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ORing Loss Data for Square Law Detectors Followed by an ORing Device and an Accumulator

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Preface

This report was prepared under NUSC Project No. A47000 for NAVSEA PMS 409, Program Manager CAPT Van Metre. This report represents an expanded version of a paper presented at the 102nd meeting of the Acoustical Society of America held during 30 November 1981 to 4 December 1981 in Miami Beach, FL.

The Technical Reviewer for this report was Dr. Albert H. Nuttall (Code 3302).

Reviewed and Approved: 28 July 1982

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

A mathematical model is developed to compute the ORing loss for square law detectors followed by an ORing device and an accumulator. The ORing loss is computed using Gaussian and Chi-square statistics for a detection probability of 0.5 and false alarm probabilities of 10^{-2}, 10^{-3}, 10^{-4}, and 10^{-6}. The ORing loss is computed as a function of the number of channels ORed and the number of samples in the accumulator.

It is concluded that there will be a large signal-to-noise ratio loss if integration is performed following ORing.

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LIST OF SYMBOLS

N	Number of channels ORed
$X_1, X_2, \ldots, X_N$	Acoustic data input to ORing device
d_I	Input deflection coefficient
m_1	Mean of the signal and noise at the input to the ORing device
m_o	Mean of the noise at the input to the ORing device
σ	Standard deviation of the noise at the input to the ORing device
SNR_I	Input signal-to-noise ratio to the square law detector
SNR_{Loss}	ORing loss
d_{I_1}	Input deflection coefficient for 1 channel
d_{I_N}	Input deflection coefficient for N channels (N > 1)
Y	Output of the ORing device
$F_o(y)$	Cumulative distribution of Y for the noise-only channels
$F_1(y)$	Cumulative distribution of Y for the signal and noise channel
$f_o(y)$	Probability density function of Y for the noise-only channels
$f_1(y)$	Probability density function of Y for the signal and noise channel
d_{oy}	Output deflection coefficient after ORing
μ_{y1}	Mean value of the signal and noise after ORing
μ_{yo}	Mean value of the noise after ORing
σ_{yo}	Standard deviation of the noise after ORing
Z	Output of accumulator
μ_{z1}	Mean value of the signal and noise at the accumulator output
μ_{zo}	Mean value of the noise at the accumulator output

LIST OF SYMBOLS (Cont'd)

σ_{zo}	Standard deviation of the noise at the accumulator output
d_{oz}	Deflection coefficient at the accumulator output
M	Number of terms in the accumulator
$\Phi(\ )$	Gaussian cumulative distribution
$\phi(\ )$	Gaussian density function
A_N, B_N	Constants for a fixed N
$C_N(d_I)$	Specialized Gaussian integral
$r_o(z)$	Probability density function for noise only case at the accumulator output
$r_1(z)$	Probability density function for signal and noise case at the accumulator output
P_D	Detection probability
P_F	False alarm probability
$P_o(x)$	Cumulative distribution function of X for the noise-only channels
$P_1(x)$	Cumulative distribution function of X for the signal and noise channel
$p_o(x)$	Probability density function of X for the noise-only channels
$p_1(x)$	Probability density function of X for the signal and noise channel

ORING LOSS DATA FOR SQUARE LAW DETECTORS FOLLOWED BY AN ORING DEVICE AND AN ACCUMULATOR

INTRODUCTION

Often it is not feasible to display all of the data produced by many signal processing systems. One such signal processing system is depicted in figure 1.

In this system, N displays are required to process N beams of acoustic data. In order to reduce the amount of data displayed and thereby reduce the amount of hardware needed, it is desired to explore a process that combines the input data but at the same time results in the least signal-to-noise ratio (SNR) loss. One process that provides a reduction of data is exclusive ORing, a process wherein one picks that single channel with the most energy. For the system shown in figure 1, exclusive ORing can take place at either point A, B, C, or D.

In earlier studies (references 1 and 2), ORing at point D was examined. In the subsequent pages, ORing at point B is analyzed. Two such cases are examined: in one case there are N channels of noise, and in the second case there are N - 1 channels of noise and one channel of signal and noise.

