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13. ABSTRACT

Sea-clutter measurements using high-resolution radar indicate that clutter cross-section returns do not usually follow a Rayleigh distribution. The log-normal and contaminated-normal descriptions of sea clutter have been considered; and detection curves for nonfluctuating targets and for these distributions have been generated for the mean, median, and trimmed-mean detectors. In this report the detection calculations are repeated for fluctuating targets, specifically Swerling II and IV fluctuations. For the log-normal distribution, the trimmed-mean is the most effective detector; and the median is slightly better than the mean. For the contaminated-normal distribution, the mean is slightly better than the trimmed-mean, which is better than the median.

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PROBLEM STATUS

This is an interim report on one phase of the problem; work on the problem is continuing.

AUTHORIZATION

NRL Problem R02-54
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Manuscript submitted December 15, 1969.

DETECTION RESULTS FOR FLUCTUATING TARGETS

INTRODUCTION

In recent studies (1-5), the effectiveness of the mean, median, and trimmed-mean detectors has been compared for detecting nonfluctuating targets in the presences of log-normal and contaminated-normal clutter. For the log-normal distribution the most effective detector is the trimmed-mean detector followed by the median and mean detectors respectively. For the contaminated-normal distribution the trimmed-mean detector is again the most effective; however, for this distribution the mean detector is better than the median detector. The question this report investigates is how the effectiveness of the various detectors changes when the targets are fluctuating. Specifically, in this report Swerling II and IV fluctuations (6) will be considered.

CALCULATIONS

Since the threshold values for a desired probability of false alarm are independent of the target model, they have already been calculated (1-5); and all that remains to be calculated is the probability of detection P_d for various signal-to-noise ratios. Since the interesting range of P_d is from 0.01 to 0.99, Monte Carlo techniques, which require considerably less computer time than the characteristic-function approach that requires several numerical integrations, will be used.

It has been previously shown (5) that the ith sample of an envelope detector x_i can be generated by

$$x_i = (y_i^2 + z_i^2)^{1/2} , \tag{1}$$

where y_i and z_i are in-phase and quadrature-phase components. For the generation of log-normal clutter

$$y_i = \exp\{\sigma[-2 \ln (r_{i1})]^{1/2} \sin(2\pi r_{i2})\}\sin(2\pi r_{i3}) + A, \tag{2}$$

$$z_i = \exp\{\sigma[-2 \ln (r_{i1})]^{1/2} \cos(2\pi r_{i2})\}\cos(2\pi r_{i3}) , \tag{3}$$

and for the generation of contaminated-normal clutter with parameters K and γ

$$y_i = [-2 \ln (r_{i1})]^{1/2} \sin(2\pi r_{i2}) \; S(r_{i3}) + A, \tag{4}$$

$$z_i = [-2 \ln (r_{i1})]^{1/2} \cos(2\pi r_{i2}) \; S(r_{i4}) , \tag{5}$$

$$S(r_{ij}) = \begin{cases} K\sigma, & r_{ij} \le \gamma , \\ \sigma, & r_{ij} > \gamma , \end{cases} \tag{6}$$

where $\{r_{ij}\}$ are independent and uniformly distributed random numbers and A is the nonfluctuating signal. For the fluctuating signal the probability densities are

$$p(A) = \frac{2A}{\sigma^2} e^{-A^2/\sigma^2} \tag{7}$$

for the Swerling II case and

$$p(A) = \frac{8A^3}{\sigma^4} e^{-2A^2/\sigma^2} \tag{8}$$

for the Swerling IV case. The generation of a variable having the density given in Eq. (7) is straightforward. Integrating Eq. (7), one obtains

$$P(u \leq A) = 1 - e^{-A^2/\sigma^2}$$

or (9)

$$e^{-A^2/\sigma^2} = 1 - P(u \leq A).$$

Now, the quantity $1 - P(u \leq A)$ is uniformly distributed between 0 and 1 and, consequently, can be replaced by a random number r. If Eq. (9) is solved for A, giving

$$A = \sigma[-\ln (r)]^{1/2}, \tag{10}$$

then A is seen to have a Swerling II distribution. The power density for a Swerling IV case is

$$p(Z) = \frac{4Z}{\sigma^2} e^{-2Z/\sigma}. \tag{11}$$

If $Z = x_1 + x_2$ and if $p(x) = (2/\sigma)e^{-2x/\sigma}$, Z will have the density given in Eq. (11). Consequently, if

$$A = \left\{-\frac{\sigma}{2}\left(\ln (r_1) + \ln (r_2)\right)\right\}^{1/2}, \tag{12}$$

A will have a Swerling IV distribution.

Using Eqs. (1) through (6), (10), and (12) a Monte Carlo was performed. For each signal-to-noise ratio, a trial sample of 5000 was used to calculate the probabilities of detection. These probabilities are plotted in Figs. 1 through 8.

