AD-773 089

EFFECT OF HARD LIMITING ON THE RECOGNITION OF GRAM TYPE DISPLAYS

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2 October 1973

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NOLTR 73-189	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Effect of Hard Limiting on the Recognition Differential of Gram Type Displays		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) C. N. Pryor P. A. Kendall		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ordnance Laboratory Code 222 Silver Spring, Maryland 20910		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS A370-370A/WF11-121-703
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command Washington, D. C. 20360		12. REPORT DATE 2 October 1973
		13. NUMBER OF PAGES ~~25~~ 27
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Displays, CRT, Gram, Detection, Degradation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Intensity modulated gram displays are often stored digitally for later display generation, or are displayed on devices of limited dynamic range. The display degradation when using a limited number of gray tones is thus of interest. An experiment was conducted to determine the degradation for hard-limited displays, where only one-bit quantization is used. An effective increase (degradation) in recognition differential of about one decibel

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) was measured for this system relative to a linear system, for both visual and electronic integration. A difference of approximately two decibels was observed between visual and electronic integration performance, for both linear and hard-limited data.

NOLTR 73-189 2 October 1973

Effect of Hard Limiting on Recognition Differential of Gram Type Displays

This report describes operator and machine detection experiments that were run to investigate the effect of hard-limiting on detection capability. Computer formed frequency domain components were used for these experiments. The results of these experiments are important since any decrease in signal quantization levels reduces instrumentation requirements. This work was done in the Signal Processing Division of the Physics Research Department and was funded by A370-370A/WF11-121-703.

The experiments were conducted by L. D. Griffith and R. D. Crusan.

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CONTENTS

ILLUSTRATIONS

INTRODUCTION

Many types of sonar equipment use gram type displays to record and display multi-channel information as a function of time. Examples are frequency-time displays used on the output of spectrum analysis systems and bearing-time-recorders used on multi-beam or scanning sonar systems. In each case the signal strength in each channel is recorded as a function of time by intensity modulation of the display. Usually only a minimal amount of averaging is done on the sonar output before writing on the display, and the operator is expected to perform post-detection averaging (or "visual integration") by visually accumulating information presented over a number of sweeps of the recorder trace. This is typically done by sighting down the time axis of the display, looking for channels (frequency or bearing) whose printing intensity differs from that of adjacent channels. Experiments have shown (references 1 through 3) that this visual integration is performed rather efficiently, so that operator performance of this task comes within 1 or 2 db of matching the recognition differential obtained when more sophisticated electronic integration and detection techniques are used. Obtaining this level of operator performance does, however, require rather careful attention to display parameter selection and quality and to other factors such as operator positioning and lighting.

Traditionally gram displays have been produced using heat or current sensitive papers and moving stylus elements, and considerable effort has been expended on maintaining wide dynamic range for the intensity. More recently a trend has developed toward cathode ray tube displays, where the gram data must be stored digitally and used to refresh the CRT display. In order to minimize storage requirements, it is desirable to use the smallest dynamic range (smallest number of gray scale or intensity values) possible without seriously degrading the display quality. The limiting case is to use only two intensity values (on and off). This permits the gram to be stored with only one bit per display cell and permits considerable simplification of the actual paper or CRT display device.

An experimental procedure had previously been developed to compare detection performance of manual and automatic systems (references 1 and 4), and analytical methods have been developed to predict the performance degradation due to single-bit quantization of the spectrum for automatic detection systems (reference 5). In order to evaluate the effect of hard-limiting of the spectrum on operator performance, a new experiment was devised specifically to test this effect.

EXPERIMENTAL PROCEDURE

The experimental setup used is illustrated graphically in Figure 1. A Nova 800 computer was used to simulate the output of a spectrum analyzer or similar system, with 470 parallel output channels (representing frequency bands, beam directions, or any equivalent multi-channel function) each containing random Raleigh distributed noise. Signal events were randomly introduced into these output channels, equivalent to the introduction of a sine wave signal into a narrow-band noise background. The time of occurrence, channel, and signal-to-noise ratio of each event was selected at random, with an average rate of occurrence of about 30 events per hour. Each signal event persisted for a total of ten minutes before it was removed. The simulated spectrum was either displayed in linear form on an electrographic paper recorder, or it could be thresholded (hard-limited) at an arbitrary level and only the resulting binary information used to drive the recorder.

In order to compare operator performance with electronic integration and automatic detection, both the linear and the hard-limited spectral information were integrated, thresholded, and displayed on other channels of the electrographic recorder. A fourth channel of the recorder was used to record reference information on the time of occurrence and signal-to-noise ratio of each event, to simplify later analysis. These display channels were hidden from the view of the operator during the experiment. Reference 6 describes the details of the simulation system.

The 470 channels of information were displayed over a paper width of 4.35 inches, giving a width of .00925 inches per channel. The paper advance rate was .463 inches per minute. Independent random noise values were formed at a one-second rate, so independent data appeared each .0077 inches of length along each channel. A pen sweep speed of about two sweeps per second was used to provide some redundancy in the display. Considerable attention was paid to human factors such as lighting and operator positioning in order to obtain the best operator performance. Some of these efforts are described in Appendix A.

Experiments were run with the operator detecting from the linear gram presentation and from hard-limited grams with three different display threshold values. These gave display false alarm rates (that is, percentage of display marking with noise only) of 10%, 20%, and 35%. Approximately 10 to 12 hours of data was collected in each mode, and operator performance was monitored to keep his false detection rate in the vicinity of three per hour. Data was also obtained for the automatic detection mode using linear spectra and using hard-limited data at the input of the integration algorithm with false alarm rates of 5%, 20%, and 50%. An instantaneous false alarm probability of 10^{-4} per cell was used in setting the detection threshold. This gives approximately the same number of false alarms per hour as the manual detection modes, for the three minute integration time chosen.

