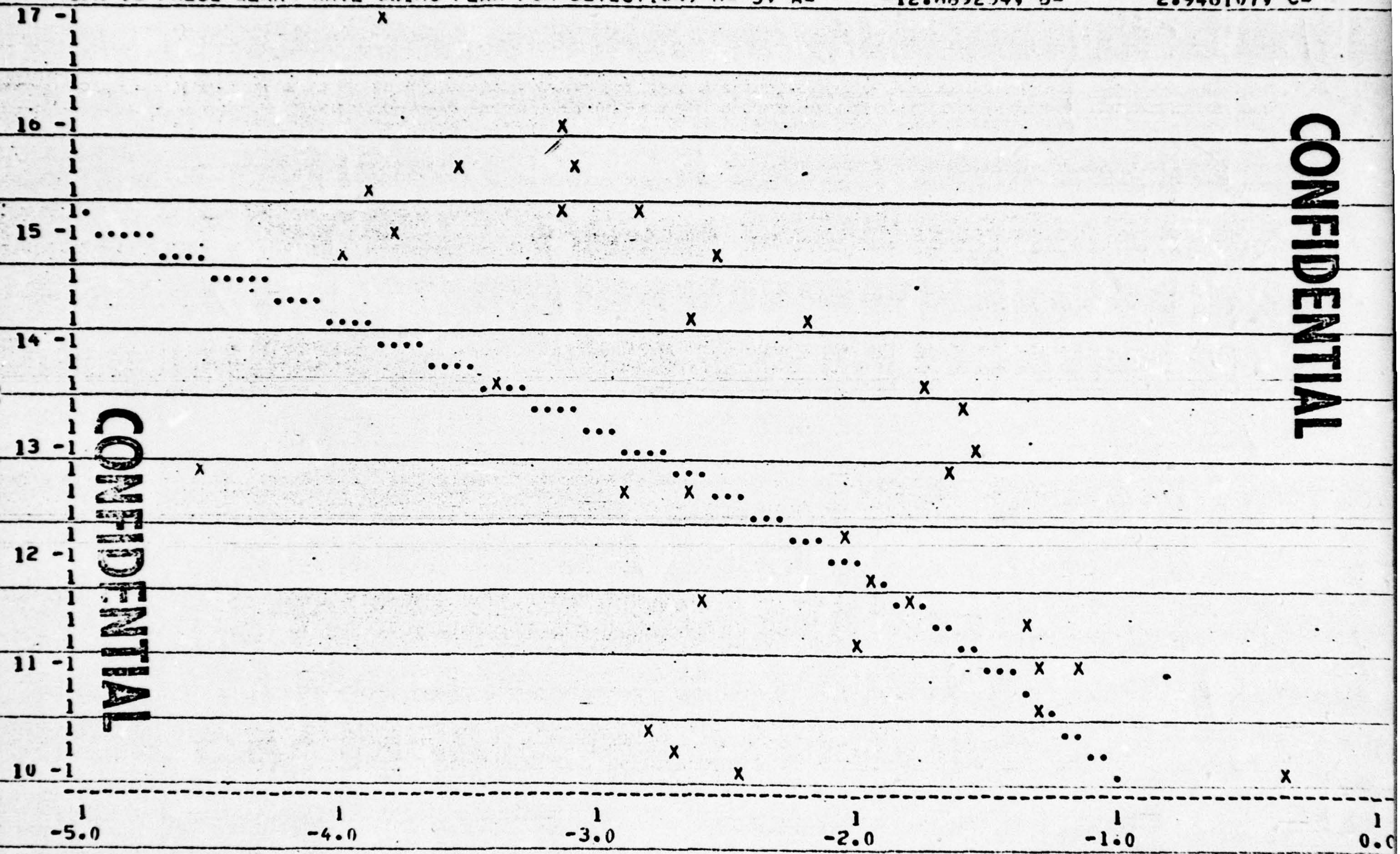

FIGURE 15

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S/N VS FALSE ALARM RATE USING PEAK FOR DETECTION, N= 4,

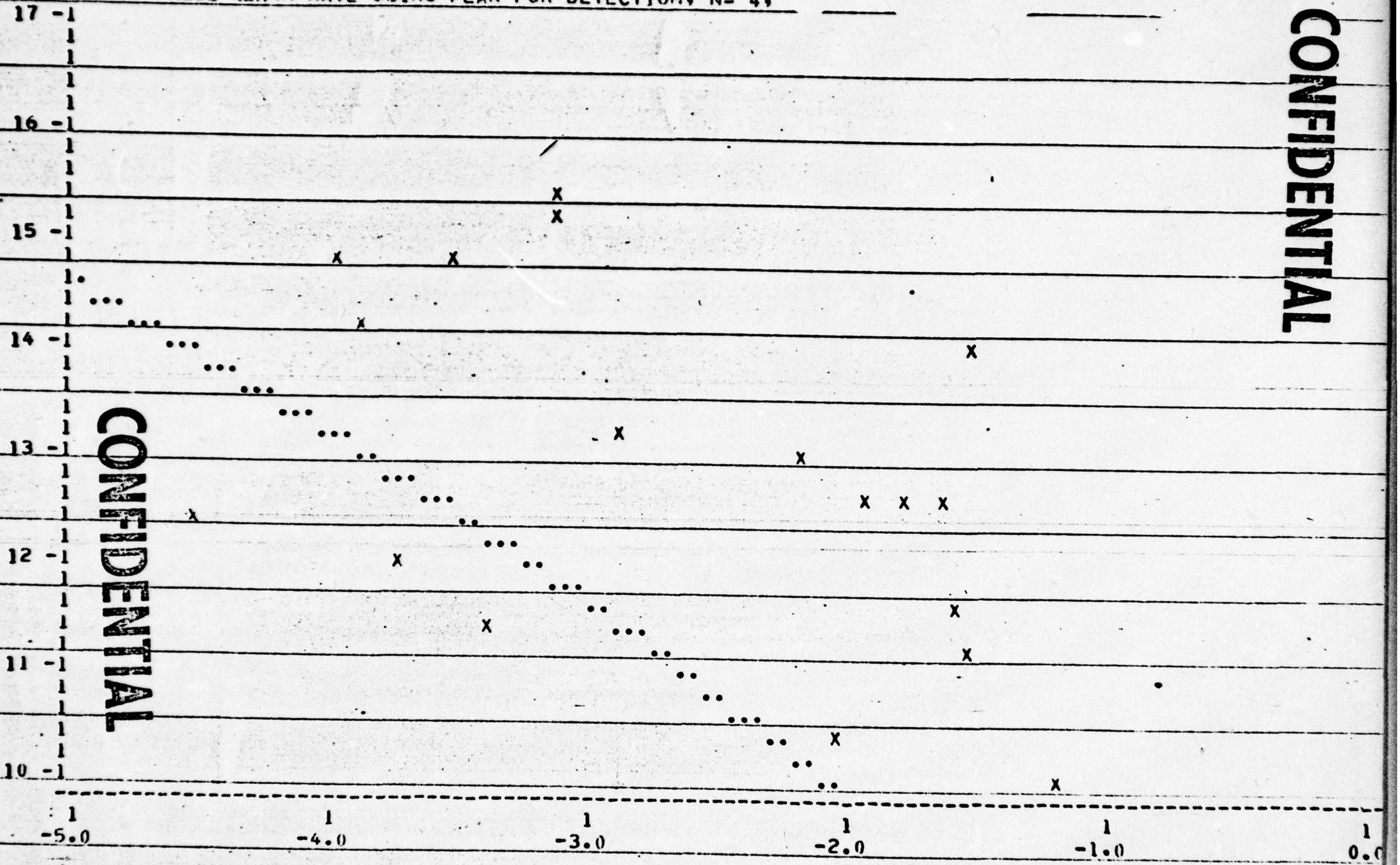

FIGURE 16

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S/N VS FALSE ALARM RATE USING PEAK FOR DETECTION, N= 5,

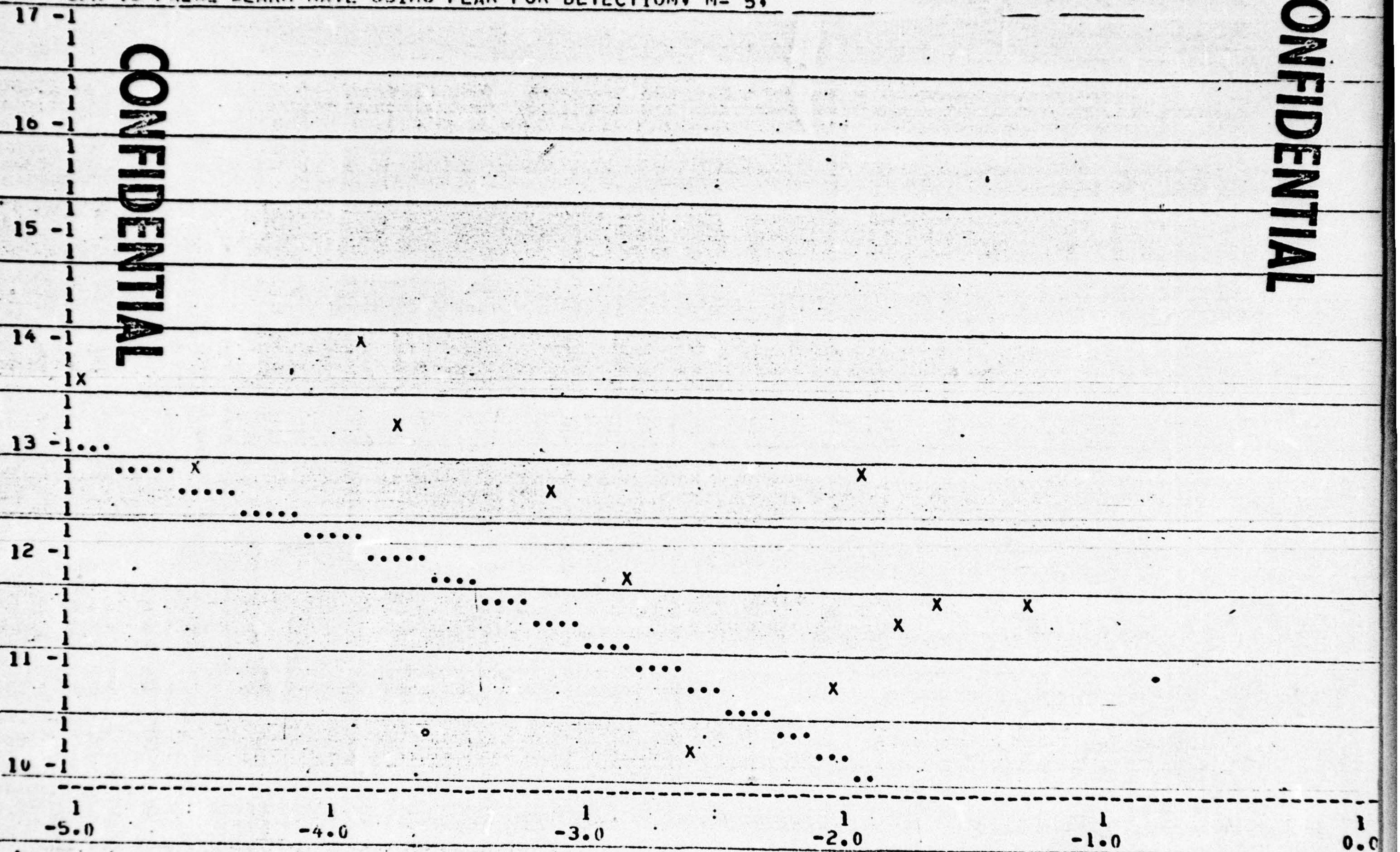

FIGURE 17

S/N VS FALSE ALARM RATE USING PEAK FOR DETECTION, N= 8,

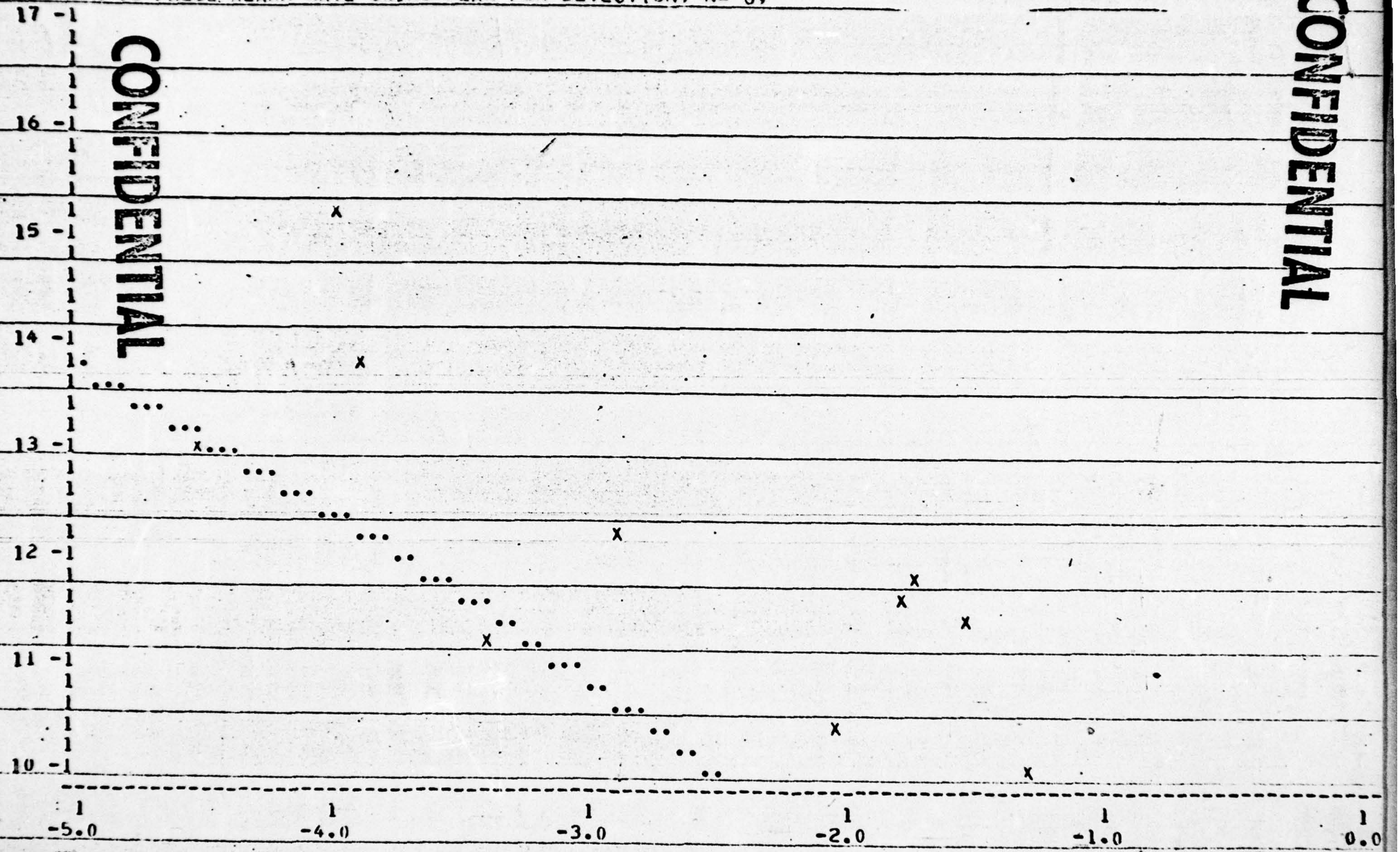

FIGURE 18

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S/N VS FALSE ALARM RATE USING PEAK FOR DETECTION, N= 8,

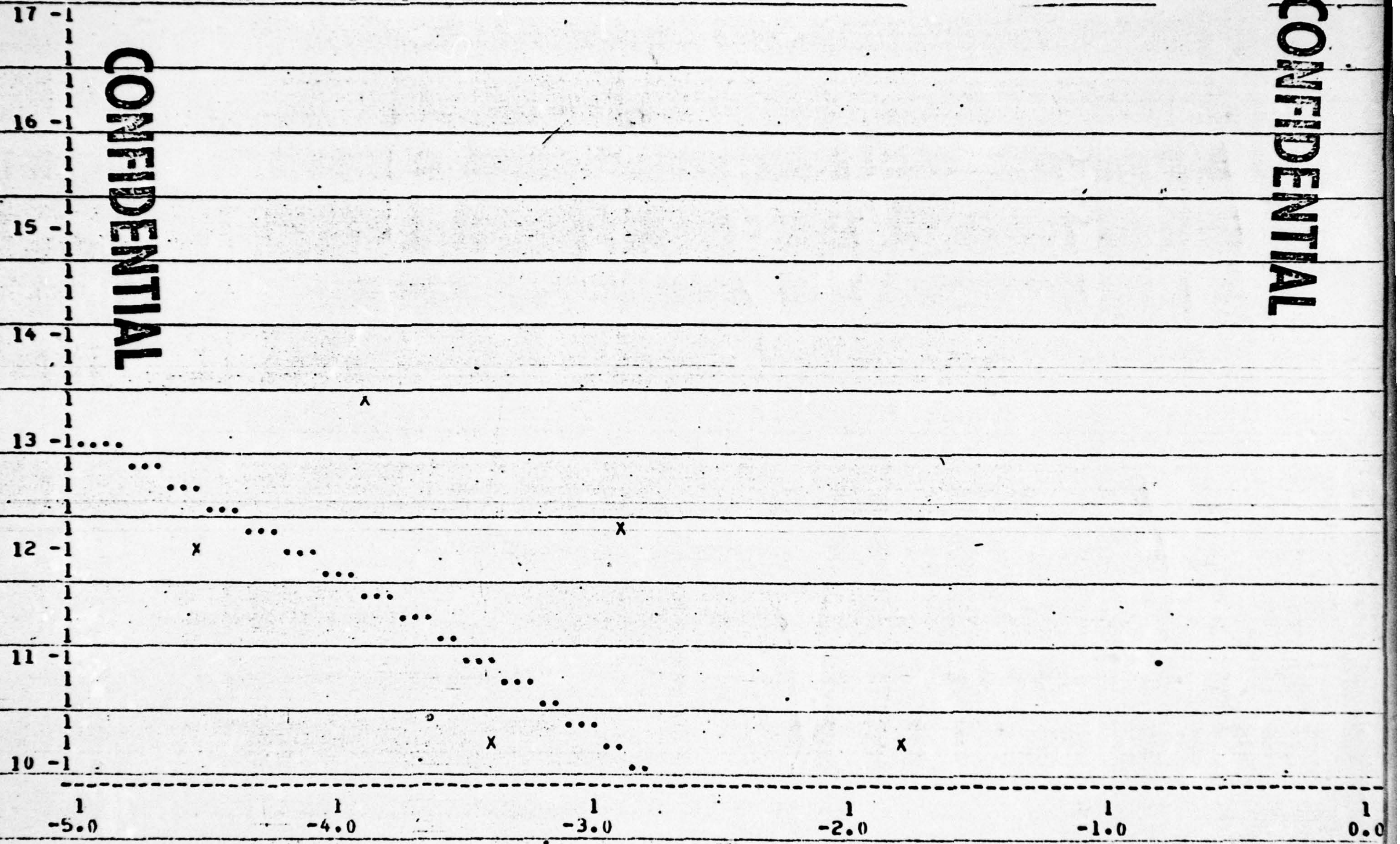

FIGURE 19

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S/N VS FALSE ALARM RATE USING PEAK FOR DETECTION, N=12,

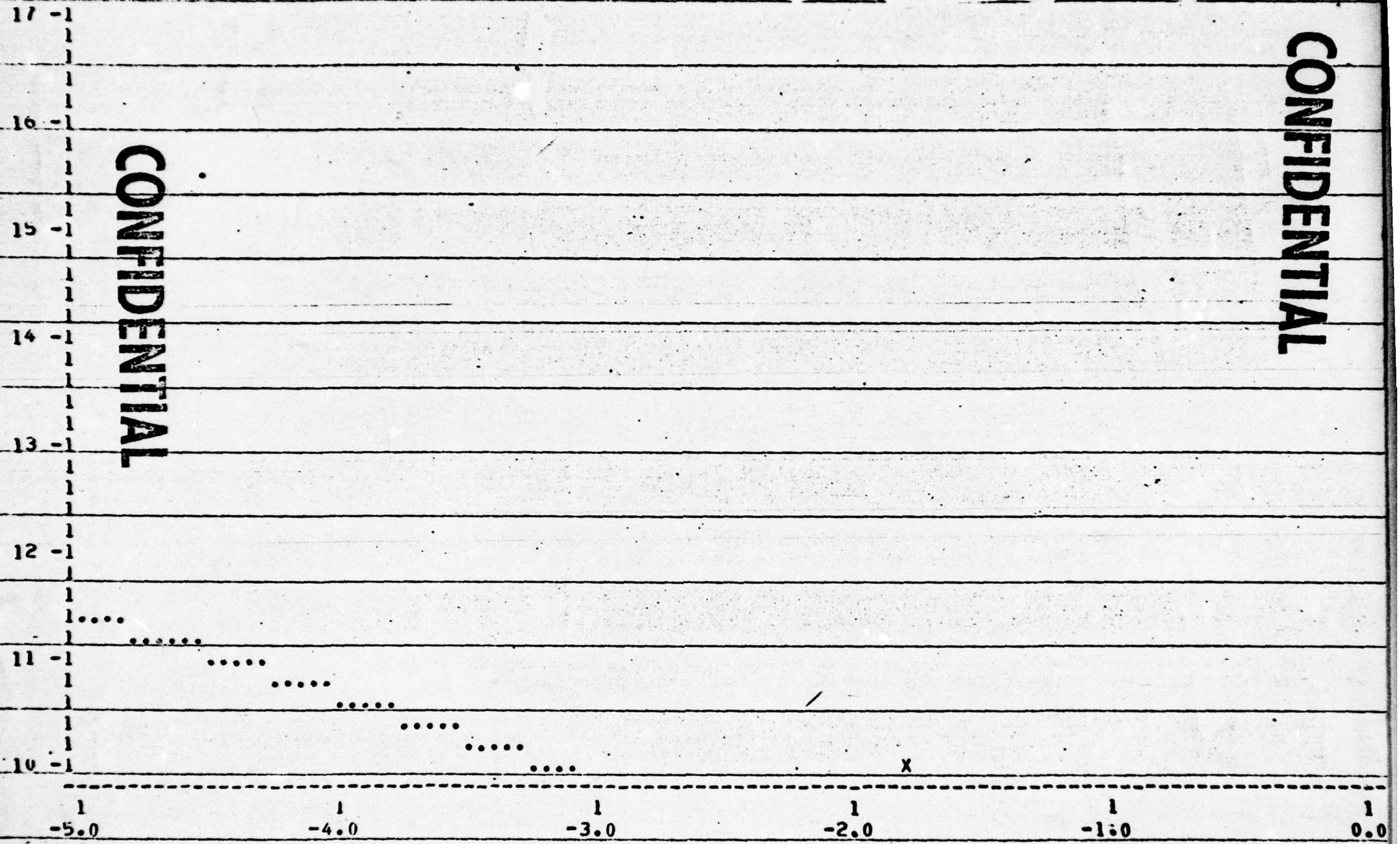

FIGURE 20 ·

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(C) (1) In an average sense the detection performance obtained with the CAD model is about 1 to 2 dB better than detection performance obtained using the peak signal for detection in the low false alarm rate region.