DISCUSSION

If the various detectors are compared, the following conclusions are reached: For the log-normal distribution the trimmed-mean detector is still the most effective; however, the median detector is only slightly better than the mean detector. For the contaminated-normal distribution the mean detector is slightly better than the trimmed-mean detector and about 2 to 3 dB better than the median detector. Of course, for large samples sizes, the behavior of the detectors for fluctuating targets will approach the nonfluctuating behavior (7). Consequently, for large sample sizes and both distributions the trimmed-mean detector will be better than the median detector, which in turn will be better than the mean detector.

If one compares the fluctuating results with the nonfluctuating results (Fig. 9), one concludes that the fewer the number of samples involved in the detector the larger the required increase in the S/N ratio needed to maintain the desired detection probabilities. For instance, to maintain $P_{fa} = 10^{-6}$ and $P_D = 0.9$ for three contaminated-normal samples and a Swerling II target the mean detector requires a 3.5-dB increase whereas the median detector requires a 5.2-dB increase. For ten samples the mean detector requires a 1.8-dB increase and the trimmed-mean detector requires a 2.8-dB increase.

ACKNOWLEDGMENT

The author thanks J. D. Wilson, who helped with various programming problems which arose during this study.

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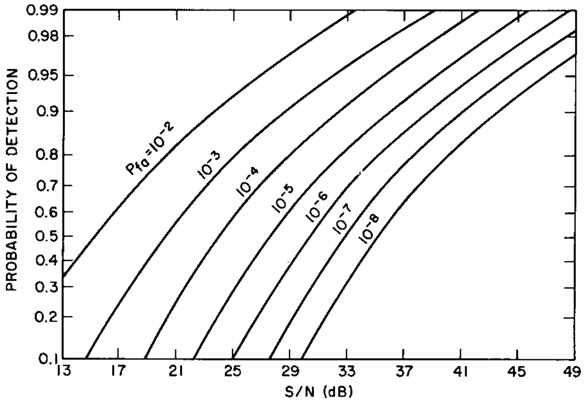

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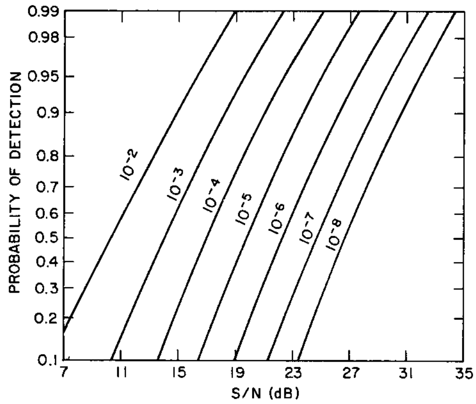
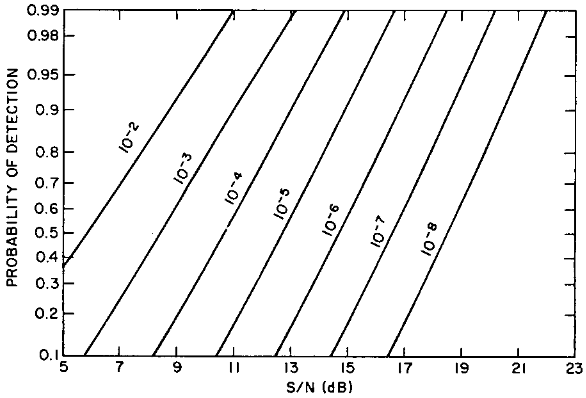
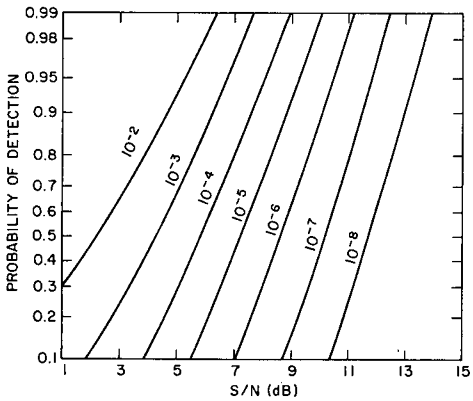


(b) $N = 3$



(c) $N = 10$



(d) $N = 30$

Fig. 1 – Probability of detection of the mean detector for the log-normal distribution (σ = 6 dB) and Swerling II fluctuations