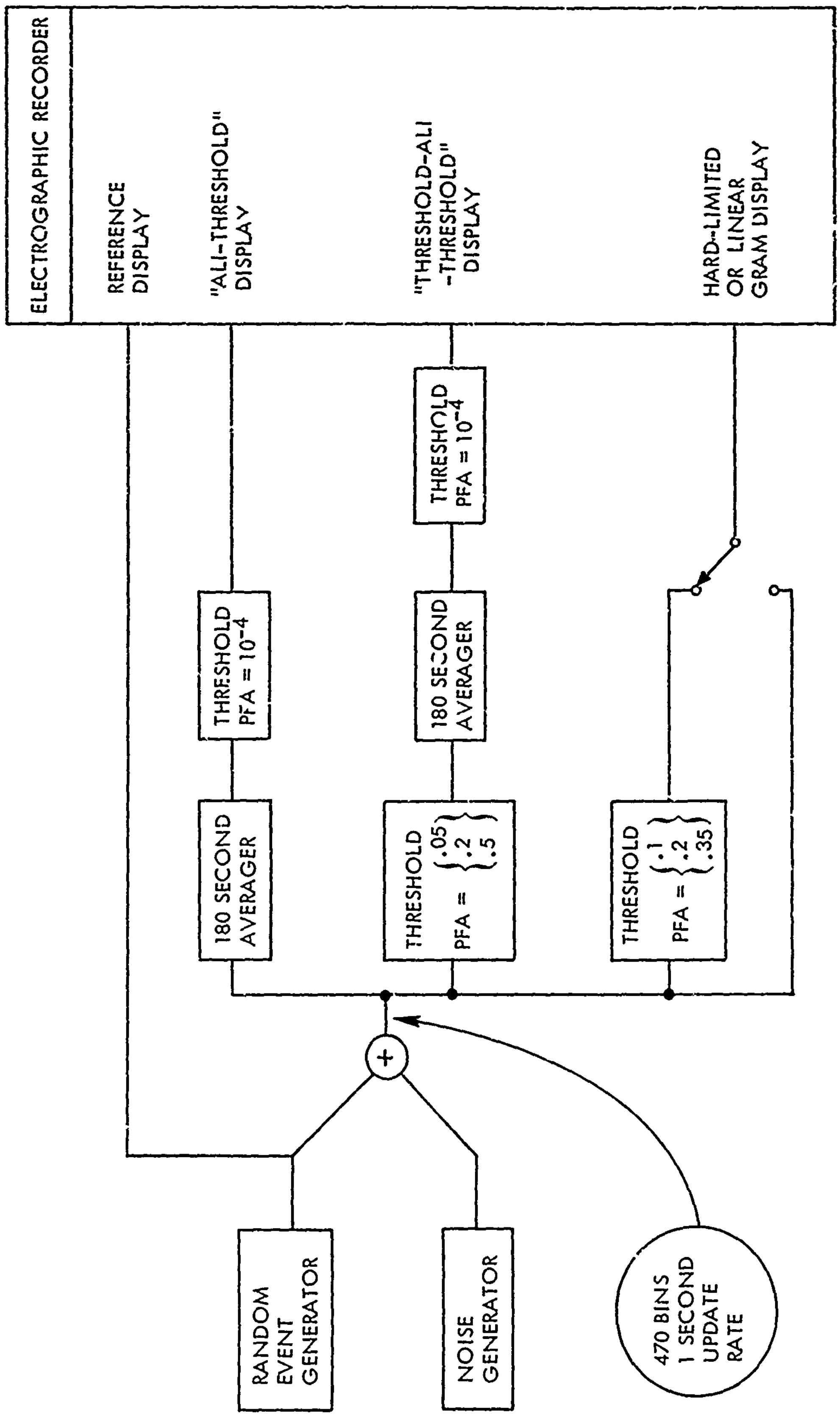

FIG. 1 BLOCK DIAGRAM OF EXPERIMENT

The form in which the data is obtained permits measurement of the time required for detection of a particular event (that is, the time from the initiation of the event until it is detected by either the operator or the automatic system) in addition to simply whether the event is detected at all. Thus among all events of a given S/N it is possible to find the distribution of times required for detection of an event. Similarly, for any given observation time delay after initiation of events, it is possible to determine the percentage of events detected at each value of S/N.

RESULTS

The experimental results for various modes are plotted in Figures 2 through 9. In each figure, the lower graph shows the distribution of detection times at each S/N value by plotting the time by which 10%, 25%, 50%, 75%, and 90% of the events at each S/N value had been detected. These curves may also be interpreted as giving the S/N required for a specified detection probability, as a function of the time allowed for detection. The upper curve shows the cumulative detection probability versus signal-to-noise ratio for an arbitrarily long observation time. The numbers above the upper curve show the number of events at each S/N used in the data sample. Generally each experiment had 25 to 30 events at each of the eleven S/N values.

Figure 2 contains the results for electronic integration of the linear spectrum, followed by an automatic detection with a nominal false alarm probability of 10^{-4}. The solid curves represent the measured contours for each probability of detection. The dashed curves are those predicted by the analytical methods of reference 5, for 25%, 50%, and 90% detection probability assuming the simulated system is equivalent to an ideal spectrum analyzer with a 1 Hz analysis bandwidth and a 180 second exponential integrator. Except for the lowest S/N values, where the measured performance degrades less rapidly than the predicted performance, good agreement is obtained between predicted and measured results. This discrepancy at the lowest S/N values is due to a difference in the criteria used for declaring a detection used in the analytical result (printing at least 50% of the time) and that used in the experiment (first threshold crossing, no matter how short). Otherwise the good agreement validates both the theory and the experimental approach.

Figures 3 through 5 show the results obtained by electronic integration of hard-limited spectra, using pre-integration false alarm rates of 5%, 20%, and 50% respectively. These results are seen to be of generally the same form as for the linear processing. Figure 10 summarizes the performance of the three hard-limited systems in comparison to the electronic linear system by plotting the 50% detection contour for each. It is predicted in reference 5 that performance of the hard-limited system with 20% pre-detection false alarm rate would be degraded by 0.94 db relative to the linear system and that the degradation of the systems with 5% and 50% false alarm rates at the first detector would be further degraded by an additional .5 to .75 db. This theoretical prediction is seen to be generally confirmed by the results presented in Figure 10. It is worth noting that the time required to detect remains fairly constant above about 0 db rather than continuing to decrease as in the linear integration case. This is to be expected since, once the S/N is high enough to give nearly 100% marking at the first detector output, further increase of the S/N cannot significantly increase the rate of signal buildup in the integrator.

Figure 6 shows the results obtained for operator detection of the linear spectrum as displayed on the gram. The form is generally like that for automatic detection using linear spectra except for two features. One is that performance is degraded by about two db at the lower S/N values, due to inability of the operator to integrate visually quite as effectively as the same function is performed electronically. The other feature is that the time to detect does not continue to fall off as rapidly for high S/N values as it does for the electronic integration. This can be attributed either to reluctance on the part of the operator to call a detection or to lack of display contrast, which forces him to wait longer to verify a signal even at high S/N.

Figures 7 through 9 show the performance of the operator using the gram display with hard-limited information. False alarm probabilities of 10%, 20%, and 35% on the raw spectrum outputs are used in the three figures respectively. Results are again similar in shape to those for the linear gram. Figure 11 summarizes the results for these three hard-limited gram modes in relation to the linear gram. The operator performance is degraded in the same way as was seen in Figure 10 for the electronic integration. An equivalent loss in signal-to-noise ratio of about one db is suffered for the hard-limited gram with 20% false alarm probability, with slightly higher loss (at low S/N) for the 10% and 35% FFA cases. Again at high S/N the minimum time to detect a high S/N event is increased because the operator has no clue as to the strength of an event once the marking probability approaches 100%. Although the detection performance of the operator using the hard-limited display approached that for a linear display, nearly everyone associated with the experiment seemed to feel that more concentration was required to obtain maximum performance when the hard-limited display was used, and this resulted in somewhat more operator fatigue. The performance does reflect this fatigue factor, since typical continuous run durations of two to three hours were used, corresponding to typical watch cycles on such equipment. However, the fatigue factor may be an improtant consideration in selecting the number of quantization levels in a display.

SUMMARY AND CONCLUSIONS

Figure 12 summarizes the results of the measurements by plotting the time required for 50% detection probability versus S/N for both electronic and manual integration and detection, both for linear processing and for hard-limiting of the detector output before display or electronic integration. Only the 20% false alarm probability case at the first detector output is shown, since this seems to be the optimum choice for both electronic and visual integration. The dashed curve in Figure 12 is the theoretical result for linear processing and electronic integration and generally fits the observed results for this case.