(C) (2) The detection performance obtained with the CAD model is much more consistent then that obtained using the peak signal for detection.

3. CONTINUING WORK

(U) During the next reporting period additional sea test data will be processed to increase the confidence of the results presented here. Also the processing of the operator response information will begin.

From
2nd Quarterly
Report

APPENDIX A. DERIVATION OF THE TRANSFORMATION FROM PEAK HEIGHT TO LOG LIKELIHOOD RATIO

(U) The transformation from processor output peak amplitude to logarithm of likelihood ratio is the initial processing stage of the target tracking model. Model performance is directly related to the accuracy of the transformation. The validity of the log likelihood conversion algorithm is in turn dependent upon an accurate statistical description of processor output amplitude in a multi-ping signal-plus-noise environment. The purpose of this Appendix is to present two different statistical approximations to a multi-ping signal-plus-noise distribution and to document their associated likelihood ratio transformations.

(U) The likelihood ratio, L_x, associated with a processor output peak of amplitude x is given by

$$L_x = \frac{P_s(x)}{P_n(x)} \tag{1}$$

where P_s is the probability density function of amplitude in a processor output exhibiting a signal-to-noise ratio S and P_n is the probability density function of amplitude in noise alone processor output.

(U) One immediate problem arises since the likelihood ratio L_x defined above is dependent upon the average signal-to-noise ratio S assumed at the processor output. In order to implement the likelihood ratio conversion, the value of S must be fixed as a system parameter. On the other hand, the actual value of S cannot be known before the fact and it may vary widely from one contact to another. One solution to this problem is to set S in the range of the minimum detectable signal-to-noise ratio at the output of the processor. When this is done, likelihood ratio estimates computed according to Eq. 1 will be inexact only for signal-to-noise ratios somewhat larger or smaller than S. This inexactness will not affect overall system performance due to the fact that the smaller signals are presumably non-detectable at the processor output and that the larger signals require