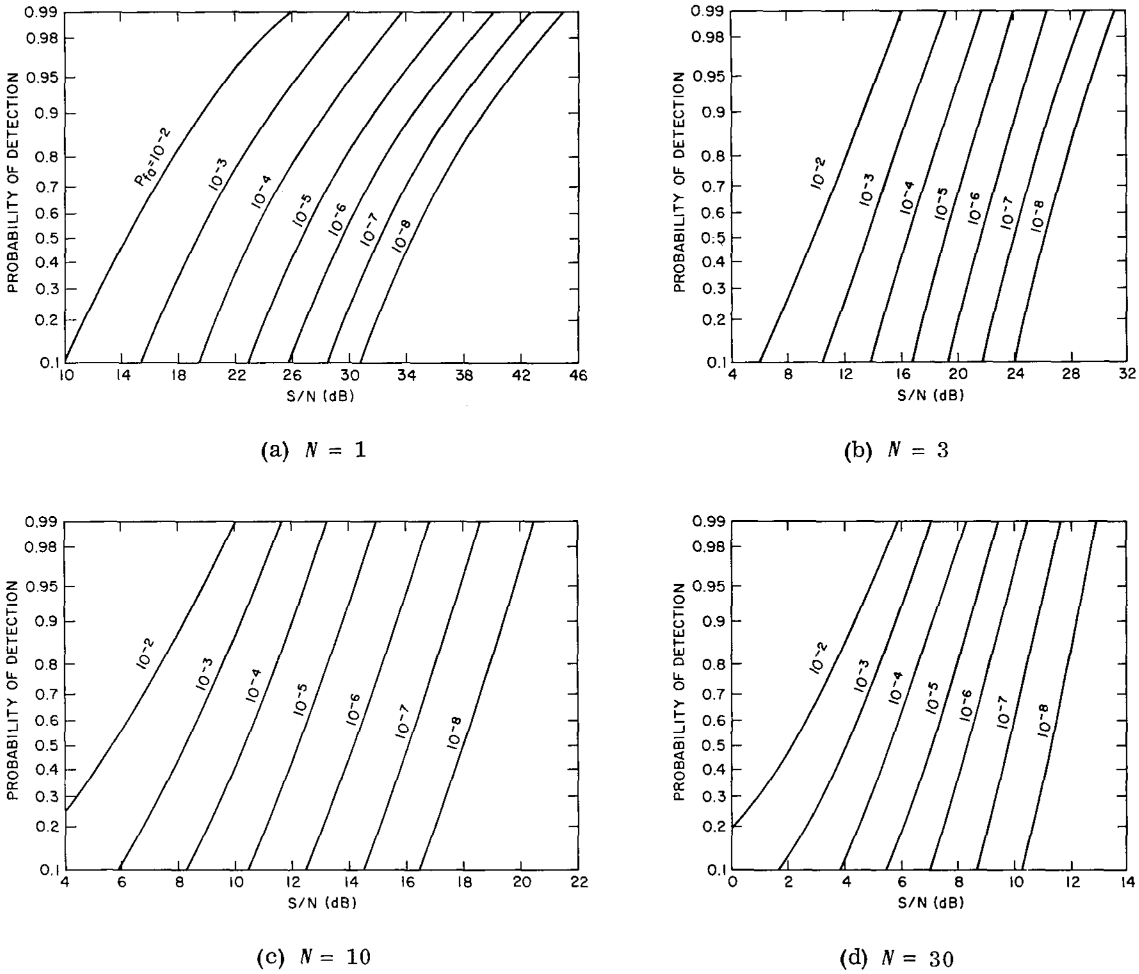
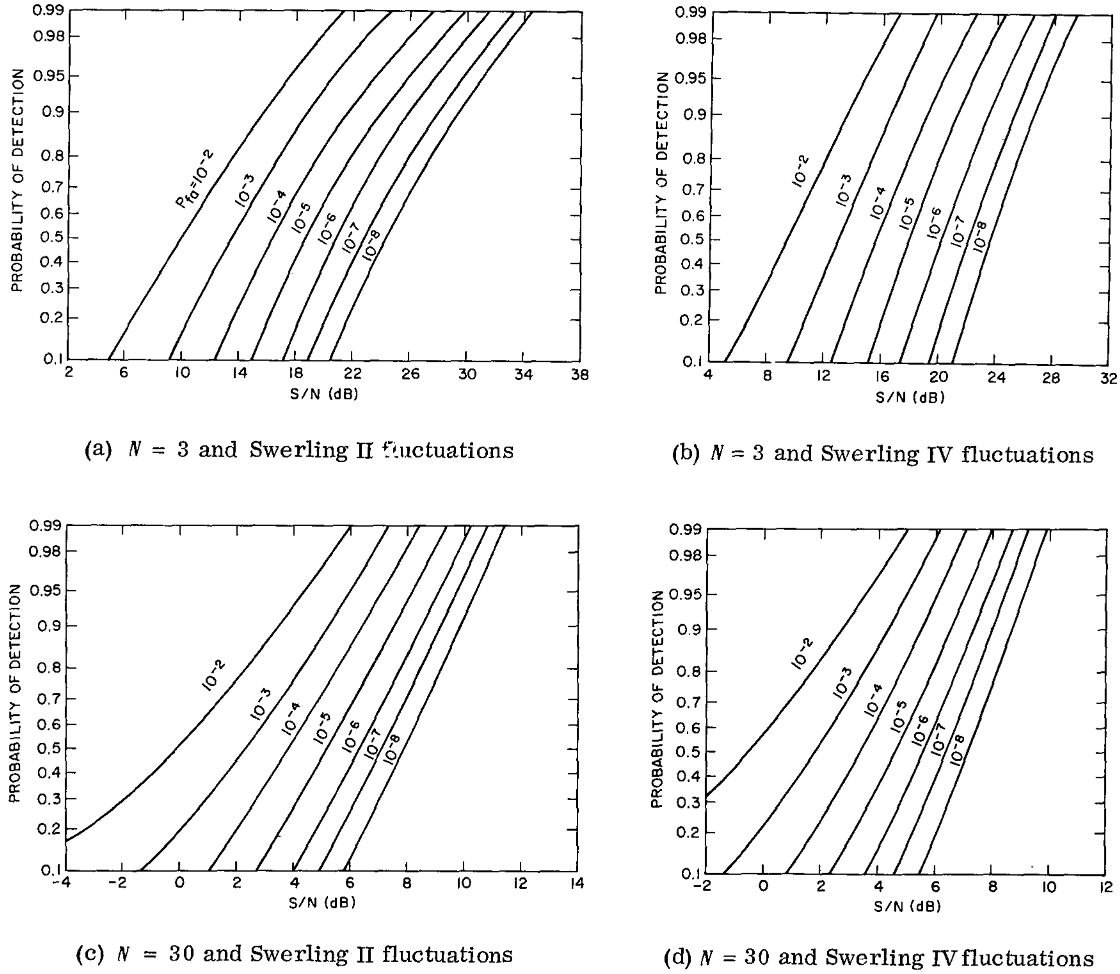