A degradation in performance (increase in minimum detectable signal) of about one db is both predicted by theory and observed experimentally when hard-limited information is substituted for the linear detector output in the automatic detection system. The most obvious reason for using such a system is to limit the dynamic range of data into an electronic integration system, with consequent saving in word size required for storage. Operator detection of linear data presented in gram form for visual integration generally required about two db higher input S/N for the same performance as electronic integration of the linear data. This result agrees well with results of other similar experiments. Evidence is also seen of a minimum time required to detect, even at high signal-to-noise ratios. Use of hard-limited data for generating the gram for operator detection evidently requires a further increase of about one db in input S/N over that required for operator detection of linear data. It is also clear that a longer time is required to detect strong signals because of the lack of display contrast as a clue.

This experiment has established that the use of hard-limited spectral data, either for operator display and detection or for electronic integration, is possible but that a penalty of about one decibel in signal-to-noise ratio is extracted in either case. While the experiment was conducted using an electrographic paper recorder as the display device, it seems reasonable to expect that the results would also apply to detection from CRT displays. Although the experiment was done in the context of spectral analysis and display, similar results would be expected for other applications such as bearing-time recorders for multibeam systems. In addition to the observed increase in required S/N, there may be other factors such as operator fatigue which are important in selecting the number of intensity levels in gram displays.

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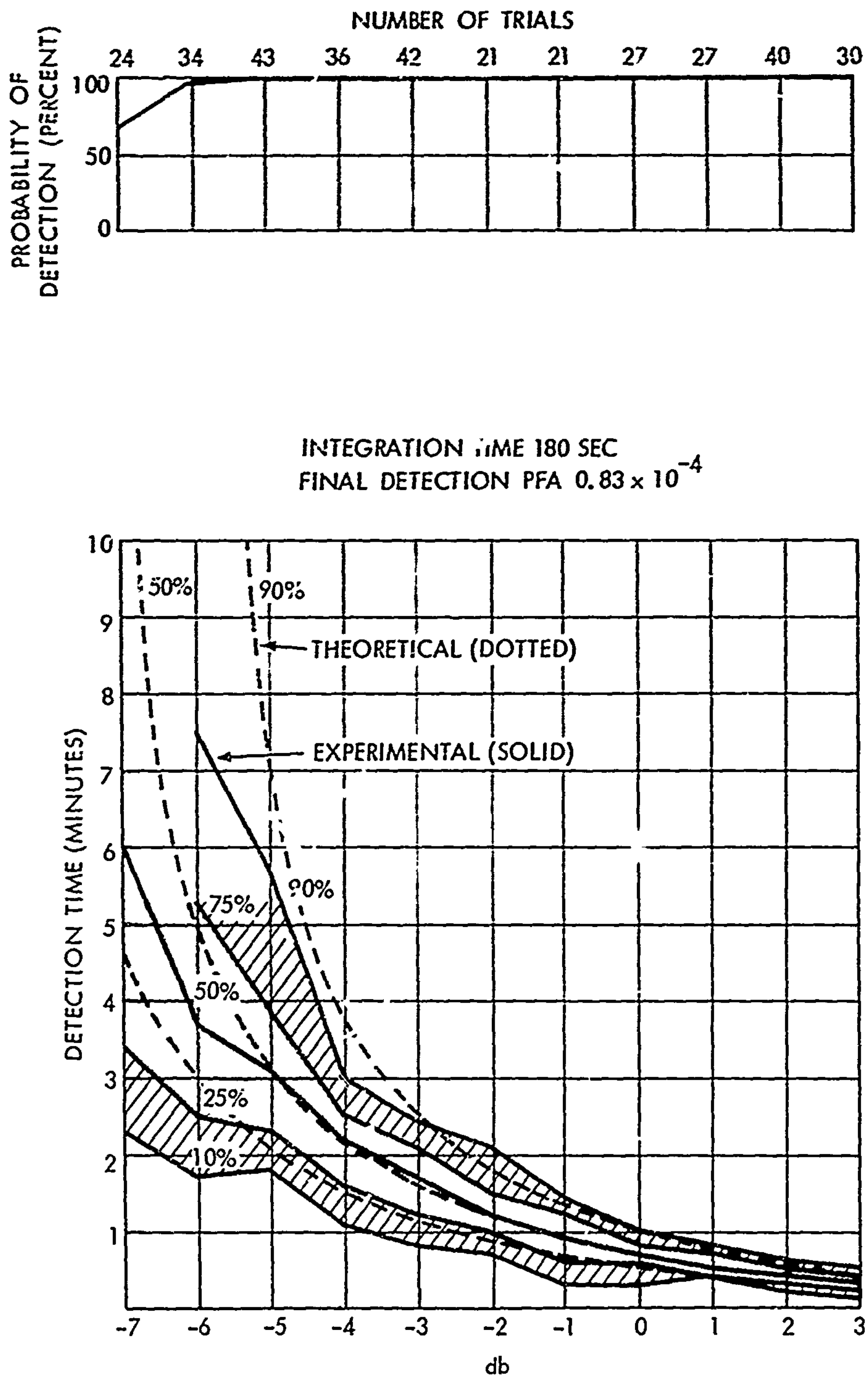