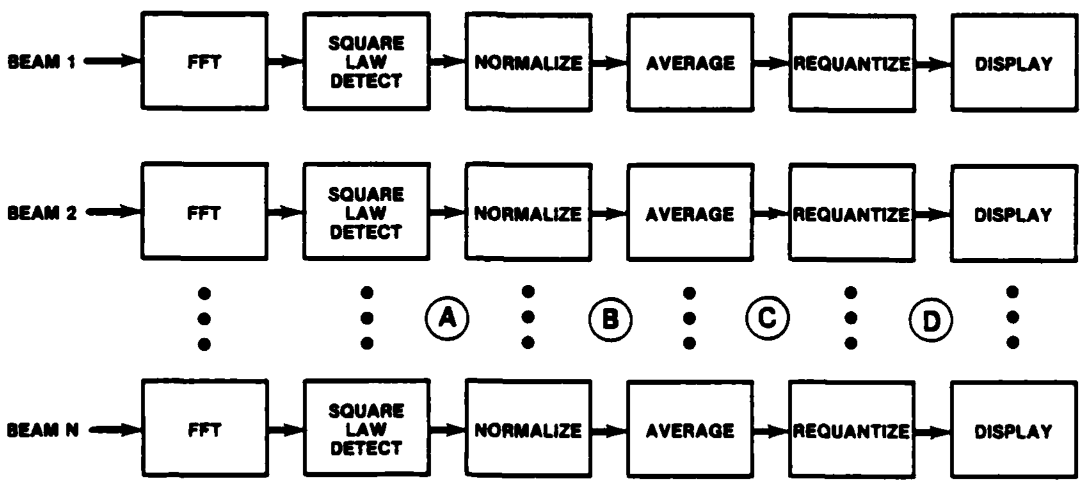

Figure 1. Signal Processing System

An SNR is derived from the statistical properties of each case. The SNR is then used to provide a quantitative description of the effects of ORing at point B.

Some related past work on ORing at point B is described in reference 3. This analysis is based on that work.

MATHEMATICAL ANALYSIS

The system of interest is shown in figure 2. The input to the ORing device is N channels of acoustic data, $X_1, X_2, \ldots, X_N$. The N channels contain either N channels of noise or N - 1 channels of noise and one channel of signal and noise. The random variables, $X_1, X_2, \ldots, X_N$, are statistically independent.

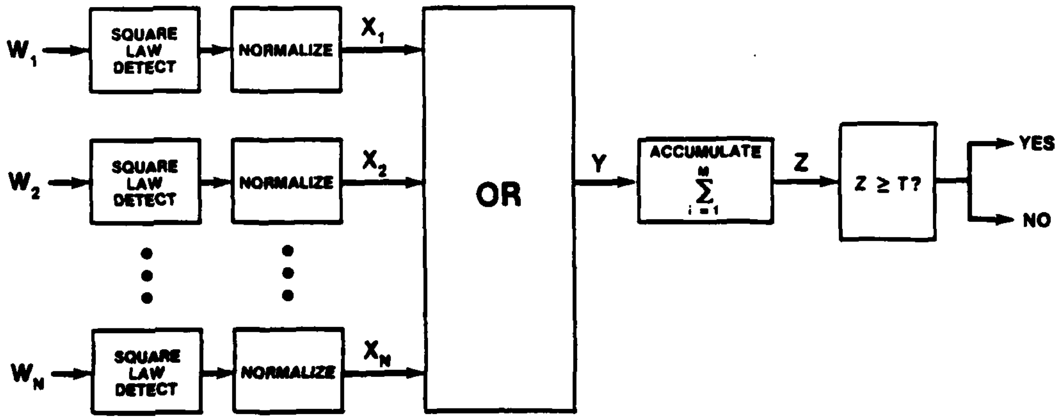

Figure 2. Generic Block Diagram

The input signal-to-noise ratio (SNR_I) to the ORing device in figure 2 is given by

$$SNR_I = 20 \log \left(\frac{m_1 - m_0}{\sigma}\right)$$

$$= 20 \log d_I \;, \qquad (1)$$

where

$$d_I = \frac{m_1 - m_o}{\sigma} = \text{input deflection coefficient}$$

m_1 = mean of the signal and noise at the input to the ORing device

m_o = mean of the noise at the input to the ORing device

σ = standard deviation of the noise at the input to the ORing device.

There will be an SNR loss when ORing N channels of data. Therefore, if the same output SNR is desired for N channels (N > 1) as for one channel, additional SNR is needed at the input to the ORing device. The additional SNR needed is the ORing loss:

$$SNR_{Loss} = 20 \log\left(\frac{d_{I_N}}{d_{I_1}}\right) \quad , \tag{2}$$

where

d_{I_N} = input deflection coefficient for N channels (N > 1)

d_{I_1} = input deflection coefficient for one channel.

The ORing loss relative to the detector input is given by

$$SNR_{Loss} = 10 \log\left(\frac{d_{I_N}}{d_{I_1}}\right) \quad . \tag{3}$$

The remainder of the analysis will be devoted to the determination of d_{I_1} and d_{I_N} for some fixed output, which will be defined in terms of an output deflection coefficient.