Fig. 2 - Probability of detection of the mean detector for the log-normal distribution (σ = 6 dB) and Swerling IV fluctuations



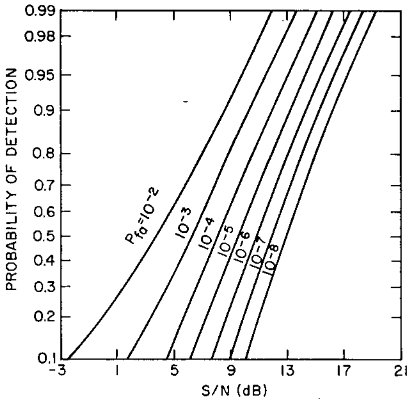
(a) N = 3 and Swerling II fluctuations

(b) N = 3 and Swerling IV fluctuations

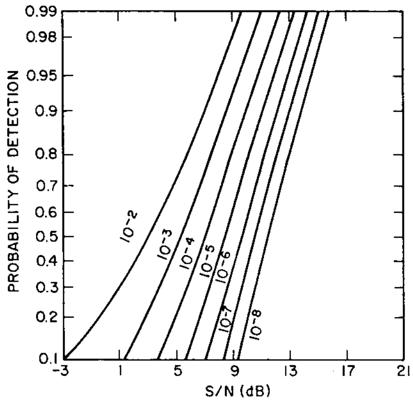
(c) N = 30 and Swerling II fluctuations

(d) N = 30 and Swerling IV fluctuations

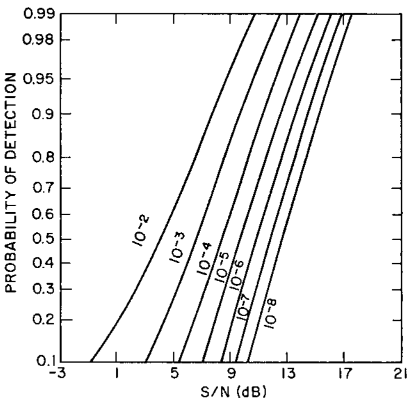
Fig. 3 - Probability of detection of the median detector for the log-normal distribution (σ = 6 dB)



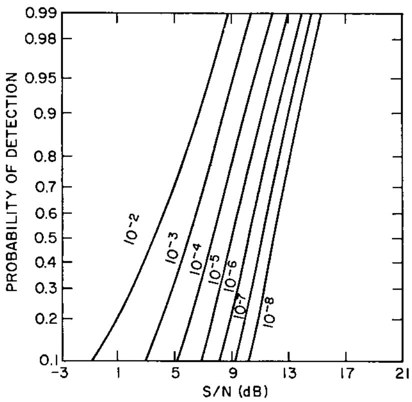
(a) $n_1 = 2$, $n_2 = 5$, and Swerling II fluctuations