FIG. 2 ELECTRONIC DETECTION OF LINEAR SPECTRA

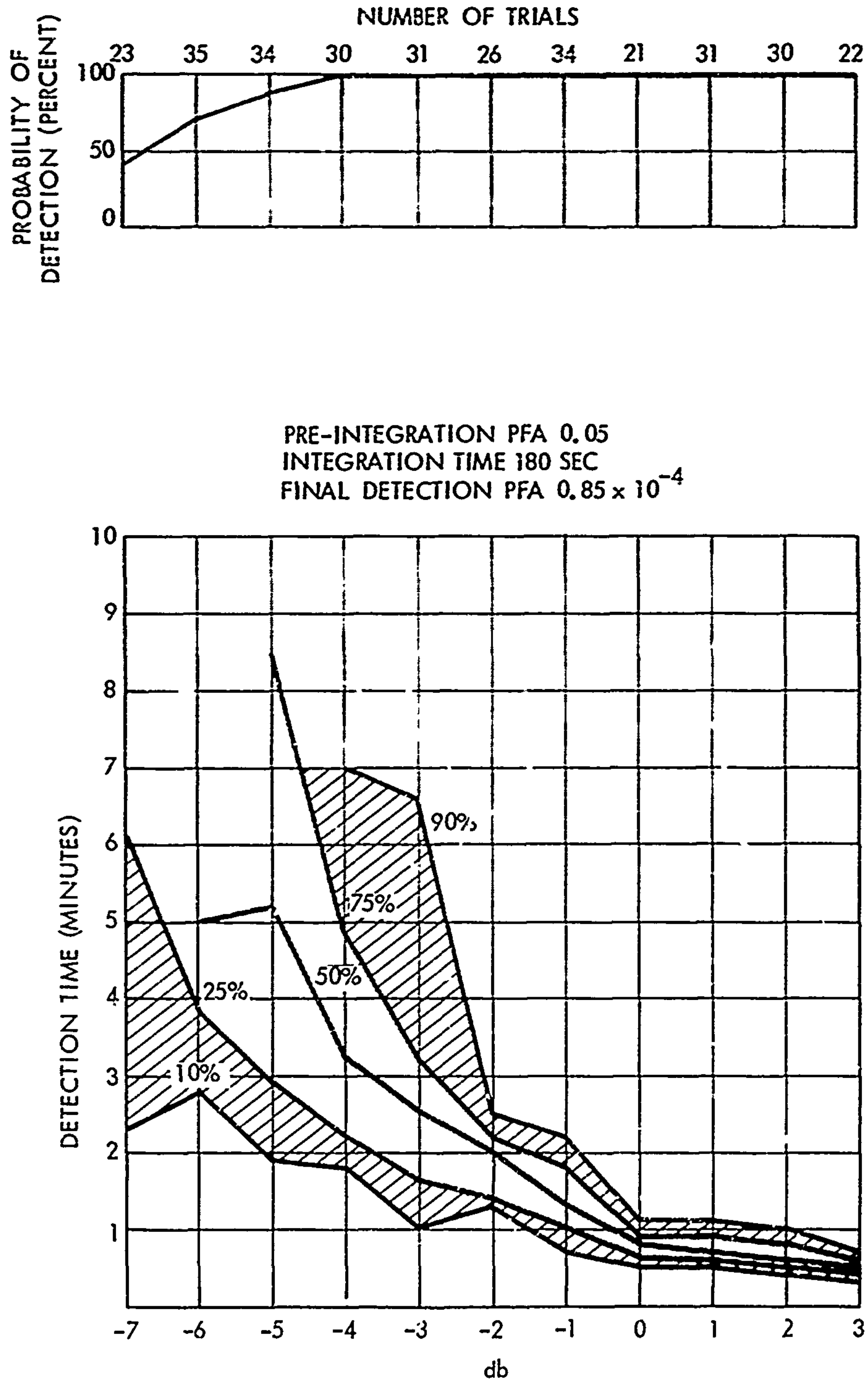

FIG. 3 ELECTRONIC DETECTION OF HARD-LIMITED SPECTRA

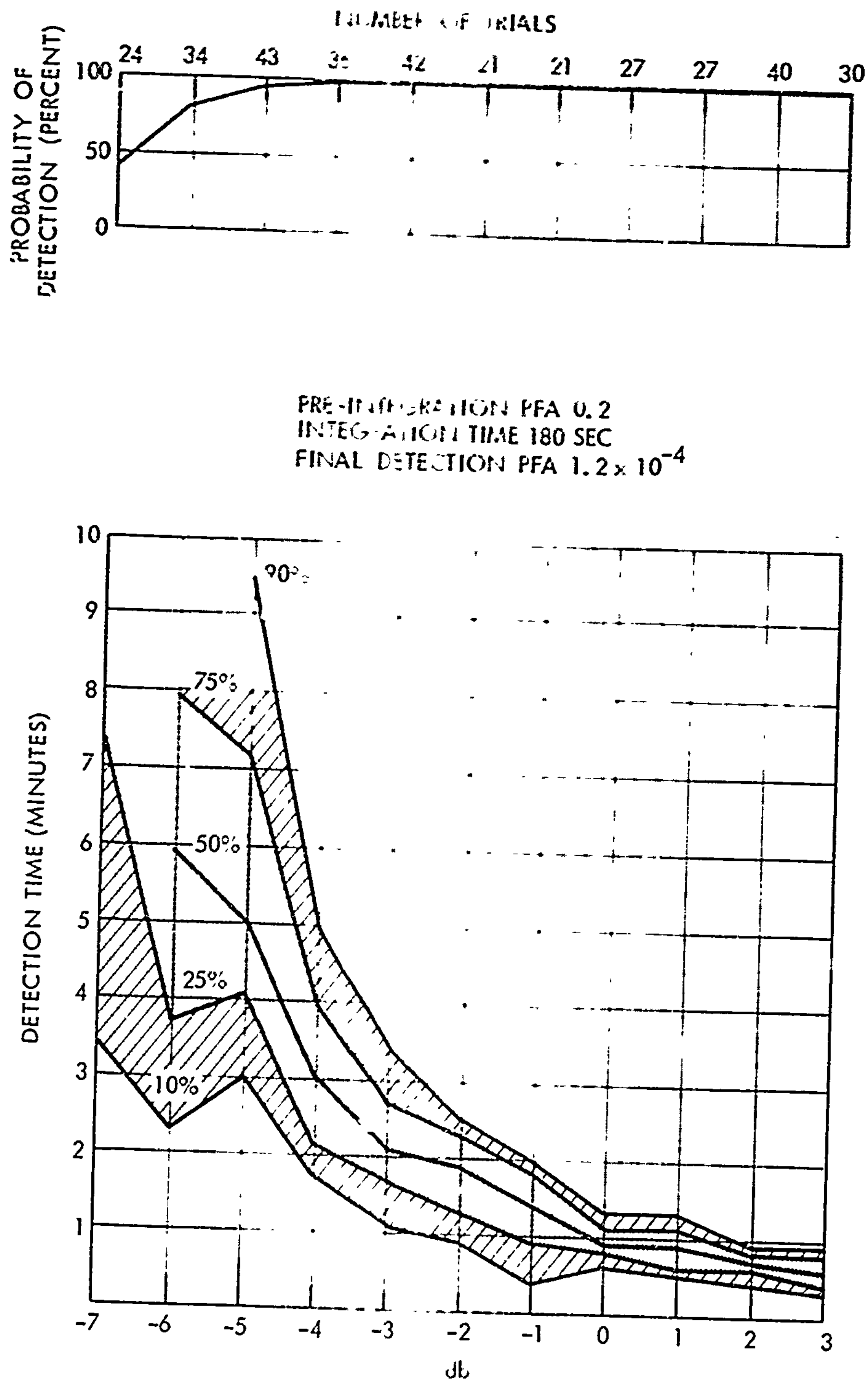

FIG. 4 ELECTRONIC DETECTION OF HARD-LIMITED SPECTRA