The output of the ORing device in figure 2 is mathematically defined in the following way:

$$Y = \text{Max}\ (X_1, X_2, \ldots, X_N) \quad . \tag{4}$$

Since one is interested in the maximum of N channels, the cumulative distribution is used. The cumulative distribution, F(y), for a random variable, X, is defined by

$$F(y) = \text{probability } (X \leq y)$$
$$= \int_{-\infty}^{y} f(x)\, dx \quad , \tag{5}$$

where

$f(x)$ = probability density function

X = random number

y = real number.

The probability density function, $f(y)$, is obtained by differentiating both sides of equation (5):

$$\frac{dF}{dy} = \frac{d}{dy}\int_{-\infty}^{y} f(x)dx = f(y) \quad . \tag{6}$$

This is a special case of Leibniz's rule for differentiation of an integral.

Consider the case of N channels of noise at the input to the ORing device. The cumulative distribution of Y for this case is

$$F_0(y) = \text{probability } (Y \leq y |\text{ all noise})$$
$$= \text{probability } (X_1, X_2, \ldots, X_N \leq y |\text{ all noise}). \tag{7}$$

Since the channels are statistically independent, equation (7) reduces to

$$F_0(y) = P(X_1 \leq y)\, P(X_2 \leq y)\, P(X_3 \leq y) \ldots P(X_N \leq y) \quad . \tag{8}$$

But $P(X_1 \leq y) = P(X_2 \leq y) = \ldots = P(X_N \leq y)$. Therefore,

$$F_0(y) = [P(X \leq y)]^N = P_0^N(y) \quad . \tag{9}$$

The probability density function, $f_0(y)$, for the noise-only case is obtained from equations (6) and (9):

$$f_o(y) = \frac{dF_o}{dy}$$

$$= NP_o^{N-1}(y)\,\frac{dP_o}{dy}$$

$$= NP_o^{N-1}(y)\;p_o(y) \quad . \tag{10}$$

Next, consider the case of N - 1 channels of noise and one channel of signal and noise. The cumulative distribution of Y for this case is

$$F_1(y) = \text{probability } (X_1, X_2, \ldots, X_N \leq y|\text{ signal})$$

$$= P(X_1 \leq y)\;P(X_2 < y)\;\ldots\;P(X_N \leq y) \quad . \tag{11}$$

Since there are N - 1 channels of noise and one channel of signal and noise, only N - 1 terms are equal this time. Therefore,

$$F_1(y) = [P(X_j \leq y)]^{N-1}\;P(X_i \leq y)$$

$$= P_o^{N-1}(y)\;P_1(y) \quad , \tag{12}$$

where $P_0(y)$ was defined previously in equation (9). The probability density function, $f_1(y)$, for the signal and noise case is obtained from equations (6) and (12):

$$f_1(y) = \frac{dF_1}{dy}$$

$$= (N - 1)\;P_o^{N-2}(y)\,\frac{dP_o}{dy}\,P_1(y) + P_o^{N-1}(y)\,\frac{dP_1}{dy}$$

$$= (N - 1)\;P_o^{N-2}(y)\;p_o(y)\;P_1(y) + P_o^{N-1}(y)\;p_1(y) \quad . \tag{13}$$

The output, Y, of the ORing device is expressed in terms of an output deflection coefficient, d_{0Y}, governed by equation (14):

$$d_{0Y} = \frac{\mu_{Y1} - \mu_{Y0}}{\sigma_{Y0}} \quad , \tag{14}$$

where

μ_{Y1} = mean value of the signal and noise after ORing

μ_{Y0} = mean value of the noise after ORing

σ_{Y0} = standard deviation of the noise after ORing.

In order to evaluate equation (14), it is necessary to compute μ_{Y0}, μ_{Y1}, and σ_{Y0}.

The mean value, μ_Y, of a random variable, Y, is defined in accordance with equation (15):

$$\mu_Y = \overline{Y} = \int_{-\infty}^{\infty} y f(y)\, dy \quad , \tag{15}$$

where f(y) = probability density function.

