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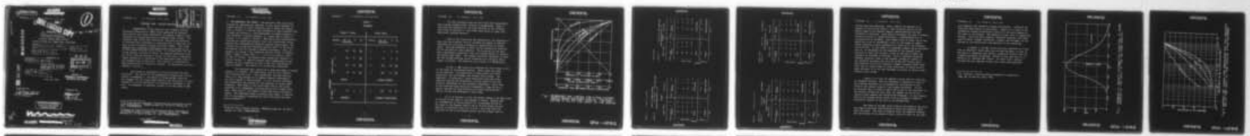

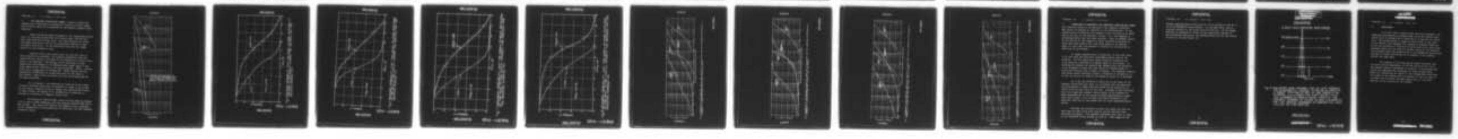

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TECHNICAL NOTE

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TECHNICAL NOTE - DISPLAY ANALYSIS

1. INTRODUCTION - This technical note compares receiver operating characteristic (ROC) curves generated by observers with clutter rate curves obtained by the digital computer sonar simulator for 6-ping histories of simulated sonar returns. The observer's ROC curves were obtained by requiring the observers to indicate their confidence in decisions that a signal was present on each of several hundred film-strip frames. Each frame presented an independent simulated 6-echo cycle history at one of four signal-to-noise ratios (S/N). It is shown that, for the 6-ping history situation at least, the computer generated curves are better than the observer's curves (in the sense of showing a larger probability of detection at the same false alarm rate) at low probabilities of detection. The situation is reversed for high probabilities of detection, however. An explanation for this behavior is given.

The method of preparation of the film-strips has been described[1]. The results of the experimental observations are presented in paragraph 2. The manner of obtaining ROC curves by the computer for the single-ping condition has been given in detail elsewhere[2]; a brief description is presented in paragraph 3, however. In paragraph 4 comparison is made of the two types of ROC curves.

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[1] J.M. Young and D.E. Robinson, "Processing Gain Achievable by Ping-to-Ping Integration," TRACOR Document No. 64-221-C, October 22, 1964, (CONFIDENTIAL).

[2] "Analysis of Signal Processing and Related Topics Pertaining to the AN/SQS-26 Sonar Equipment (U), A Summary Report II," TRACOR Document No. 64-290-C, October 16, 1964, (CONFIDENTIAL).

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2. THE OBSERVER'S ROC CURVES - The observer's ROC curves were obtained by requiring the observers to rate their responses of "signal present" by their confidence that a signal was present. Thus, a rating of 1 denoted high confidence or near certainty that a signal was present; 2, less assuredness in signal presence; 3, low confidence in signal presence; 4, a guess that a signal is present; 5, no signal is present. ROC curves were constructed by plotting the cumulative percent "hits" for a particular rating against the corresponding cumulative percent false alarms. For a particular rating the cumulative percent "hits" is the sum of the percent hits for ratings of greater confidence. Thus, for example, for rating 3 the cumulative percent "hits" is $\Sigma[P(D)_1 + P(D)_2, + P(D)_3]$, where $P(D)_i$, i - 1,2,3 is the percent "hits" for the i^{th} rating. The percent false alarms are treated in a similar fashion. A typical response sheet summarizing the performance of four observers for one of the test film-strips is shown in TABLE I. The values to be plotted are underlined.

The observers were instructed to keep the number of missed signals to a minimum. The observation time for each frame of the film-strip was 6 sec. This observation time was used because it is long enough not to degrade operator performance [3] yet short enough to avoid boredom. A 3 sec interval following each observation was allowed for the operators to record their responses. Each frame of the film-strips used in this study consisted of an independent six-ping history for a single sonar beam. About half of the frames in each film-strip contained a signal. The remaining frames contained noise alone. A description of the method of preparing the test film-strips has been given elsewhere[1,2].

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[3] Technical Note, Display Analysis, TRACOR Document No. 65-107-C, January 15, 1965, (CONFIDENTIAL).

TABLE I

STIMULUS

		Signal + Noise				Noise Alone			
		Rating	No. of Responses	%	Σ%	Rating	No. of Responses	%	Σ%
RESPONSE	Signal Present	1	157	30	30	1	1	0	0
		2	163	31	61	2	14	2	2
		3	131	25	86	3	109	18	20
		4	58	11	97	4	266	44	64
			(HITS)				(FALSE ALARMS)		
	No Signal	5	11	2	2	5	210	35	35
			(MISSES)				(CORRECT REJECTIONS)		

The four observers used for this study were young adult, male college students with a variety of backgrounds. Some of them were the observers for the work reported in the technical note cited in footnote 3. The others were given at least five, three-hour training sessions.

Each of the film-strips was presented to the observers on more than one occasion, both to increase the number of operator decisions and to provide a measure of repeatability or consistency. The data presented in Table II were obtained by totaling all of the data for each condition. The variation in the data (for a particular condition), from one viewing session to another, was surprisingly small. The largest variations naturally occurred for the ratings denoting little confidence in a decision that a signal is present. The observers were scored on a YES-NO basis.

In Fig. 1, ROC curves are presented for four values of S/N at the input to the matched display. Three scales are shown on the abscissa: the probability of false alarm, the false alarm rate, and the average time between false alarms. The operators', or observers', false alarm rate scale was determined by dividing the probability of false alarm by the time interval represented by the displayed information. Since each of our simulated ping histories corresponds to some 18 sec of actual time and six ping histories are shown simultaneously, 108 sec of data are portrayed in each frame.

It is of interest to note the marked change in the ROC curves as the S/N at the input to the display is varied. Observe that at a probability of false alarm of 0.2, increasing the S/N at the input to the display from 8.5 dB to 10.0 dB raises the probability of detection from 0.34 to 0.84. Also note that the curve for 8.5 dB is not greatly better than the chance line re-