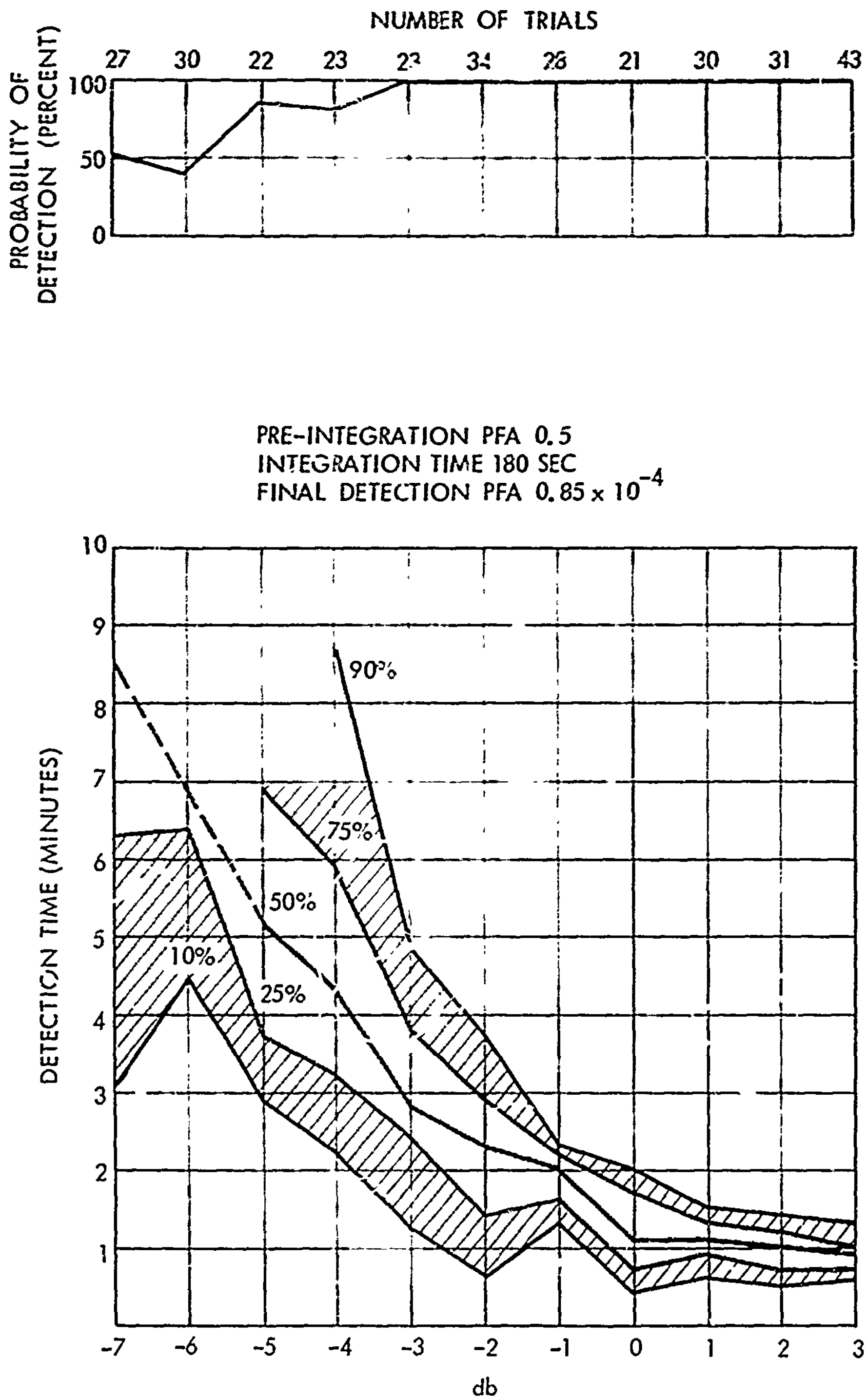

FIG. 5 ELECTRONIC DETECTION OF HARD-LIMITED SPECTRA

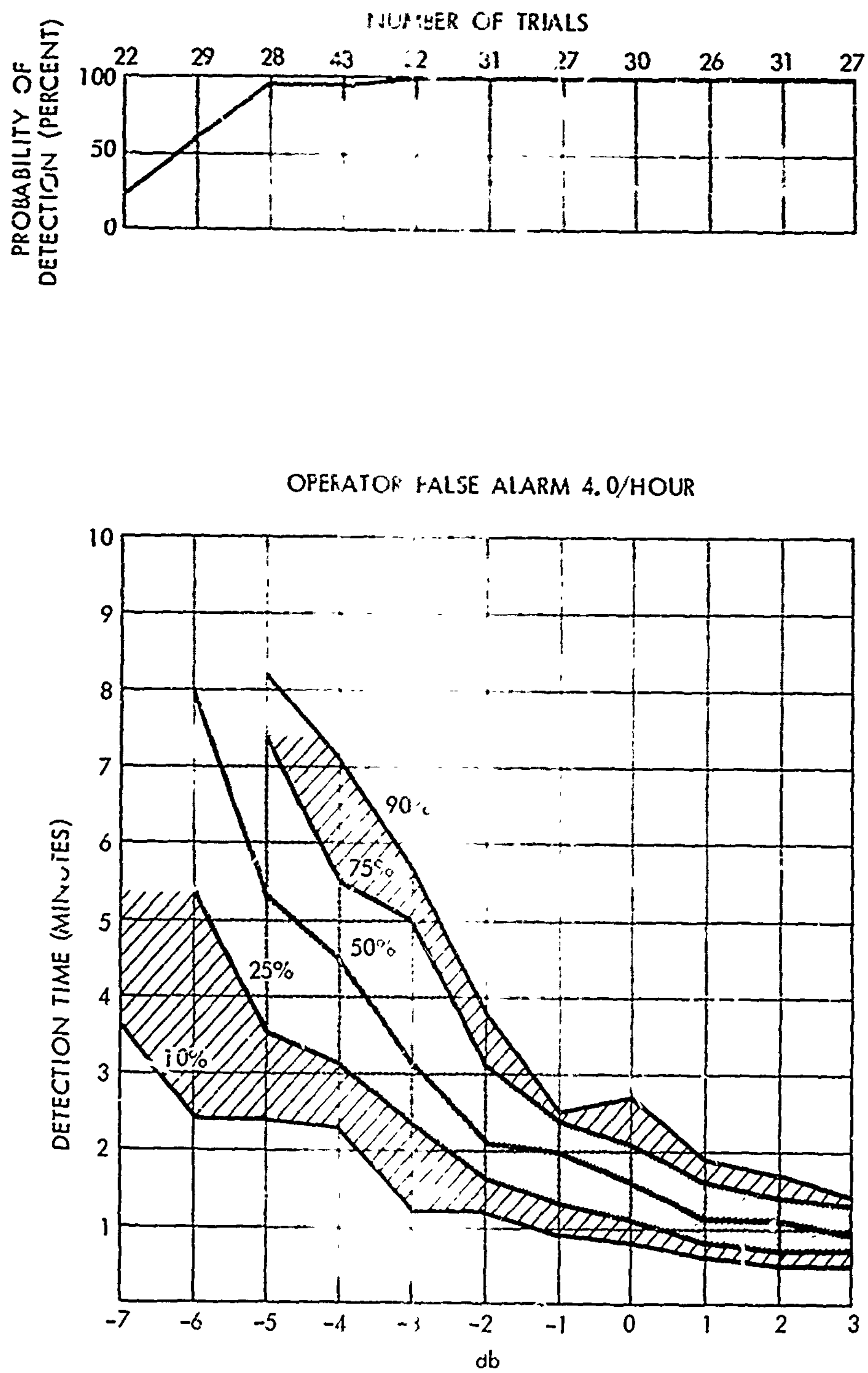

FIG. 6 OPERATOR DETECTION TIME AND PROBABILITY FOR RAW GRAMS (LINEAR SIGNALS)