less processing gain for detectability. Thus, when S is set at a marginally detectable signal-to-noise ratio, the tracking model is optimized to provide maximum processing gain for those signals that are presently only barely detectable. In the validation study, the region of minimal detectable signal-to-noise ratio at the output of the correlator is from 10 dB to 12 dB.

(U) The next problem in deriving a log likelihood transformation is to determine the probability density functions P_s and P_n required for the computation of Eq. 1. Two calsses of probability density functions have been used to date to derive log likelihood ratio conversion algorithms. The first class of functions, discussed in Section 2 of this Appendix, arise from the assumption that the ping-to-ping signal-plus-noise statistics of correlator output amplitude are described by the envelope distribution of an ideal signal in Gaussian noise. The second class of functions, discussed in Section 3 of this Appendix, arise from the assumption that signal-plus-noise and noise alone correlator output amplitude statistics are both described by the Rayleigh distributions with different standard deviations.

2. LOG LIKELIHOOD RATIO OF IDEAL SIGNAL PLUS GAUSSIAN NOISE ENVELOPE

(U) If the assumption is made that signal amplitude is constant from ping-to-ping, then echo returns following the correlator are similar to short CW pulses of the same signal amplitude. The linear rectifier and averager following the correlator then act as an envelope detector for these pulses. Thus, the probability density functions required for evaluating Eq. 1 are those which describe the envelope of a sine wave plus random noise. These density functions are given by S. O. Rice* is

$$P_S(X) = e^{-S/N} e^{\frac{-X^2}{2N}} I_o(\sqrt{2}\ \sqrt{S/N}\ \frac{X}{\sqrt{N}})$$

$$P_N(X) = \frac{X}{N} e^{-\frac{X^2}{2N}}$$

where X is the height of the envelope
N is the average noise power
S is the average signal power
I_o is the modified Bessel function of order o .

(U) Using these two equations to compute likelihood ratio, Eq. 1 yields

$$L_X = e^{-S/N} I_o(\sqrt{2}\ \sqrt{S/N}\ \frac{X}{\sqrt{N}}) .$$

---

*Rice, S. O., "Mathematical Analysis of Random Noise," Bell System Technical Journal, Vol. 24, 1945, p. 100.