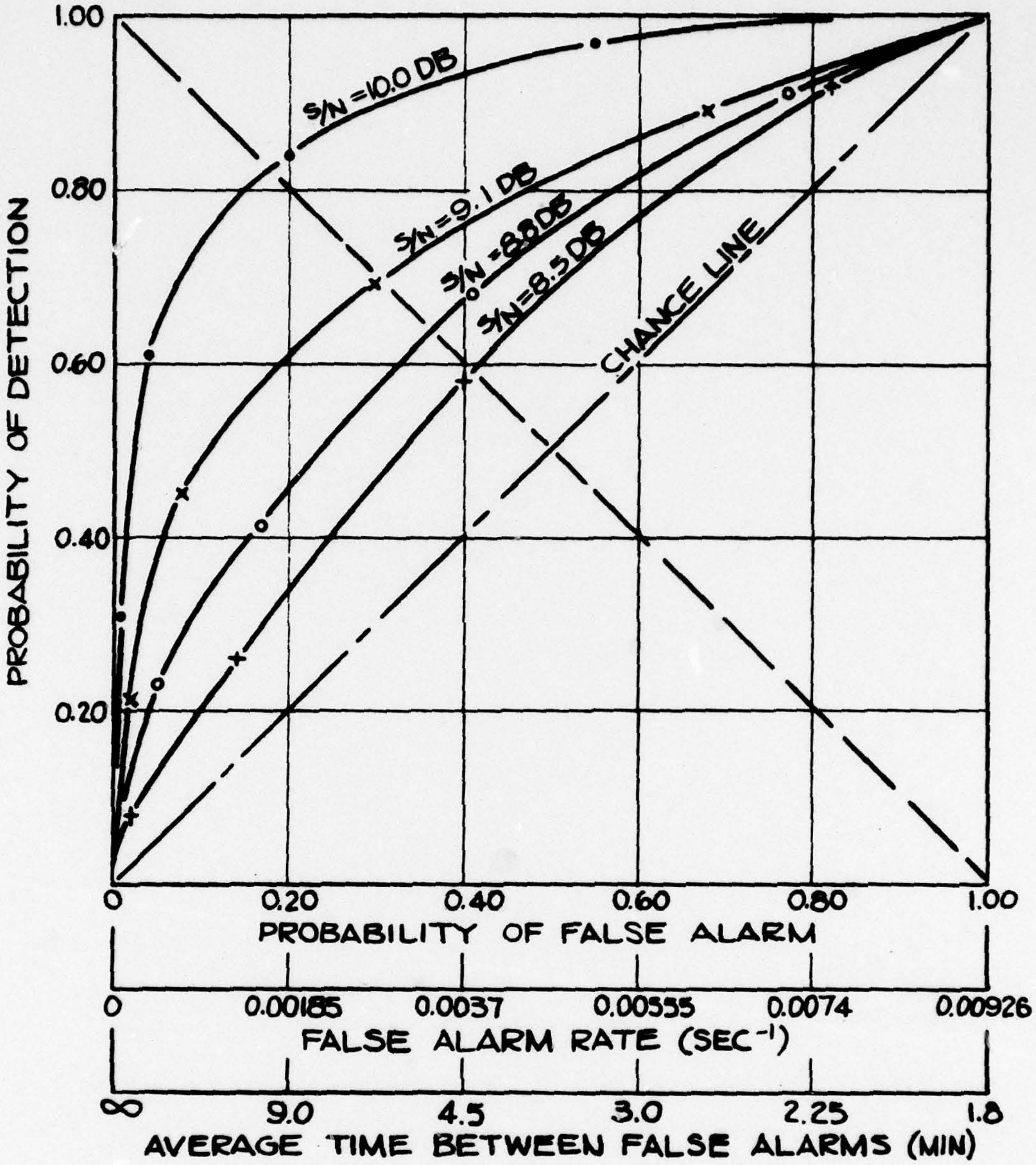

Fig. 1 OBSERVERS' ROC CURVES FOR 6-PING HISTORY, SINGLE BEAM MATCHED DISPLAY. THE PARAMETER IS S/N AT THE INPUT TO THE DISPLAY.

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TABLE II - SUMMARY OF RESULTS

Run No. 18 S/N = 10.0 dB 2250 Frames Judged

Measured Marking Density = 0.24

STIMULUS

RESPONSE	Signal + Noise				Noise Alone			
	Rating	No. of Responses	%	Σ%	Rating	No. of Responses	%	Σ%
Signal Present	1	314	31	31	1	7	1	1
	2	317	30	61	2	36	3	4
	3	243	23	84	3	190	16	20
	4	135	13	97	4	423	35	55
		(HITS)				(FALSE ALARMS)		
No Signal	5	37	4	4	5	548	48	5
		(MISSES)				(CORRECT REJECTIONS)		
		1046				1204		

Table II (Cont)

Run No. 10 S/N = 9.1 dB 2085 Frames Judged

Measured Marking Density = 0.24

STIMULUS

RESPONSE	Signal + Noise				Noise Alone			
	Rating	No. of Responses	%	Σ%	Rating	No. of Responses	%	Σ%
Signal Present	1	207	21	21	1	14	2	2
	2	224	24	45	2	78	6	8
	3	240	24	69	3	245	22	30
	4	197	20	89	4	410	38	68
		(HITS)				(FALSE ALARMS)		
No Signal	5.	103	11	11	5	367	33	33
		(MISSES)				(CORRECT REJECTIONS)		
		971				1114		

Table II (cont)

Run No. 25 S/N = 8.8 dB 3080 Judgments

STIMULUS

Measured Marking Density = 0.22

RESPONSE	Signal + Noise Rating	No. of Responses	%	Σ%	Noise Alone Rating	No. of Responses	%	Σ%
Signal Present	1	333	23	23	1	82	5	5
	2	261	18	41	2	196	12	17
	3	391	27	68	3	392	24	41
	4	333	23	91	4	588	36	77
		(HITS)				(FALSE ALARMS)		
No Signal	5	131	9	9	5	373	23	23
		(MISSES)				(CORRECT REJECTIONS)		
		1449				1631		

Table II (cont)

Run No. 52 S/N = 8.5 dB 2100 Judgments

Measured Marking Density = 0.22

STIMULUS

RESPONSE	Signal + Noise Rating	No. of Responses	%	Σ%	Noise Alone Rating	No. of Responses	%	Σ%
Signal Present	1	78	8	8	1	29	2	2
	2	124	18	26	2	133	12	14
	3	301	32	58	3	300	26	20
	4	327	34	92	4	478	42	82
		(HITS)				(FALSE ALARMS)		
No Signal	5	72	8	8	5	208	18	18
		(MISSES)				(CORRECT REJECTIONS)		
		952				1148		

sulting from mere guessing. (Here, signals are assumed to be present in half of the trials.) This situation points out the narrow range in S/N between complete undetectability and near certainty of detection. When digital techniques are used to analyze records of noise, or signal-plus-noise, a predetermined set of decisions must be followed. Each sample value of noise can be compared with a set of thresholds; a plot of the number of sample values exceeding a given threshold as a function of the threshold value results. If the number of independent sample values available per sec, as determined by the bandwidth of the original noise function is taken into account, a plot of the rate at which the threshold is exceeded is obtained. Since a threshold excession normally produces a mark on the display, tending to clutter it, the threshold excession rate will be called the "clutter rate." This practice will avoid confusion between "computer false alarm rate" and the normal usage of false alarm rate, in which the primary reference is to the rate (average of course) at which a sonar observer false alarms.

Figure 4 is a plot of computer clutter rate as a function of threshold setting. Here the threshold is measured in units of the standard deviation of the probability distribution of the noise at the scanned output of the clipped correlator. It will be recalled that, in order to match the output of the correlator to the display cathode ray tube, only the largest of each 24 successive output samples was retained and displayed. In this fashion each of the scanned output values could be assigned a separate, resolvable location on the face of the display-tube.

The shape of the ROC curves reflects the shape of the noise and signal-plus-noise distributions on which the observers based their decisions. The lack of symmetry about the negative diagonal and the failure of the slopes to have a value of unity at the negative diagonal both indicate a skewed distribution. Jeffress[4] has discussed these points in some detail. Figure 2 is a plot of the probability density distribution function of the noise samples at the input to the display. The skewness of this curve is immediately obvious. Since the noise samples, originally Gaussian, were band-pass-filtered, clipped, correlated, scanned, and averaged, the departure of the distribution from Gaussian is not surprising.

In Figure 3, the ROC curves have been replotted as a function of observers' false alarm rate on semi-log paper in order to facilitate a comparison with machine (computer) clutter rates for clipped correlation processing. Curves of this type will be referred to as "modified ROC curves". We shall first, however, describe how the computer clutter rate curves were generated.

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[4] L.A. Jeffress, "Stimulus-Oriented Approach to Detection," JASA, 36, pp.766-774, April 1964.