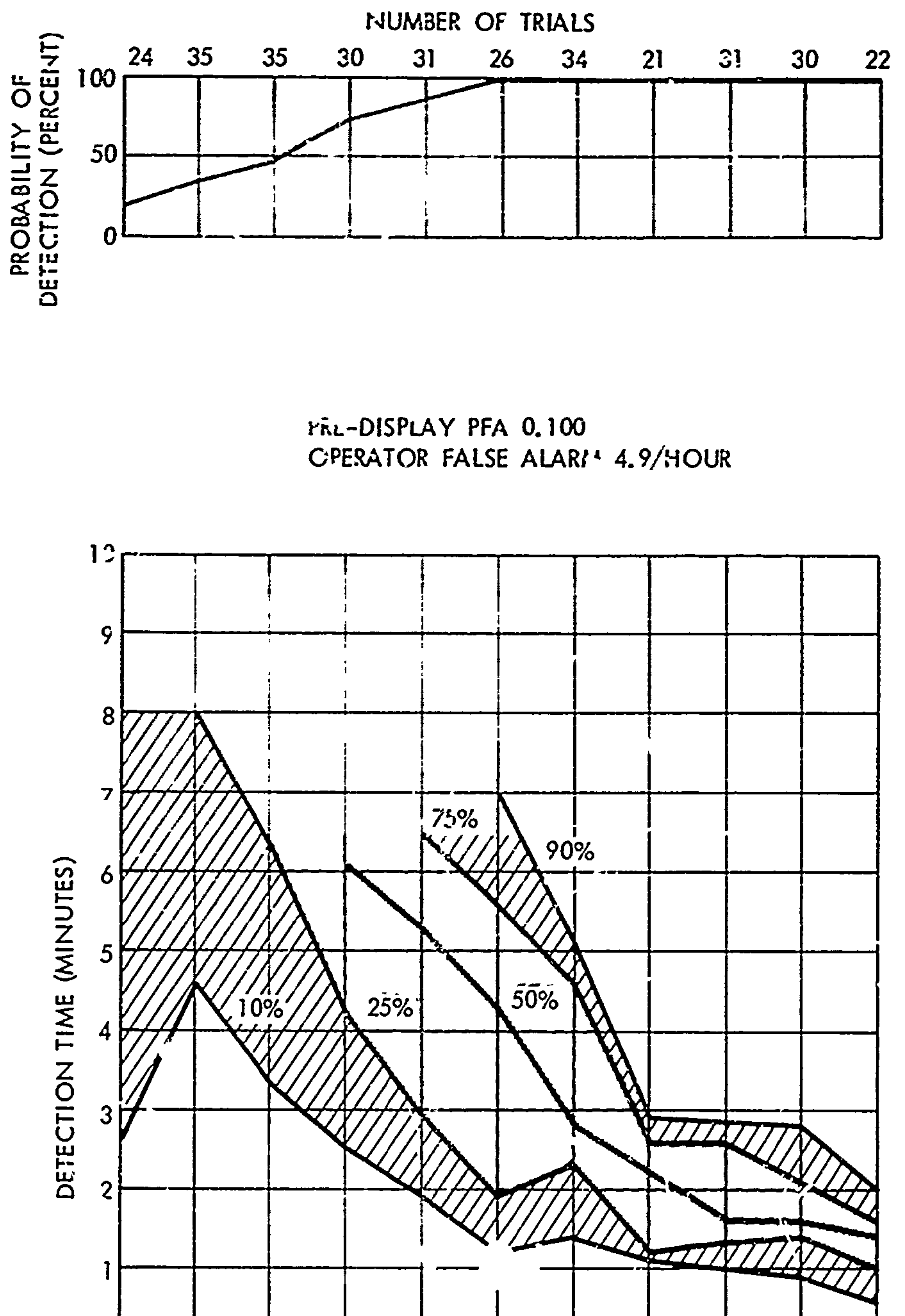

FIG. 7 OPERATOR DETECTION TIME AND PROBABILITY FOR RAW GRAMS (CLIPPED SIGNALS)

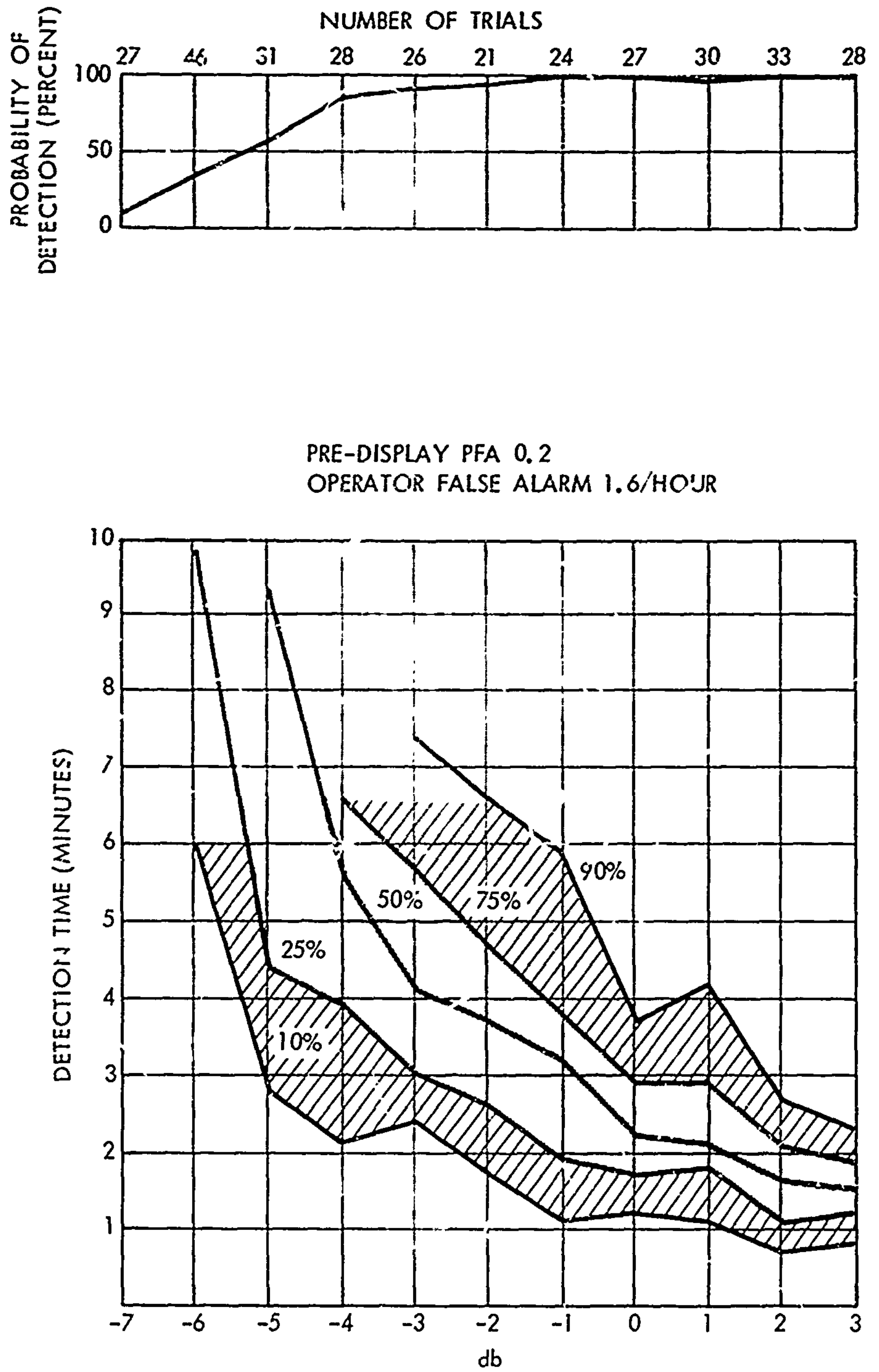

FIG. 8 OPERATOR DETECTION TIME AND PROBABILITY FOR RAW GRAMS (CLIPPED SIGNALS)