As given by Rice, the output noise mean, μ, is $\sqrt{N\pi/2}$ and the output noise standard deviation σ is $\sqrt{N(2-\pi/2)}$. If r denotes the envelope height in units of σ relative to μ, then

$$r = (X-u)/\sigma$$

or

$$X = \sigma \cdot r + u$$

$$= \sqrt{N(2-\pi/2)} \cdot r + \sqrt{N\pi/2} \quad .$$

Substitution for X in the equation for L_X above yields

$$L_X = e^{-S/N} \, I_o[\sqrt{S/N} \, (\sqrt{4-\pi} \cdot r + \sqrt{\pi} \,] \qquad (2)$$

The conversion algorithm for correlator output amplitude samples X is then obtained by taking the natural logarithm of Eq. 2 where X has been converted to r using measured values of u and σ. This has been done in Fig. A-1 where the logarithm of Eq. 2 has been plotted as a function of r for three values of S/N that yield average output signal-to-noise ratios of 10 dB, 11 dB and 12 dB.

(U) The curves that appear in Fig. A-1 thus yield the fruitful result that the logarithm of Eq. 2 is closely approximately by a straight line in the region of interest (i.e. values of r from 2 to 6 which correspond to output signal-to-noise ratios from 6 dB to 15.5 dB). The logarithm of likelihood ratio conversion of a measured output peak of amplitude X then reduces to

$$\ln L_X = a \cdot r + b$$

$$= a\left(\frac{X-u}{\sigma}\right) + b$$

$$\ln L_X = \frac{a}{\sigma} \cdot X + b - \frac{au}{\sigma} \qquad (3)$$

where a and b are the slope and slope intercept values defining the appropriate straight line in Fig. A-1 and u and σ are measured values of correlator output noise mean and standard deviation. For example, if the expected correlator output signal-to-noise ratio is to be set at 10 dB, then Fig. A-1 is examined and values of a = 2.0 and b = -2.86 are computed as (the values) determining the straight line marked 10 dB. In this case then, the transformation from peak height X to logarithm of likelihood ratio $\ln L_X$ is given by

$$\ln L_X = 2.0 \frac{X}{\sigma} - 2.86 - \frac{2.0u}{\sigma} .$$

(U) In summary, the assumption that correlator output peak statistics are described on a multiping basis by the distribution of constant amplitude ideal signal plus Gaussian noise yields the easily implemented linear transformation in Eq. 3 from peak height to logarithm of likelihood ratio.

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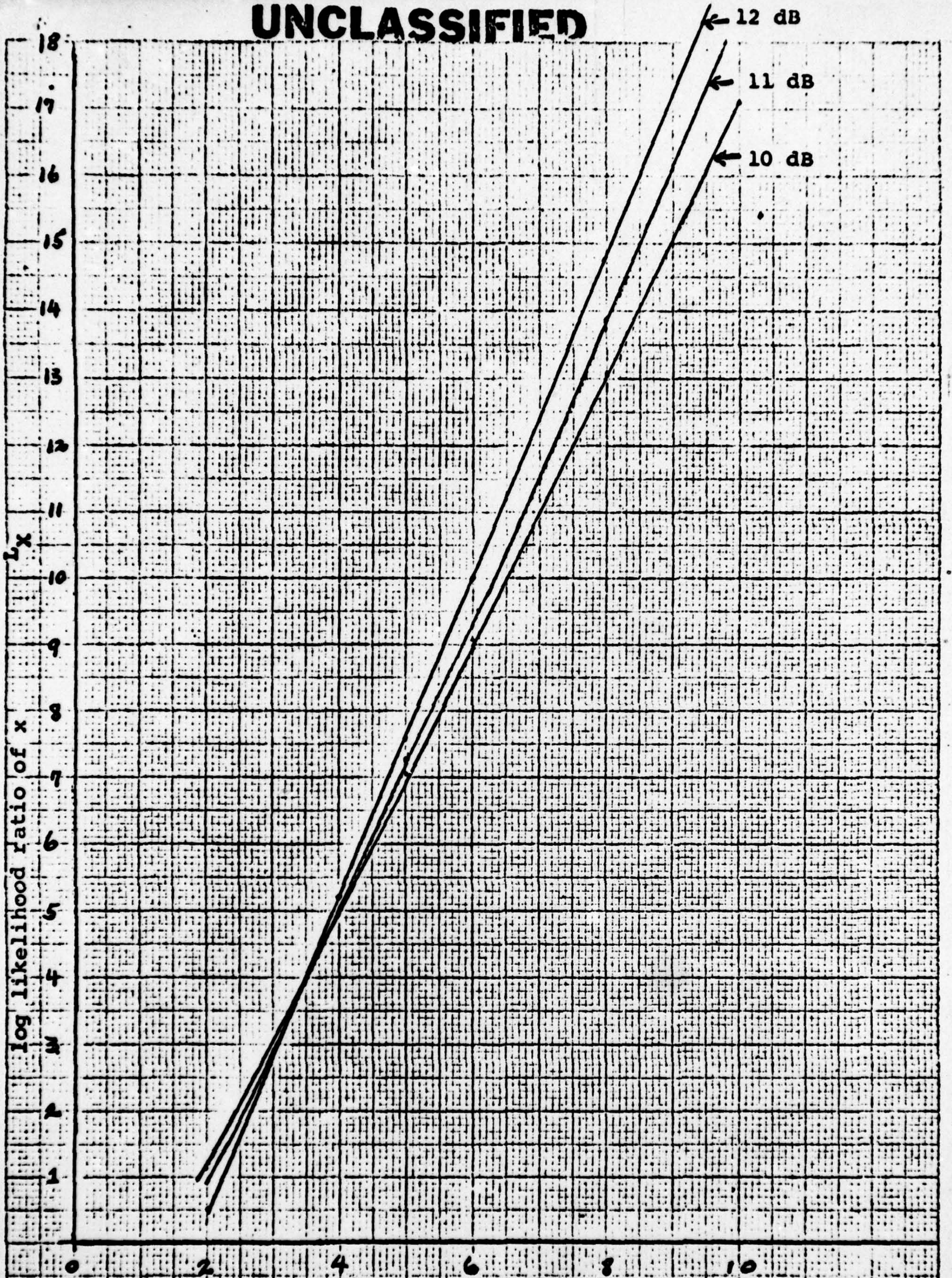