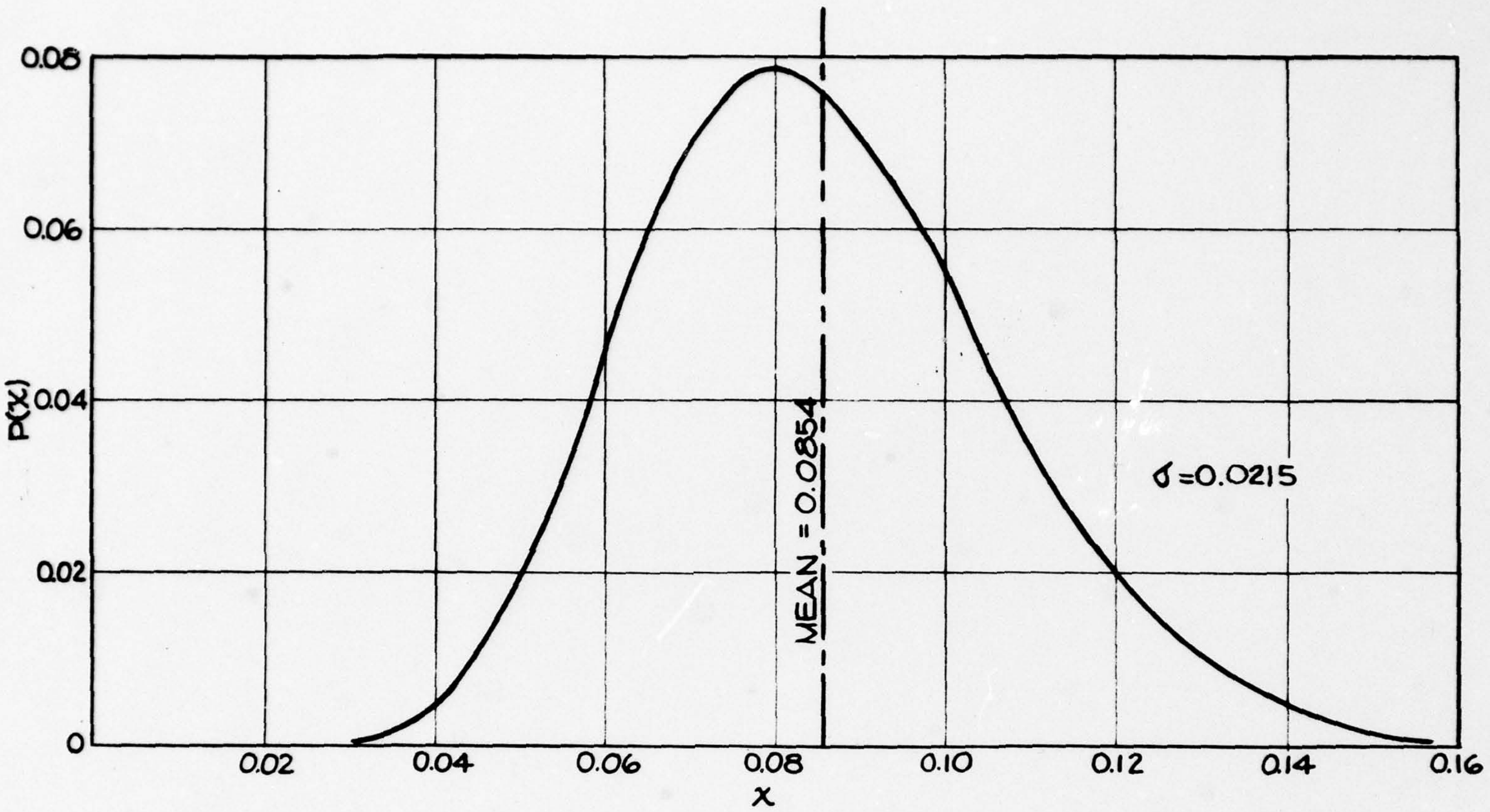

Fig. 2 PROBABILITY DENSITY DISTRIBUTION FUNCTION OF NOISE SAMPLES AT THE INPUT TO THE MATCHED DISPLAY

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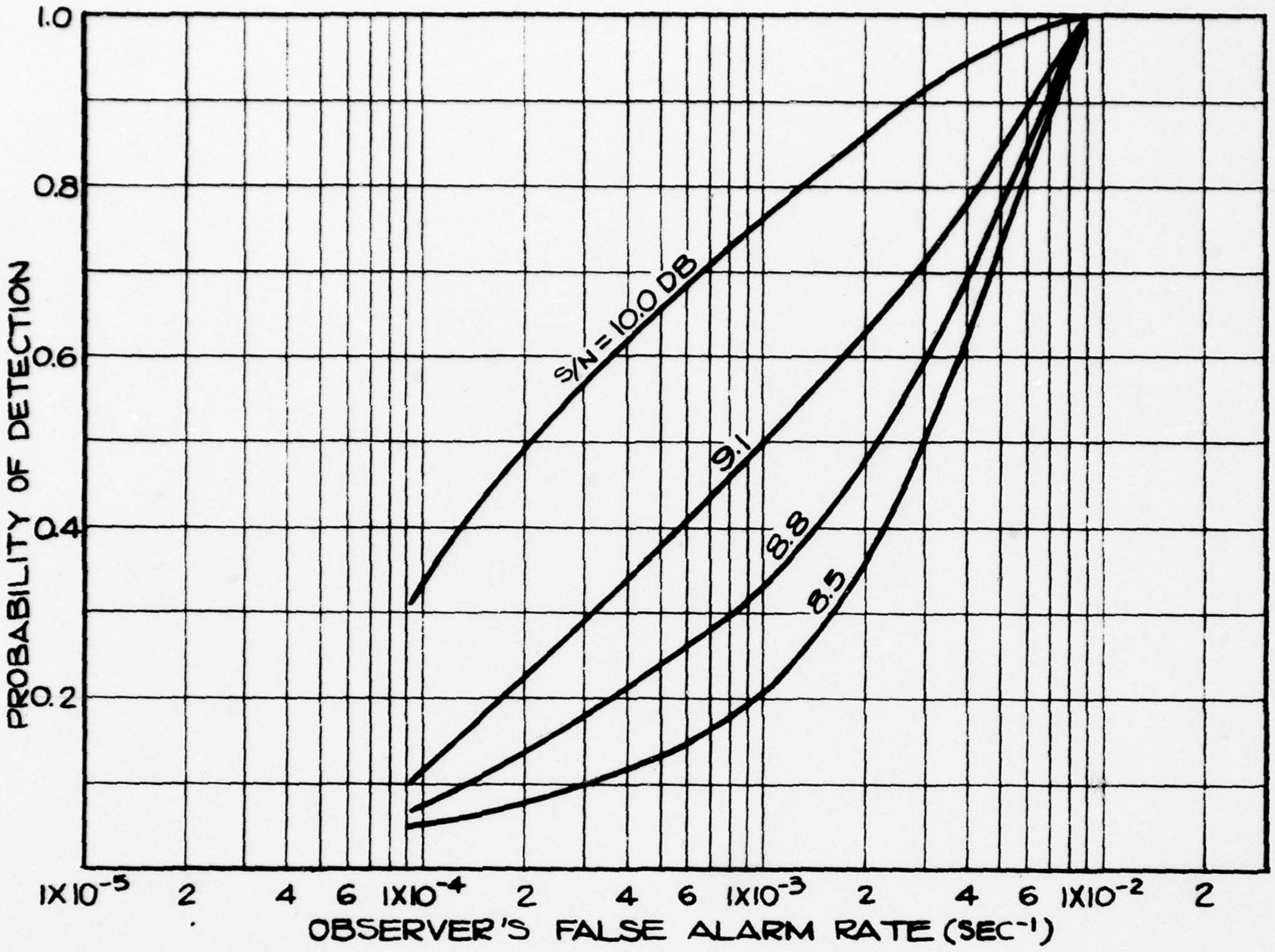

Fig. 3 MODIFIED ROC CURVES FOR OBSERVERS FOR THE INDICATED S/N AT THE INPUT TO THE DISPLAY. 6-PING HISTORIES

3. THE COMPUTER CLUTTER RATE CURVES - Curves in which the probability of detection is plotted as a function of false alarm rate (clutter rate) can be generated by the digital computer sonar simulator.