(b) $n_1 = 2$, $n_2 = 5$, and Swerling IV fluctuations



(c) $n_1 = 4$, $n_2 = 7$, and Swerling II fluctuations



(d) $n_1 = 4$, $n_2 = 7$, and Swerling IV fluctuations

Fig. 4 - Probability of detection of the trimmed-mean detector for the log-normal distribution (σ = 6 dB) and N = 10

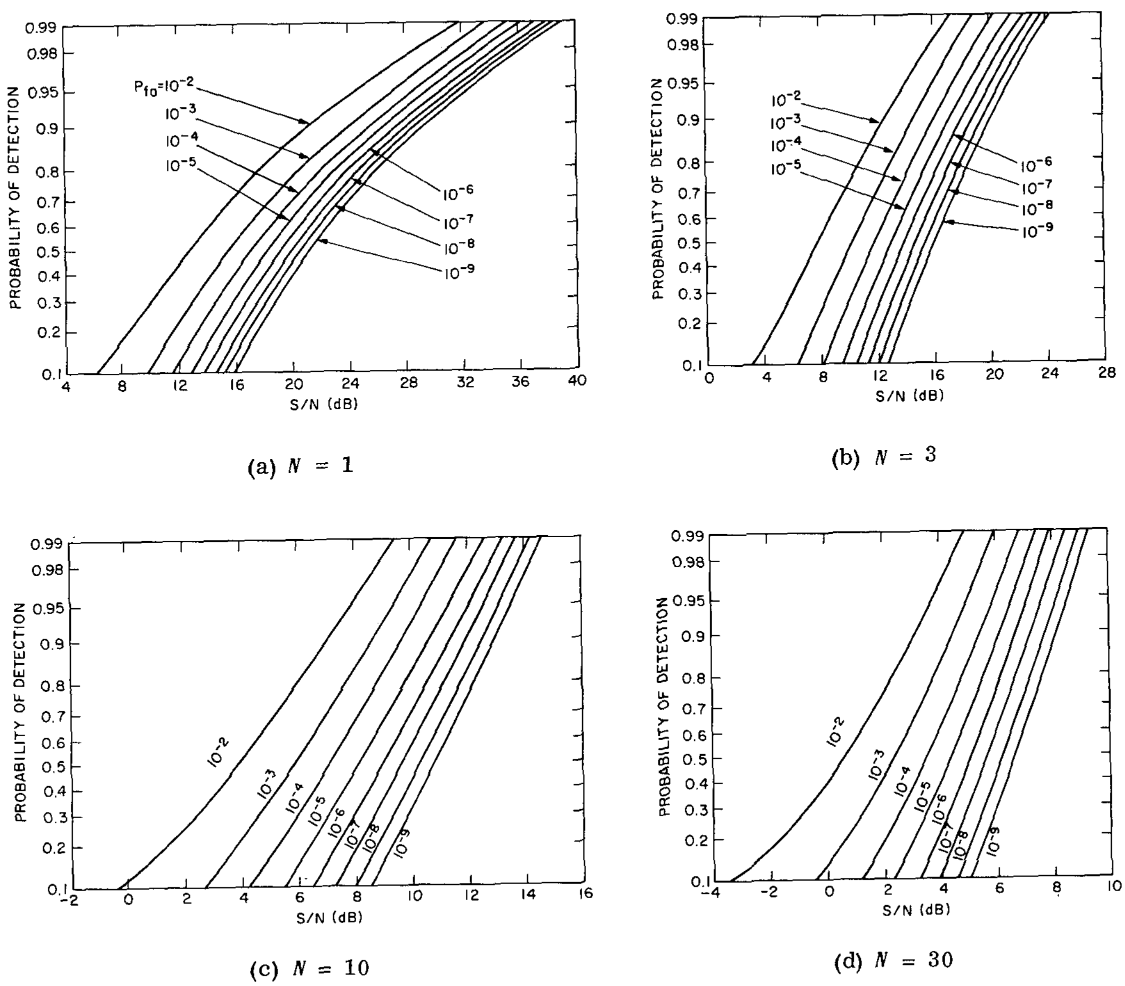


Fig. 5 - Probability of detection of the mean detector for the contaminated-normal distribution ($\gamma = 0.25$ and $\kappa = 2.25$) and Swerling II fluctuations