Fig. A-1

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3. LOG LIKELIHOOD RATIO OF RAYLEIGH SIGNAL PLUS RAYLEIGH NOISE

(U) Although the log likelihood ratio conversion discussed in Section 2 is simple to implement, the assumptions upon which it is based seem rather stringent. In particular, the assumption that consecutive echo cycles contain ideal constant amplitude signals plus Gaussian noise is not confirmed by empirical data which indicates that peak heights have a larger variation than that expected in an ideal case. For this reason, a "noisy" signal distribution was considered. This distribution is to be denoted as Rayleigh signal plus Rayleigh noise.

(U) The Rayleigh probability density function, which is identical to the Rice noise alone distribution, is given by

$$P(X) = \frac{X}{\alpha^2} e^{-\frac{X^2}{2\alpha^2}} .$$

The signal-plus-noise hypothesis investigated in this section assumes that both signal-plus-noise and noise alone peaks are distributed by Rayleigh density functions P_S and P_N with different parameters α_S and α_N. Hence

$$P_S(X) = \frac{X}{\alpha_S} e^{-\frac{X^2}{2\alpha_s^2}}$$

and

$$P_u(S) = \frac{X}{\alpha_N} e^{-\frac{X^2}{2\alpha_n^2}}$$

Under the assumption of the above density factors, the likelihood ratio measurement L_X is given by

$$L_X = \frac{\alpha_u^2}{\alpha_s^2} \; e^{X^2\left(\frac{1}{2\alpha_n^2} - \frac{1}{2\alpha_s^2}\right)}$$

The mean values u_s and u_n and standard deviation values σ_s and σ_n of the signal and noise distributions are given by

$$u_s = \alpha_s \sqrt{\pi/2} \quad ;$$

$$u_n = \alpha_n \sqrt{\pi/2}$$

$$\sigma_s = \alpha_s \sqrt{2 - \pi/2}$$

$$\sigma_n = \alpha_n \sqrt{2 - \pi/2} \quad .$$

Consequently, amplitude values X, when measured in units r of noise standard deviation σ_n relative to the noise mean u_n are given by

$$X = \sigma_n \, r + u_n$$

$$= \alpha_n \sqrt{2 - \pi/2} \; r + \alpha_n \sqrt{\pi/2}$$

Substituting the above for X in the expression above for L_X, the following is obtained

$$L_X = \frac{\alpha_n^2}{\alpha_s^2} \; e^{\alpha_n^2 [k_1 r + k_2]^2 \left(\frac{1}{2\alpha_n^2} - \frac{1}{2\alpha_s^2}\right)}$$

$$= \frac{\alpha_n^2}{\alpha_s^2} \; e^{[k_1 r + k_2]^2 \left(\frac{1}{2} - \frac{d_n^2}{2\alpha s^2}\right)}$$

where $k_1 = \sqrt{2 - \pi/2}$ and $k_2 = \sqrt{\pi/2}$.

Finally, taking log likelihood ration, we obtain

$$\ln L_X = \ln\left(\frac{\alpha_n^2}{\alpha_s^2}\right) + \left(\frac{1}{2} - \frac{\alpha_n^2}{2\alpha_s^2}\right)[k_1 r + k_2]^2 \qquad (4)$$

The relation between $\frac{\alpha_n}{\alpha_s}$ and correlator output signal-to-noise ratio is easily obtained. For example, since the tracking model is to be optimized for 10 dB, it is required that

$$10 = 20 \log \left(\frac{u_s - u_n}{\sigma_n}\right)$$

$$= 20 \log \left(\frac{\alpha_s\ k_2 - \alpha_n\ k_2}{\alpha_n k_1}\right)$$

$$= 20 \log \left(\frac{\alpha_s}{\alpha_n} \frac{k_2}{k_1} - \frac{k_2}{k_1}\right)$$

Consequently,

$$\frac{\alpha_s}{\alpha_n} = \frac{k_1}{k_2} \sqrt{10} + 1 = 2.65 \quad \text{and} \quad \frac{\alpha_n}{\alpha_s} = .377$$

Thus, to optimize Eq. 4 for a 10 dB correlator output signal-to-noise ratio, the value .377 is substituted in Eq. 4 for $\frac{\alpha_n}{\alpha_s}$ and the following conversion algorithm results.

$$\ell m\ L_X = \ell n(.377)^2 + (\tfrac{1}{2} - .377^2)[k_1 r + k_2]^2$$

$$= -1.275 + (0.706)r + (0.185)r^2$$

(U) Equation 4 has been evaluated for values of $\frac{\alpha_n}{\alpha_s}$ corresponding to correlator output signal-to-noise ratios of 10 dB and 11.5 dB. The resulting curves in which $\ell n\ L_X$ is plotted as a function of r appear in Fig. A-2. The quadratic transformation indicated in Eq. 4 may be simplified further by computing a least means square linear fit in the region of interest to the curves in Fig. A-2. This has been done for the 10 dB curve and the resulting linear fit is indicated by the dotted line. The slope and slope intercept values a and b yield a simplified log likelihood transformation given by

$$\ell n\ L_X = 2.45r - 5.2$$

(U) In summary, the assumption of a Rayleigh signal plus Rayleigh noise distribution yields a quadratic transformation from peak height X to log likelihood ratio that is quite practical to implement and which further may be approximated by a linear transformation in the range of interesting signal-to-noise ratio. This form of log likelihood ratio transform is being used in the validation study.