Three curves are shown in Figure 4, the single-ping clutter rate, the six-ping unrestricted scan clutter rate, and the six-ping restricted scan clutter rate. The unrestricted scan allows the signal position to vary by one resolution interval in each successive echo cycle. In the restricted scan case the signal position is not allowed to vary.

Figures 5-8 are plots which show, for the four sets of data viewed by the observers, the measured probability that the signal-to-noise ratio at the input to the display will exceed values given on the abscissa. The $(S/N)_{AV}$ values indicated on these figures are the averages of all measured peak signal power to rms noise power ratios occurring in the data presented. (Note: average power ratio is <u>not</u> equal to average dB). These figures show the probability distribution of signal-plus-noise at the input to the display. Again curves are shown for both the single-ping and six-ping situations.

If, in Figure 4, the threshold is converted to dB, representing a S/N ratio which must be exceeded if a mark is to be made on the display, Figures 5-8 may be mapped into modified ROC curves. In these curves, see Figures 9-12, probability of detection is plotted as a function of computer clutter rate.

The observer's modified ROC curves are also shown on Figures 9-12 so that a ready comparison with the computer modified ROC curves may be made. The curves for observer and computer cross, generally in the neighborhood of 50% probability of detection, but have markedly different slopes.

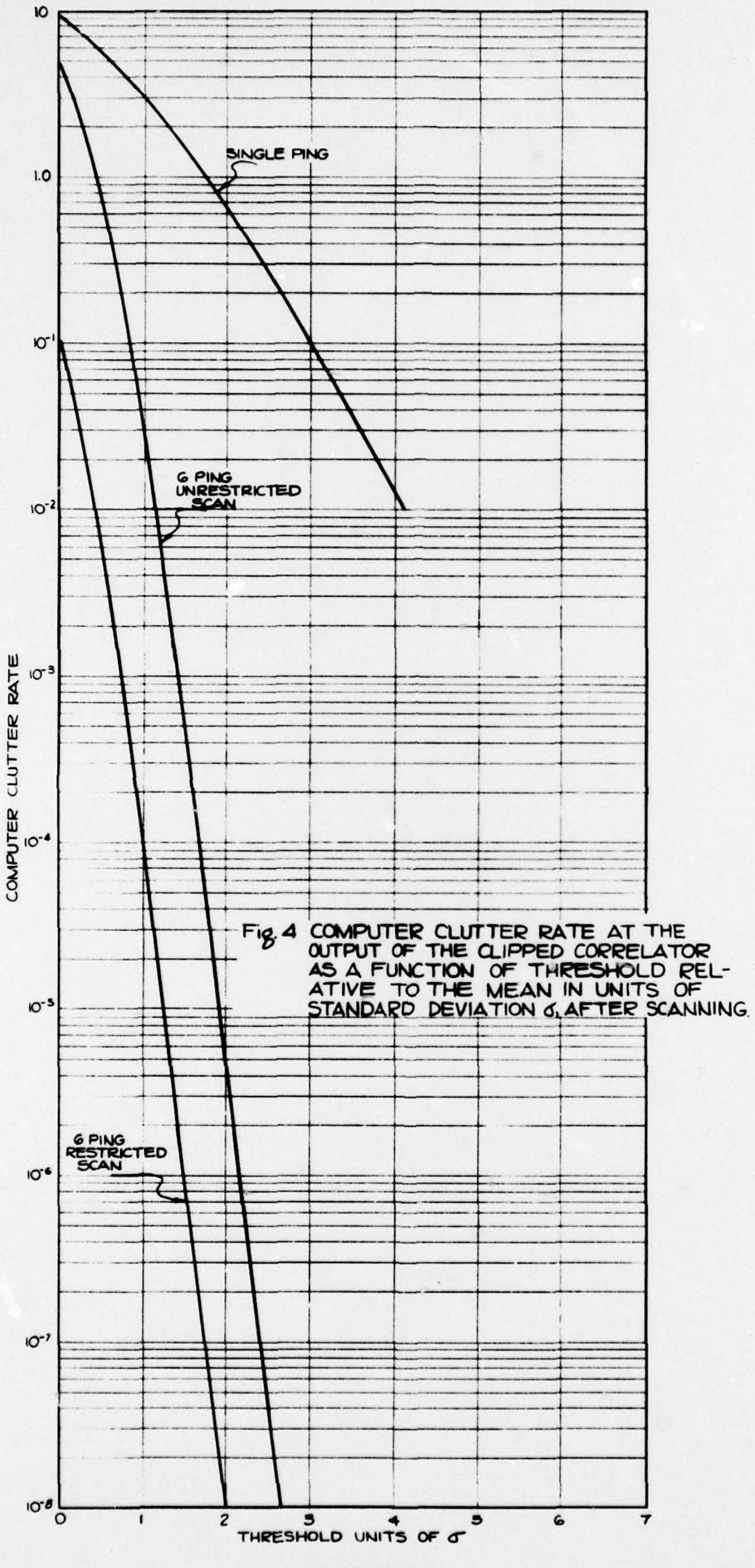

Fig. 4 COMPUTER CLUTTER RATE AT THE OUTPUT OF THE CLIPPED CORRELATOR AS A FUNCTION OF THRESHOLD RELATIVE TO THE MEAN IN UNITS OF STANDARD DEVIATION σ, AFTER SCANNING.

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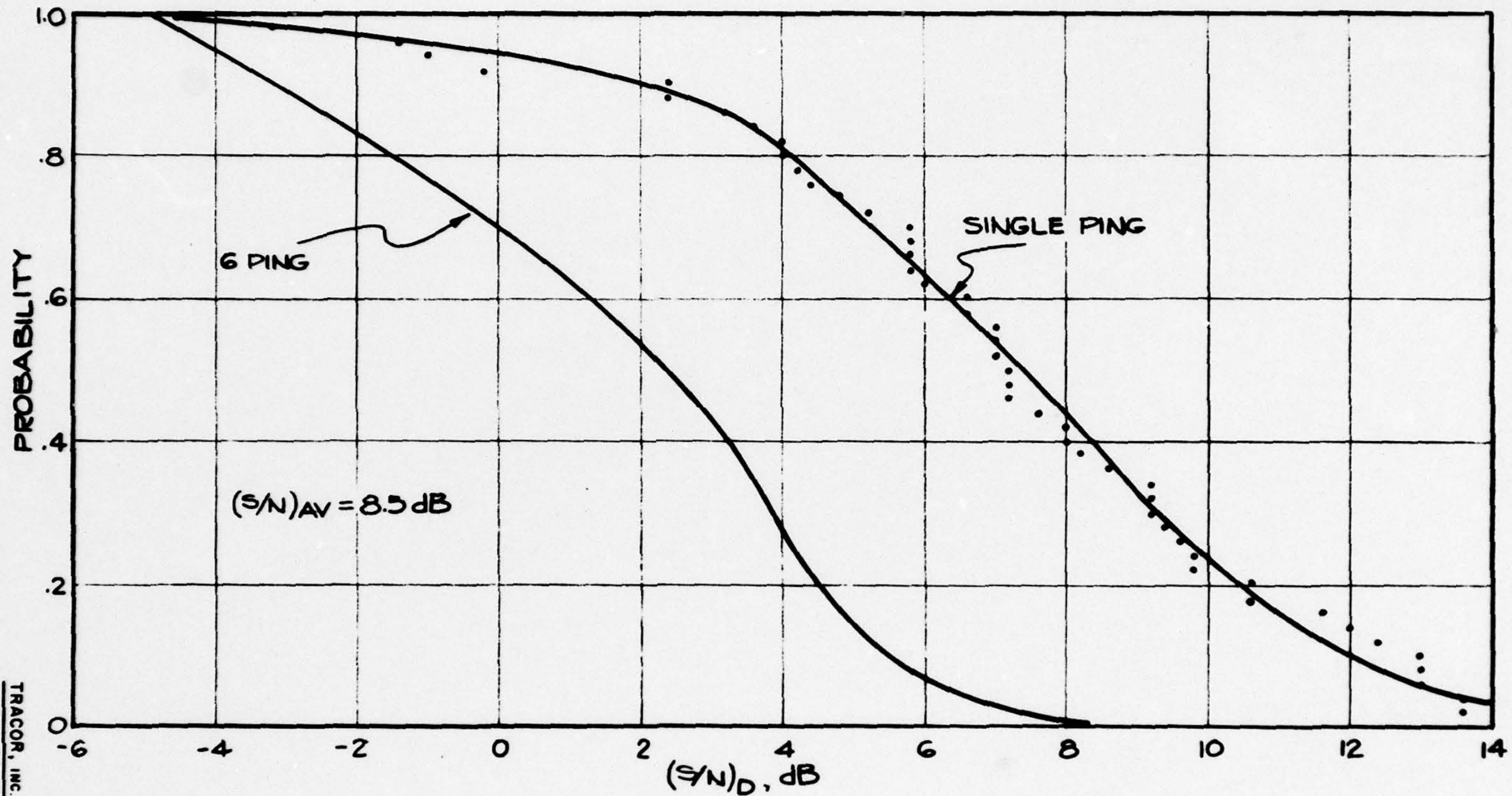