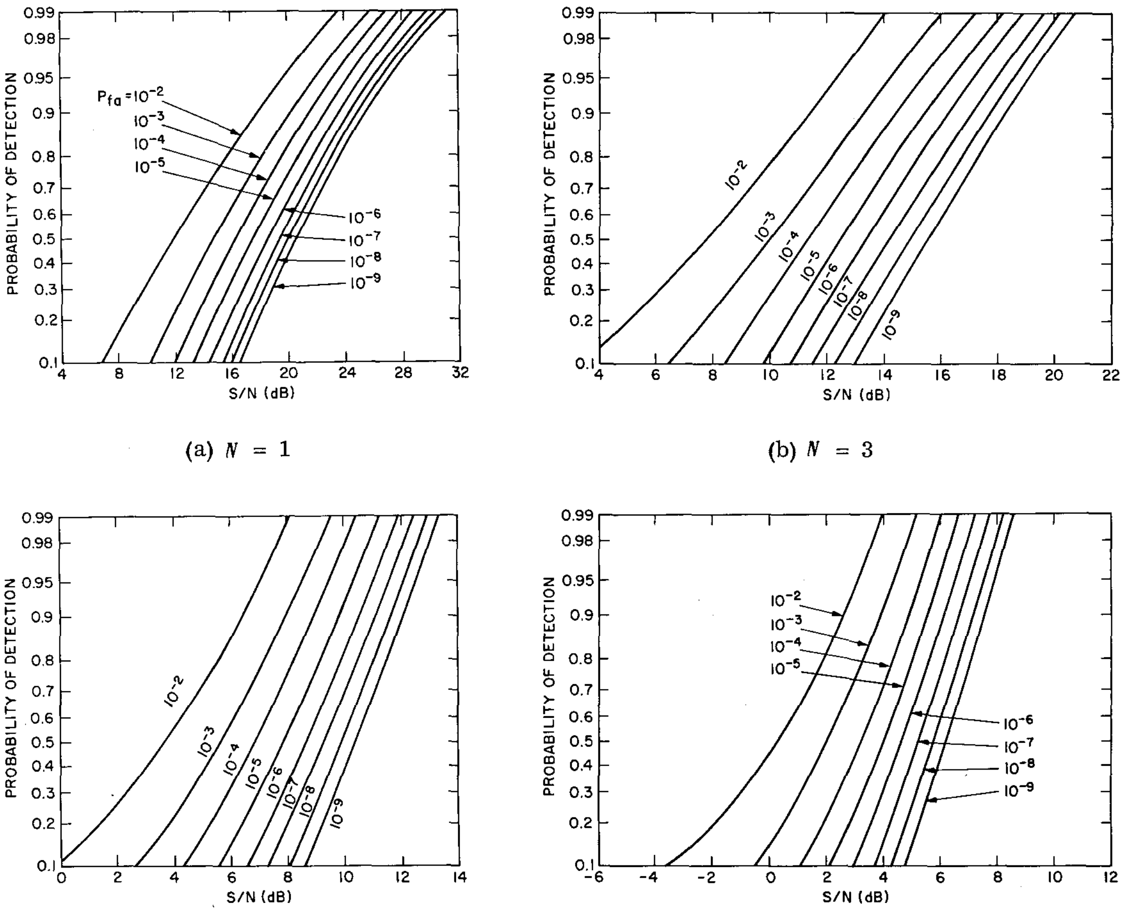
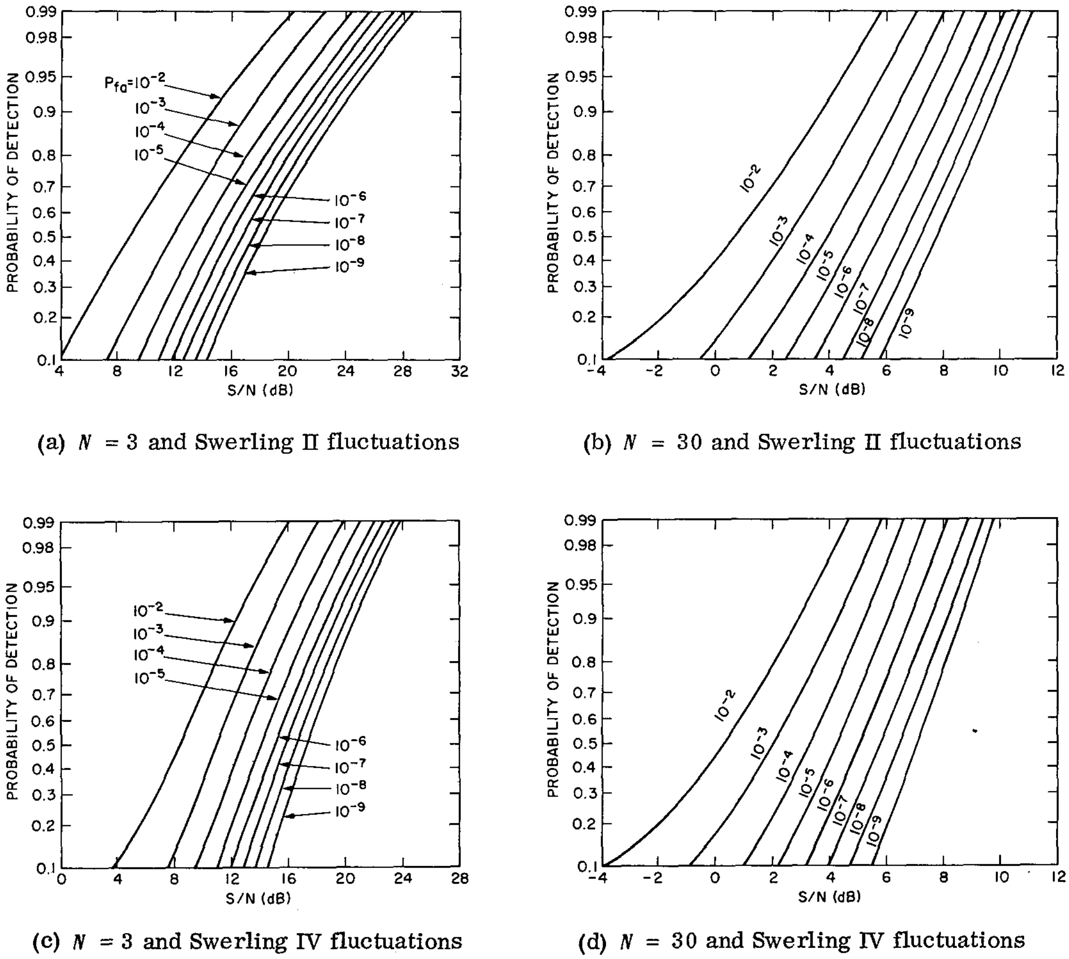