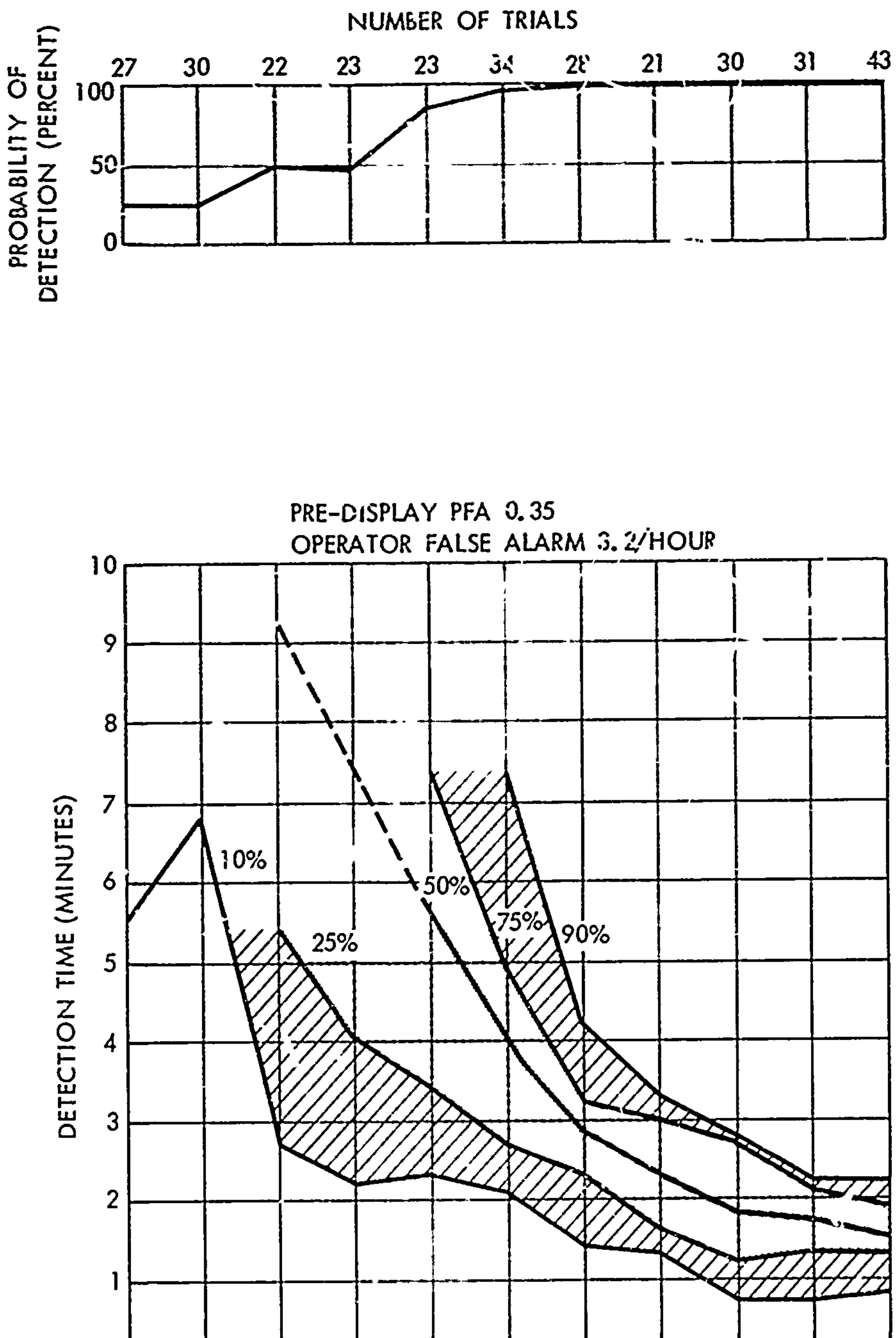

FIG. 9 OPERATOR DETECTION TIME AND PROBABILITY FOR RAW GRAMS (CLIPPED SIGNALS)