Fig. 5 MEASURED PROBABILITY THAT THE SIGNAL-TO-NOISE RATIO $(S/N)_D$ AT THE INPUT TO THE DISPLAY EXCEEDS THE ABSCISSA FOR THE INDICATED AVERAGE S/N.

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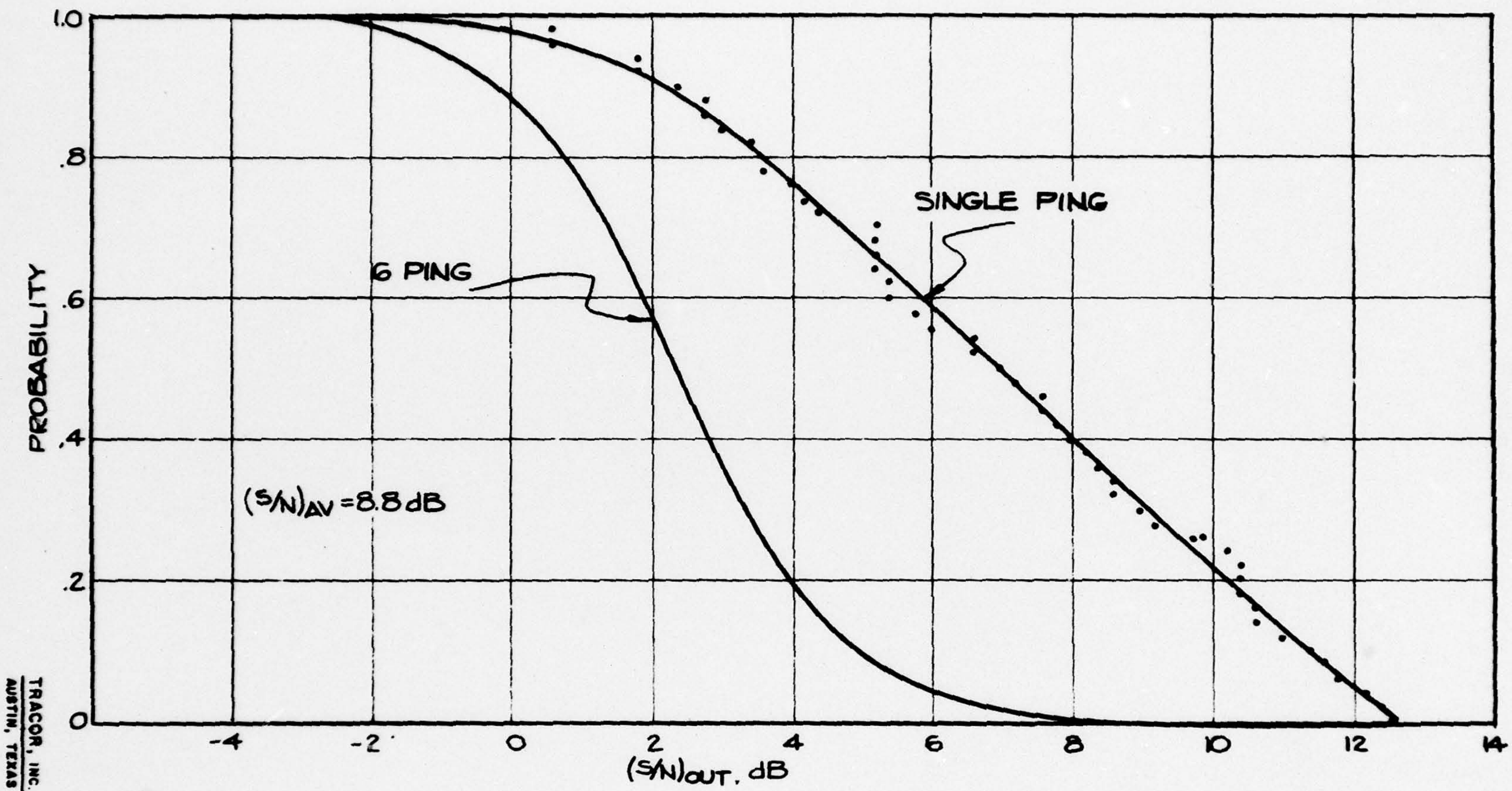

Fig. 6 MEASURED PROBABILITY THAT THE SIGNAL-TO-NOISE RATIO $(S/N)_D$ AT THE INPUT TO THE DISPLAY EXCEEDS THE ABSCISSA FOR THE INDICATED AVERAGE S/N.