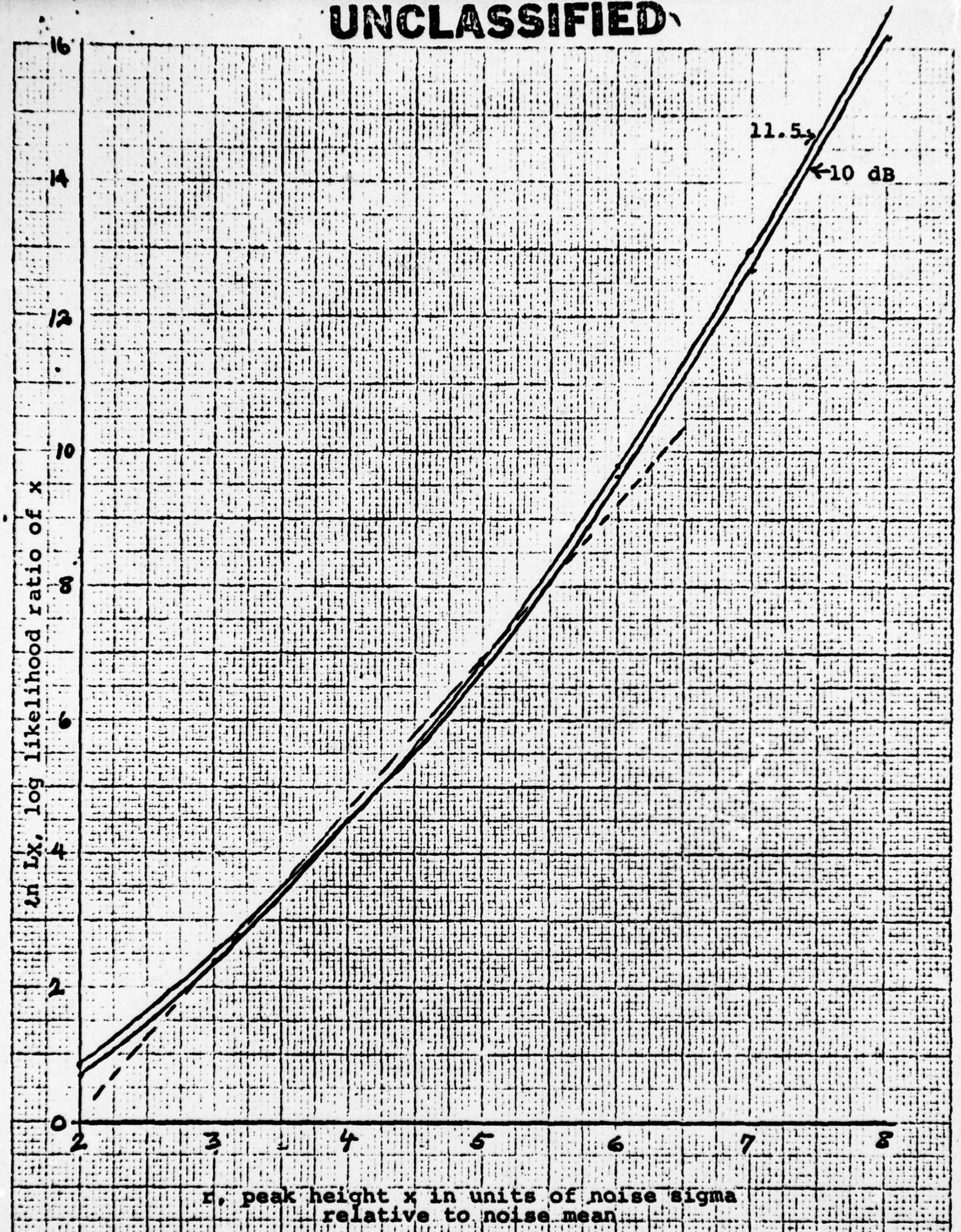
16
14
12
10
8
6
4
2
0
2
3
4
5
6
7
8
11.5
10 dB
ln Lx, log likelihood ratio of x
r, peak height x in units of noise sigma relative to noise mean

Fig. A-2

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DOCUMENT CONTROL DATA - R&D

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1. ORIGINATING ACTIVITY *(Corporate author)*

UNITECH, Inc.
2209 Manor Road
Austin, Texas 78722

2a. REPORT SECURITY CLASSIFICATION

[redacted]

2b. GROUP

IV

~~**3. REPORT TITLE**~~

(6) VALIDATION OF THE COMPUTER AIDED DETECTION MODEL USING SEA DATA: PRELIMINARY RESULTS.

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

INTERIM TECHNICAL REPORT TYPE I

5. AUTHOR(S) *(Last name, first name, initial)*

[redacted]; (10) HOWARD R. Courts

(14) UNITECH-68-035-C

~~**6. REPORT DATE**~~

(11) 16 Dec[redacted] [redacted]968

(12) 43p.

7a. TOTAL NO. OF PAGES

39

7b. NO. OF REFS

-0-

~~**8a. CONTRACT OR GRANT NO.**~~

(15) N00024-68-C-1238

9a. ORIGINATOR'S REPORT NUMBER(S)

Document Number 68-035-C

~~**b. PROJECT NO.**~~

(9) Quarterly progress rept. no. 2,

c.

d.

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

10. AVAILABILITY/LIMITATION NOTICES

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11. SUPPLEMENTARY NOTES

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13. ABSTRACT

This report contains preliminary results obtained by processing sea data through the computer-aided-detection. (U)

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A		LINK B		LINK C	
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