Fig. 6 - Probability of detection of the mean detector for the contaminated-normal distribution ($\gamma = 0.25$ and $\kappa = 2.25$) and Swerling IV fluctuations



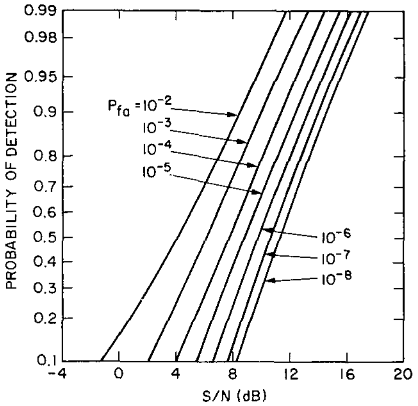
(a) N = 3 and Swerling II fluctuations

(b) N = 30 and Swerling II fluctuations

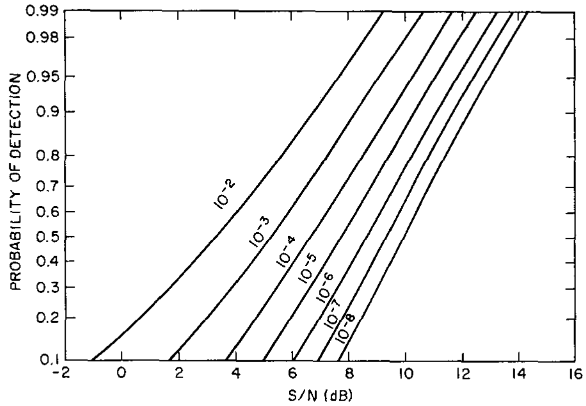
(c) N = 3 and Swerling IV fluctuations

(d) N = 30 and Swerling IV fluctuations

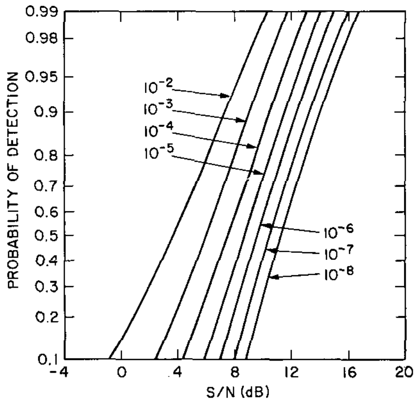
Fig. 7 - Probability of detection of the median detector for the contaminated-normal distribution (γ = 0.25 and κ = 2.25)



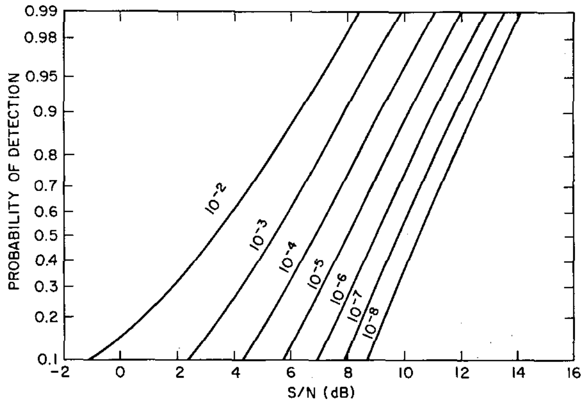
(a) $n_1 = 2$, $n_2 = 5$, and Swerling II fluctuations