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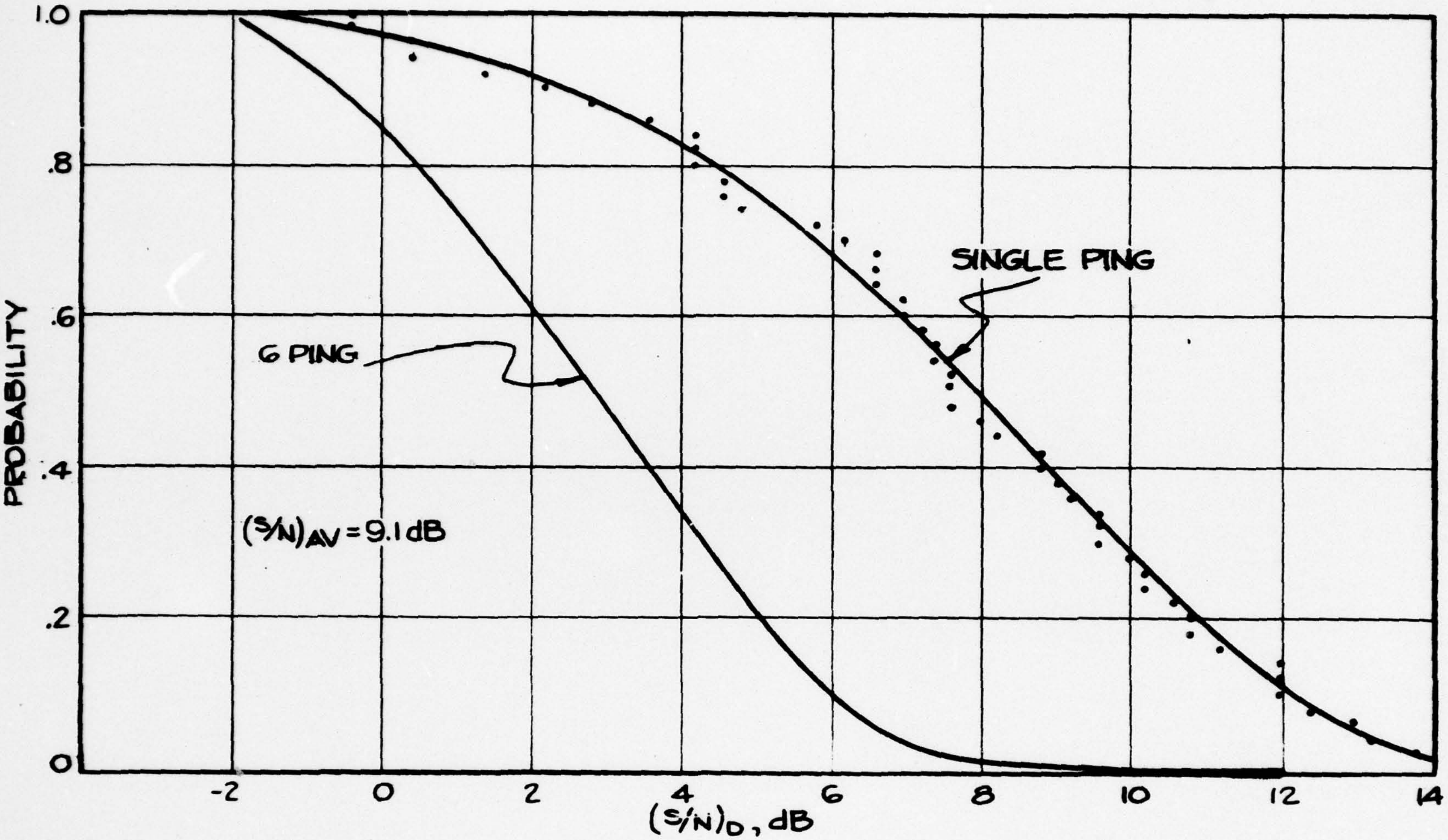

Fig. 7 MEASURED PROBABILITY THAT THE SIGNAL-TO-NOISE RATIO $(S/N)_D$ AT THE INPUT TO THE DISPLAY EXCEEDS THE ABSCISSA FOR THE INDICATED AVERAGE S/N.

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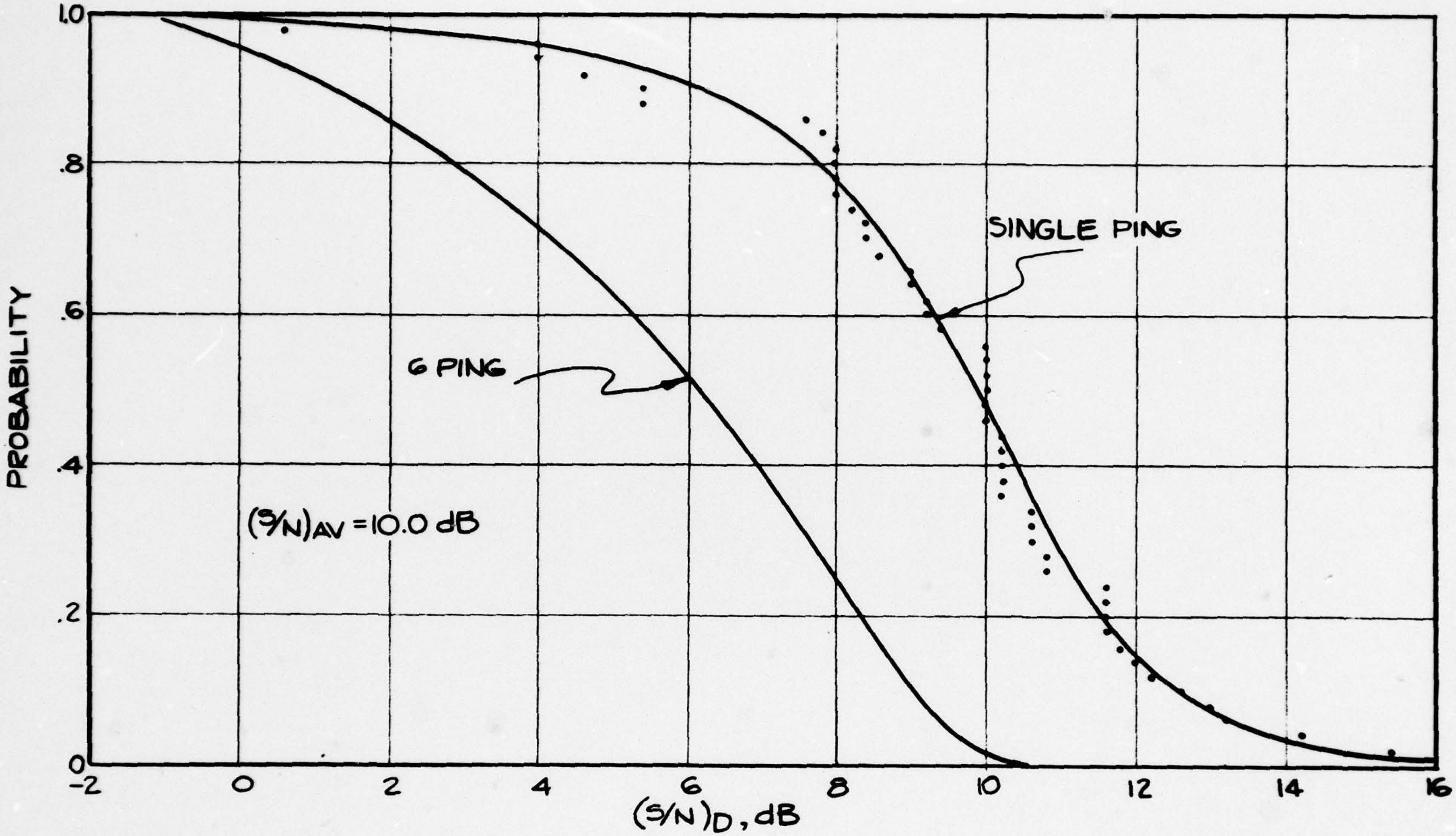

Fig. 8 MEASURED PROBABILITY THAT THE SIGNAL-TO-NOISE RATIO $(S/N)_D$ AT THE INPUT TO THE DISPLAY EXCEEDS THE ABSCISSA FOR THE INDICATED AVERAGE S/N.

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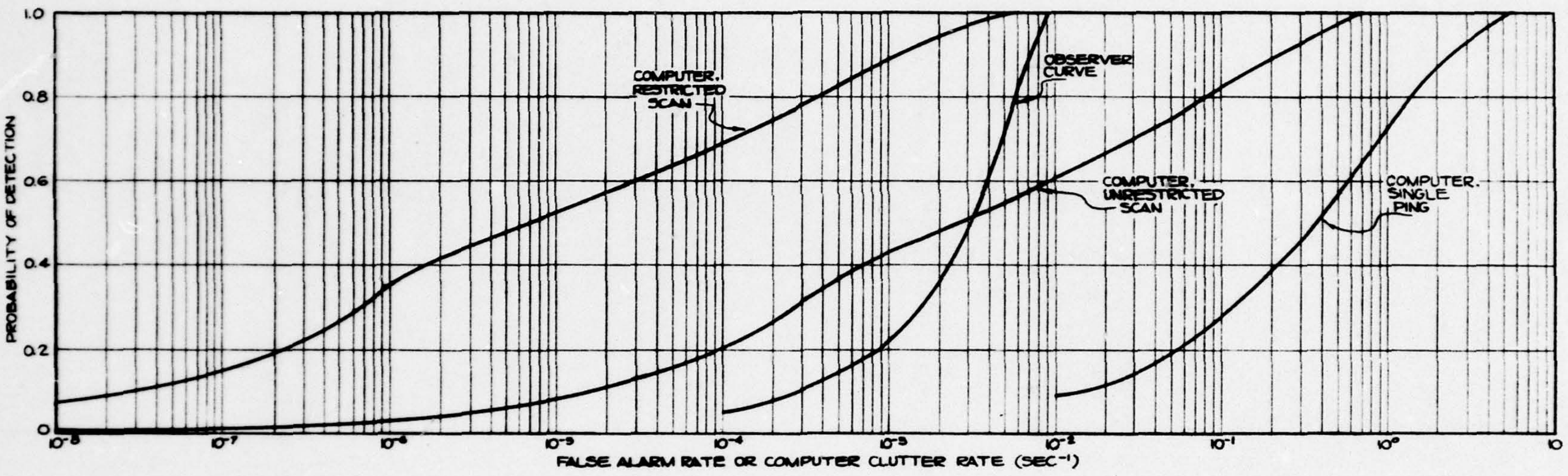