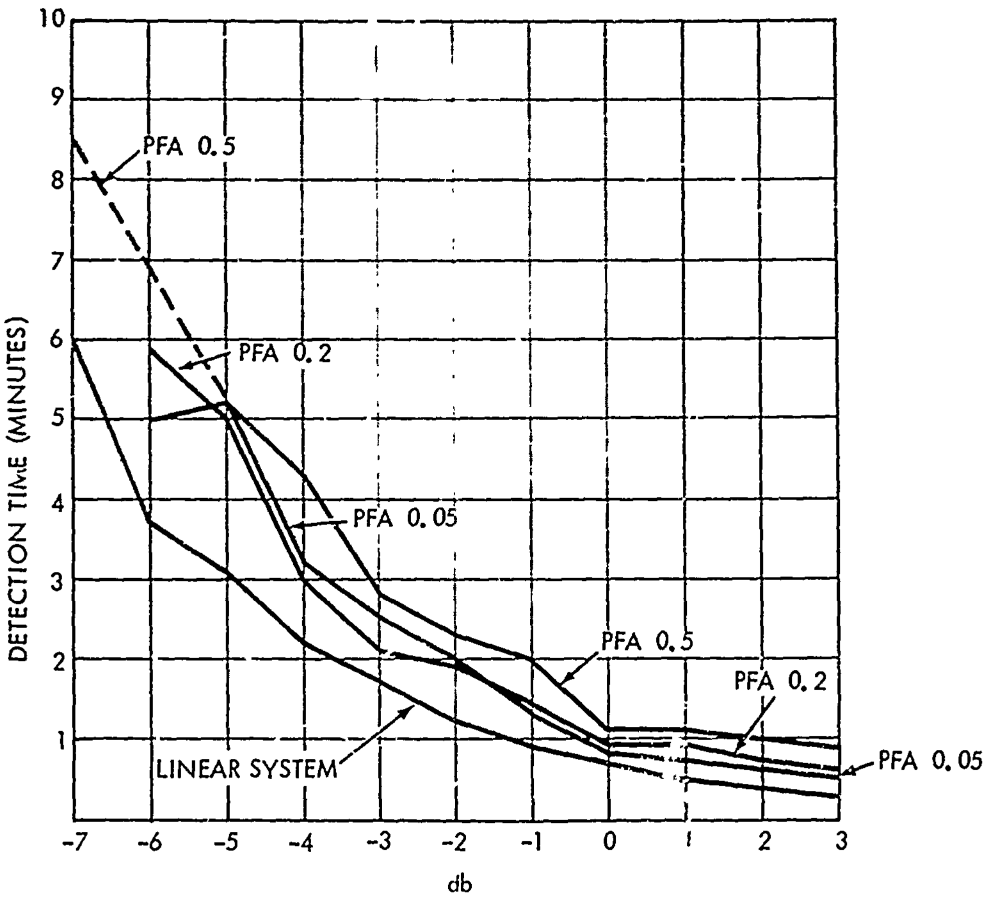

FIG. 10 COMPARISON OF 50% DETECTION TIMES FOR ELECTRONIC DETECTION OF HARD-LIMITED SPECTRA AND LINEAR SPECTRA

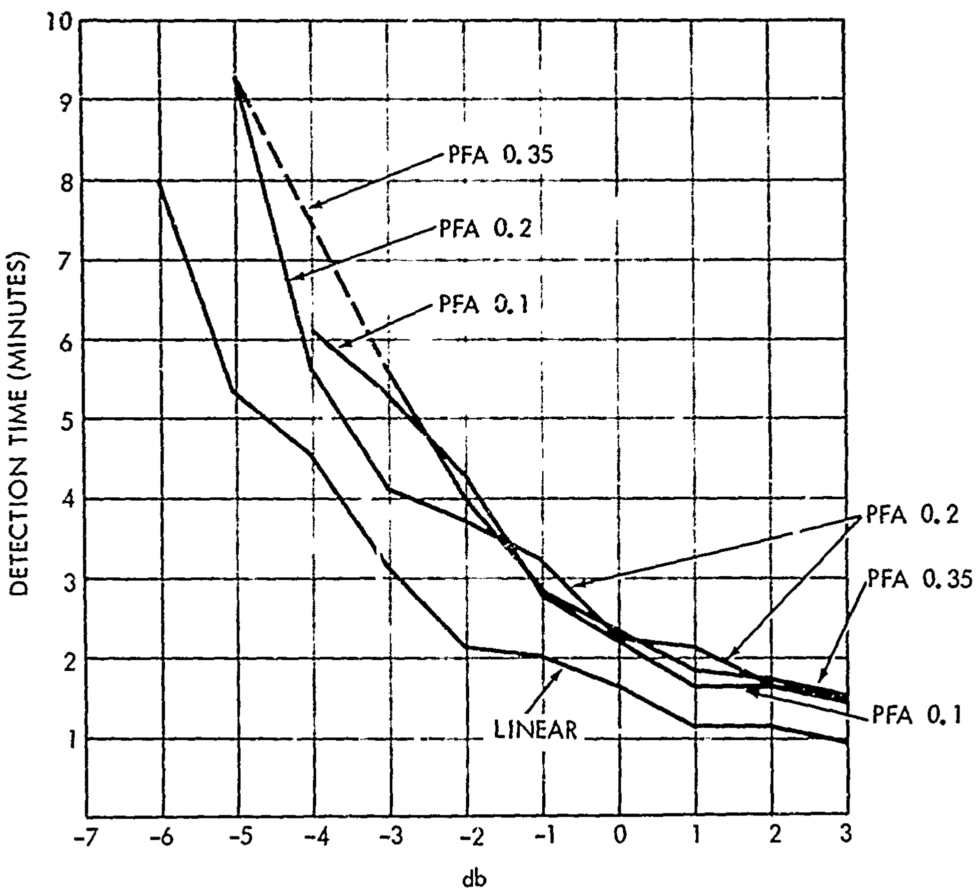

FIG. 11 COMPARISON OF 50% OPERATOR DETECTION TIMES

1. THEORETICAL CURVE ASSUMING LINEAR PROCESSING AND ELECTRONIC INTEGRATION
2. ELECTRONIC DETECTION FOR LINEAR SPECTRA
3. ELECTRONIC DETECTION FOR HARD-LIMITED SPECTRA AT 20% PRE-INTEGRATION PFA
4. OPERATOR DETECTION FOR LINEAR SIGNALS
5. OPERATOR DETECTION FOR CLIPPED SIGNALS, PRE-DISPLAY PFA 0.2

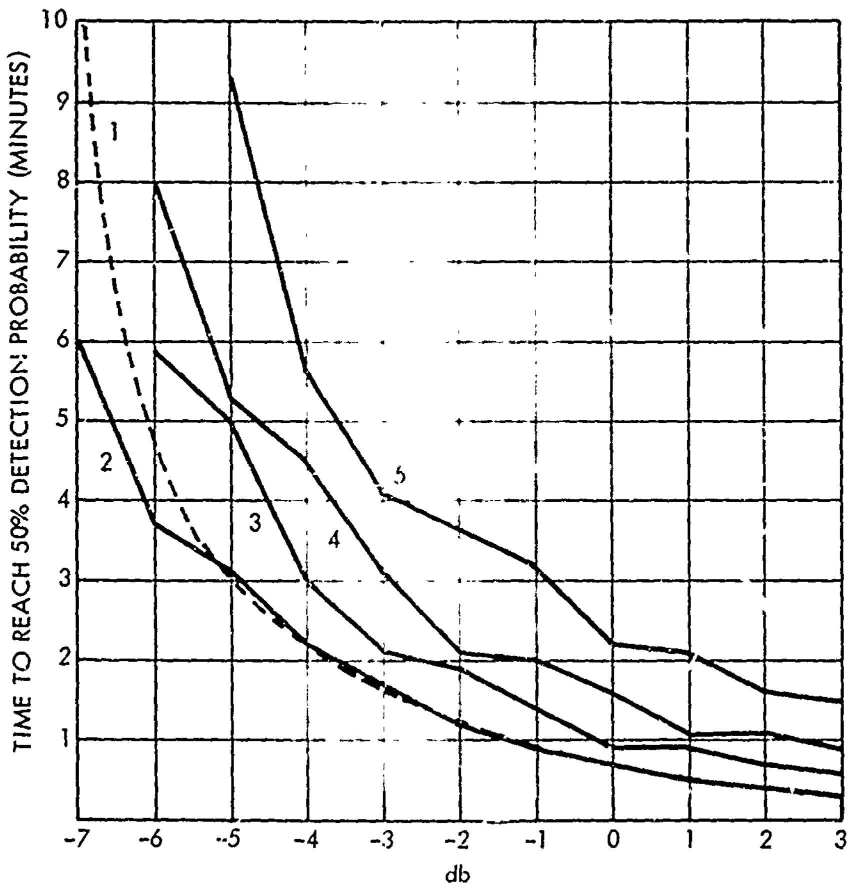

FIG. 12 COMPARISON OF 50% DETECTION TIMES

APPENDIX A

Experimental Background

At the outset of these experiments the operator results were disappointing, being degraded about 2 db below expected performance. This situation caused us to consider various ways to assist the operator which also included taking a closer look at the recorder performance.

An electrographic recorder model 4600 made by EPC Lab. Inc. was used for these experiments. The line display was improved by using a .008 inch wide stylus tip instead of the standard .03 inch wide stylus tip on the recorder writing belt. Since we were constrained to about .008 inches per second chart speed due to optical integration considerations two sweeps per second using a .008 inch tip would result in an overlap factor of 2. To insure equal spacing of the 3 writing stylii and thus ensure narrow lines, judicious bending of these stylii are required. The recorder controls are temporarily set so that the print dots of the stylii are separated and thus the offending stylus can be bent in a "cut and try" approach.

Concurrently with these recorder changes we were also experimenting with polarized illumination of the operator gram and a novel mirro technique. Using polarized light an operator was able to improve his minimum S/N 50% probability of detection about 1 db; however a full experiment (300 events) was not run before going to the present setup. Improvement using polarized light probably resulted from less eye strain.

The final setup consisting of polarized light and a mirror has now improved operator performance by at least 2 db. The mirror technique was an outgrowth of dealing with constant frequency lines. A front silvered mirror 4 x 1 inches is aligned with its 4 inch axis perpendicular to the spectral frequency lines and is positioned at the rear of the gram. Thus only the virtual image of a constant frequency line would form a straight line with the real spectral frequency line on the gram. In addition the mirror is held so that it can be rotated slightly about its 4 inch axis in the plane of the gram. This makes it possible for the operator to view the gram from a grazing angle for performing optical integration to a perpendicular angle without moving his head.