(b) $n_1 = 2$, $n_2 = 5$, and Swerling IV fluctuations

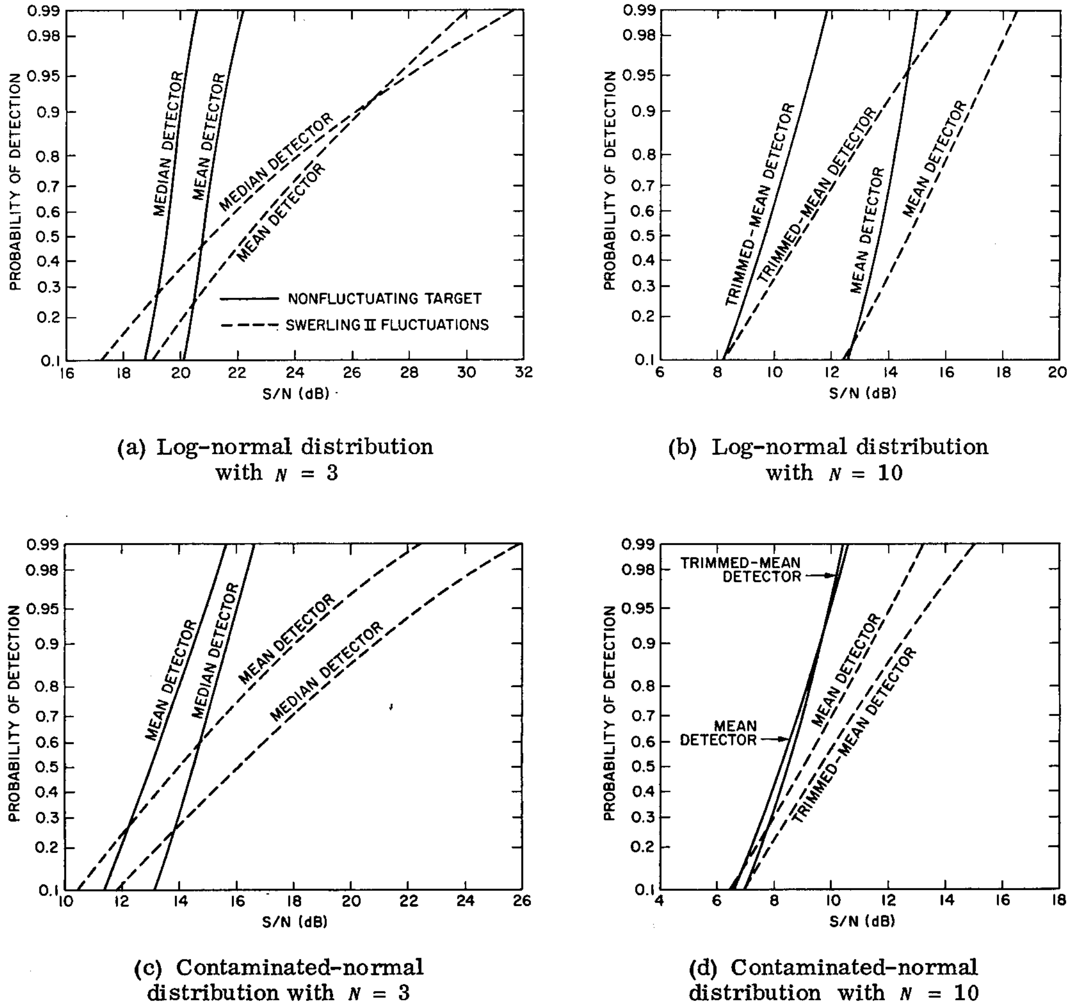


(c) $n_1 = 4$, $n_2 = 7$, and Swerling II fluctuations



(d) $n_1 = 4$, $n_2 = 7$, and Swerling IV fluctuations

Fig. 8 - Probability of detection for the trimmed-mean detector for the contaminated-normal distribution ($\gamma = 0.25$ and $K = 2.25$) and $N = 10$



(a) Log-normal distribution with N = 3

(b) Log-normal distribution with N = 10

(c) Contaminated-normal distribution with N = 3

(d) Contaminated-normal distribution with N = 10

Fig. 9 - Comparison of various detectors for $P_{fa} = 10^{-6}$, for the log-normal (σ = 6 dB) and contaminated-normal (γ = 0.25 and K = 2.25) distributions, and for fluctuating and nonfluctuating targets