Fig. 9 A COMPARISON OF THE OBSERVER'S MODIFIED ROC CURVE FOR A 6 PING HISTORY AND THE COMPUTER CLUTTER RATE VS PROBABILITY OF DETECTION CURVE FOR A DISPLAY INPUT S/N = 8.5 dB.

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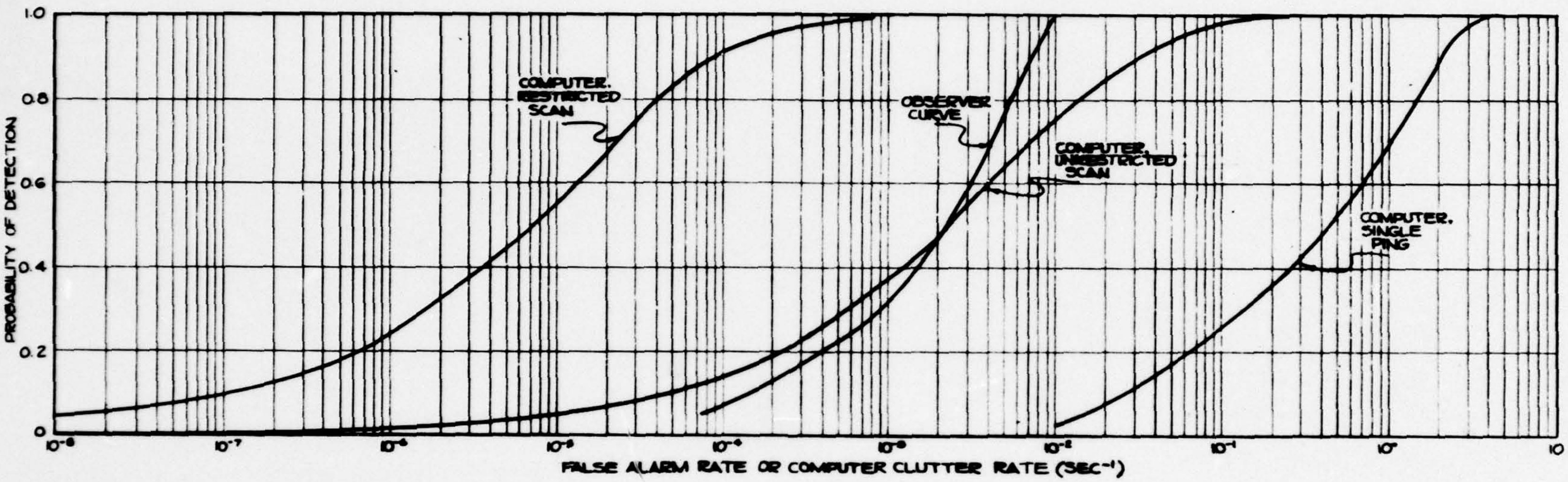

Fig. 10 A COMPARISON OF THE OBSERVER'S MODIFIED ROC CURVE FOR A 6 PING HISTORY AND THE COMPUTER CLUTTER RATE VS. PROBABILITY OF DETECTION CURVE FOR A DISPLAY INPUT S/N = 8.8 dB.

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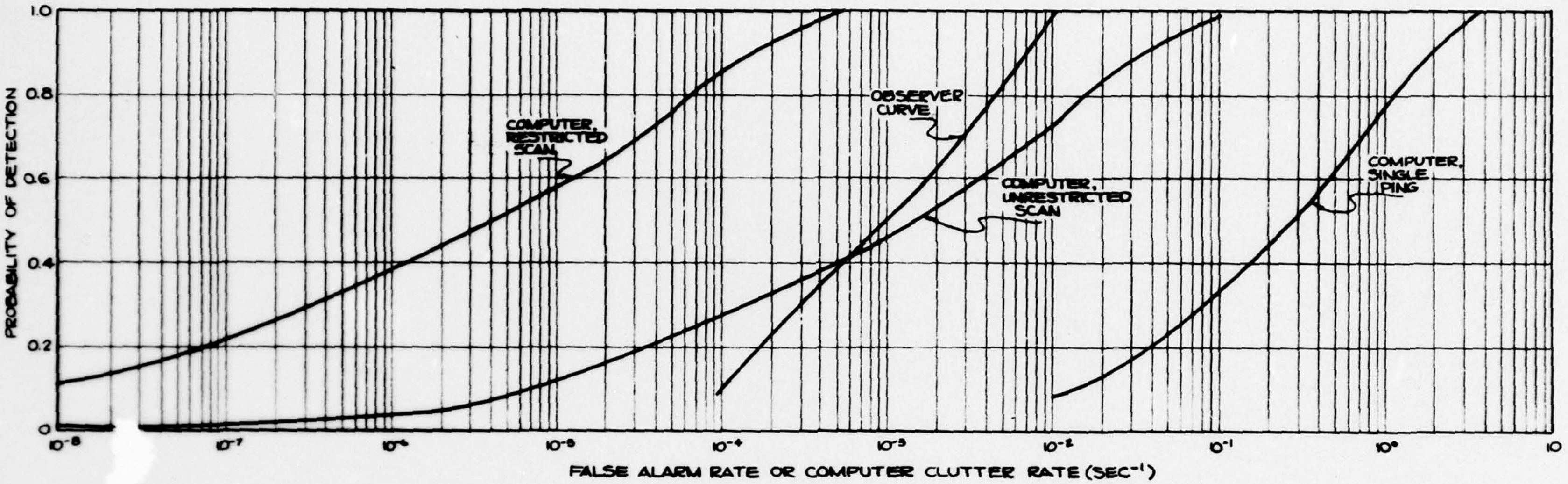

Fig 11 A COMPARISON OF THE OBSERVER'S MODIFIED ROC CURVE FOR A 6 PING HISTORY AND THE COMPUTER CLUTTER RATE VS. PROBABILITY OF DETECTION CURVE FOR A DISPLAY INPUT S/N = 9.1dB.

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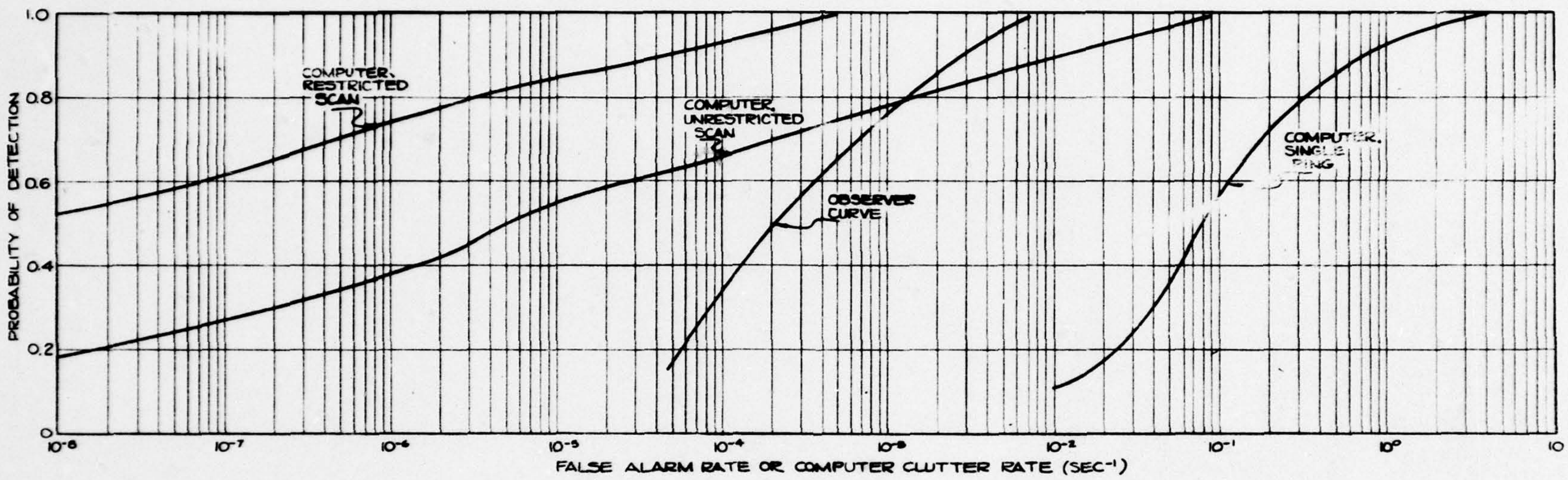

Fig 12 A COMPARISON OF THE OBSERVER'S MODIFIED ROC CURVE FOR A 6 PING HISTORY AND THE COMPUTER CLUTTER RATE VS. PROBABILITY OF DETECTION CURVE FOR A DISPLAY INPUT S/N = 10.0 dB.

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4. COMPARISON OF OBSERVER'S AND COMPUTER'S MODIFIED ROC CURVES

The different slopes of the observer's and computer's modified ROC curves can perhaps be explained in the following way. At low probabilities of detection the computer curves are seen to be above and to the left of the observer's curves, i.e., the computer is performing better than the human observer. This is probably caused by the ability of the computer to sense threshold excessions so small that they produce only very faint marks on the display - marks so faint that the observer's attention is not directed to that area of the display.

At higher probabilities of detection, on the other hand, it is seen that the observer's performance excels that of the computer. In this region more large threshold excessions are to be expected, resulting in brighter marks on the display. In scanning the display the observer may readily focus his attention on an alignment of marks and then search for fainter marks to verify his decision that a signal is present. The computer, however, only makes binary decisions; either a threshold is exceeded or it is not, no account is taken of the amount by which it is exceeded.

As to why the observer's curves are to the right of the computer restricted scan curve, it is doubted that the observers can discriminate a signal position offset of one resulution interval from one echo cycle to the next. Although we have presented only zero range-rate signals, which results in an alignment of marks perpendicular to the series of marks representing a single echo cycle return, we do not know and cannot determine if the observers look for, or can indeed tell if, exact perpendicularity exists.

Consider the situation in which the signal position can vary from one echo cycle to the next by one bin position (one resolvable interval). The measured resolvable spot size, or mark, on our simulated A-scan display is 0.02 cm. (The length of the display representing one echo cycle is 10 cm instead of some 10 in as in the AN/SQS-26 A-scan display. To the same scale, the resolution interval on the A-scan would be 0.02 in). If the target position is displaced or offset by one resolution interval for each successive echo-cycle, the maximum offset for six echo cycles is only 0.1 cm (see Figure 13).

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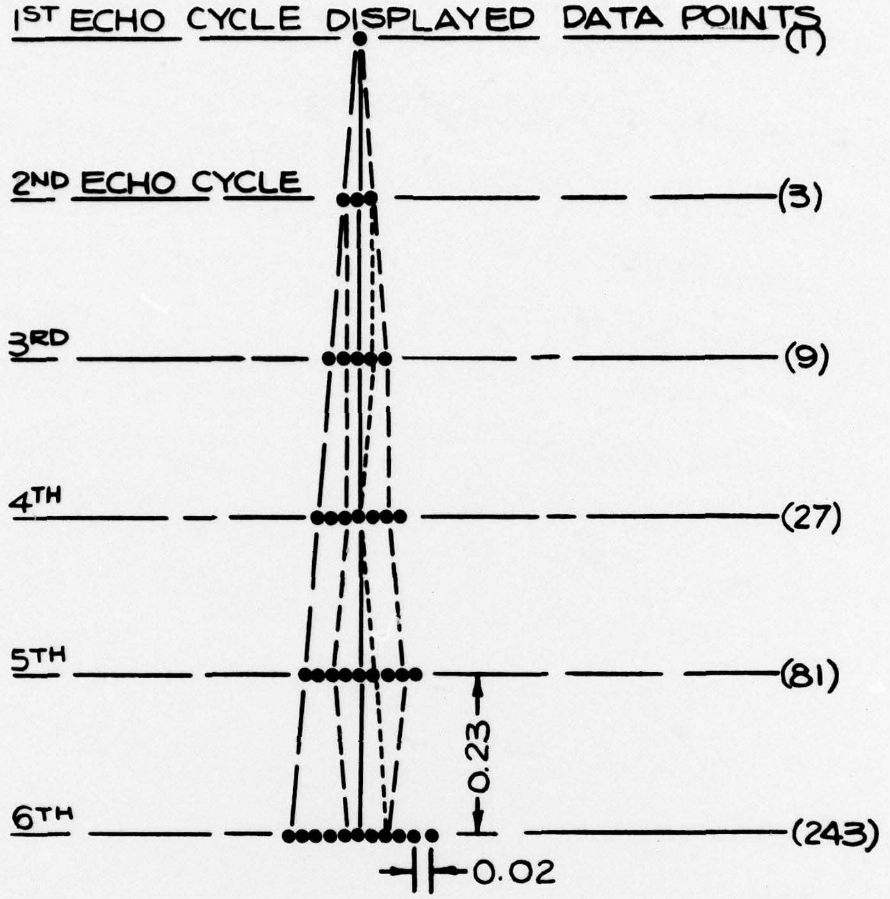

Fig. 13 ENLARGED VIEW SHOWING FIVE OF THE POSSIBLE 243 ALIGNMENTS LEADING TO FALSE ALARMS IF A TARGET POSITION OFFSET OF ONE RESOLUTION INTERVAL IS ALLOWED FOR EACH ECHO CYCLE. THE NUMBERS IN PARENTHESIS INDICATE THE POSSIBLE NUMBER OF FALSE ALARM ALIGNMENTS FOR THE VARIOUS NUMBERS OF SEQUENTIAL ECHO CYCLES ON THE DISPLAY.

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5. CONCLUSIONS

It is felt that a logical basis has been promulgated for comparing experimentally determined ROC curves and computer generated plots of probability of detection as a function of clutter rate. The narrow spread in signal-to-noise ratio at the input to the display that separates the regions of complete undetectability and certainty of detection in multi-echo cycle, multi-beam displays points out the need for careful control of the displays. The increased detection capabilities of the AN/SQS-26 sonar system provided by signal processing can be negated if the displays distort the input data.

The outputs of the sonar system signal processor must be stored without degradation of S/N and retrieved for use in the display without alternation of location. A continuing need exists for improving the techniques of using storage tubes. Means for normalizing the inputs to the storage-tube screen and the inputs to the display must be devised, so that an input at a certain S/N will have the same significance to the sonar observer at any location on the display.