Utilizing equations (10), (13), and (15), we find that the mean values, μ_{Y0} and μ_{Y1}, for the signal absent and signal present cases are

$$\mu_{Y0} = \int y f_o(y)\, dy = N \int y\, P_o^{N-1}(y)\, p_o(y)\, dy \quad \text{(signal absent)} \tag{16}$$

$$\mu_{Y1} = \int y f_1(y)\, dy = \int y \left[(N - 1)\, P_o^{N-2}(y)\, p_o(y)\, P_1(y) + P_o^{N-1}(y)\, p_1(y) \right] dy \quad . \qquad \text{(signal present)} \tag{17}$$

The standard deviation of the noise-only case, σ_{Y0}, is defined in accordance with equation (18):

$$\sigma_{Y0} = +\sqrt{\sigma_{Y0}^2} = \left(\overline{Y_o^2} - \mu_{Y0}^2 \right)^{1/2} \quad , \tag{18}$$

where

μ_{Y0} = mean value of the noise after ORing, given by equation (16)

$$\overline{Y_o^2} = \int y^2 f_o(y)\, dy = N \int y^2\, P_o^{N-1}(y)\, p_o(y)\, dy \quad .$$

The final device in the system of figure 2 is the accumulator. The output of the accumulator, Z, is given by equation (19):

$$Z = \sum_{i=1}^{M} Y_i \quad . \tag{19}$$

The accumulator output, Z, can also be expressed in terms of an output deflection coefficient in the following way:

$$d_{0Z} = \frac{\mu_{Z1} - \mu_{Z0}}{\sigma_{Z0}} \quad , \tag{20}$$

where

μ_{Z1} = mean value of the signal and noise at the accumulator output

μ_{Z0} = mean value of the noise at the accumulator output

σ_{Z0} = standard deviation of the noise at the accumulator output.

The deflection coefficient at the accumulator output, d_{0Z}, can be expressed in terms of the deflection coefficient at the ORing device output, d_{0Y}. Since the random variables in this analysis are independent and uncorrelated, the following is true:

$$\mu_{Z0} = M\mu_{Y0}$$

$$\mu_{Z1} = M\mu_{Y1}$$

$$\sigma_{Z0}^2 = M\sigma_{Y0}^2$$

$$\sigma_{Z0} = \sqrt{M}\sigma_{Y0} \quad , \tag{21}$$

where M = number of terms in the accumulator.

Inserting equation (21) into equation (20) gives

$$d_{OZ} = \frac{\mu_{Z1} - \mu_{Z0}}{\sigma_{Z0}}$$

$$= \frac{M\mu_{Y1} - M\mu_{Y0}}{\sqrt{M}\sigma_{Y0}} = \sqrt{M}\left(\frac{\mu_{Y1} - \mu_{Y0}}{\sigma_{Y0}}\right)$$

$$= \sqrt{M} d_{OY} \quad . \tag{22}$$

The analysis of the system in figure 2 is now complete. A specific example follows.

EXAMPLE

It is desired to quantify the ORing loss for N = 1 through 8 and M = 1, 8, 16, 32, 64, 128, and 256 in figure 2. In order to compute the ORing loss, it is necessary to determine the cumulative distribution functions and the probability density functions in equations (16) and (17).

When no integration is performed (M = 1), the statistics used are a basic chi-square distribution for the signal absent case and a modified chi-square distribution for the signal present case (reference 4). There are two degrees of freedom for each case and, therefore, the chi-square distributions reduce to simple exponentials.

When integration is performed, the input and output statistics are taken to be Gaussian. Utilizing Gaussian statistics, we will now derive the mathematical expression for the output deflection coefficient, d_{OZ}.

For Gaussian input statistics, the cumulative distribution functions and the probability density functions for equations (16) and (17) are

$$P_o(x) = \Phi\left(\frac{x - m_o}{\sigma}\right)$$

$$P_1(x) = \Phi\left(\frac{x - m_1}{\sigma}\right)$$

$$p_o(x) = \frac{1}{\sigma}\,\phi\left(\frac{x - m_o}{\sigma}\right)$$

$$p_1(x) = \frac{1}{\sigma}\,\phi\left(\frac{x - m_1}{\sigma}\right) \quad , \tag{23}$$

where

$P_o(x)$ = cumulative distribution of X for the signal absent case

$P_1(x)$ = cumulative distribution of X for the signal present case

$p_o(x)$ = probability density function of X for the signal absent case

$p_1(x)$ = probability density function of X for the signal present case

m_o = mean of the noise at the input to the ORing device

m_1 = mean of the signal and noise at the input to the ORing device

σ = standard deviation of the noise at the input to the ORing device

$$\Phi(x) = \int_{-\infty}^{x} \phi(t)\,dt$$

$$\phi(t) = \frac{1}{\sqrt{2\pi}}\,e^{-t^2/2} \quad .$$

Substituting equation (23) into equation (16) yields, after some manipulations,

$$\mu_{YO} = m_o + \sigma A_N \quad , \tag{24}$$

where

$$A_N = N \int x\phi(x)\Phi^{N-1}(x)\,dx \quad .$$

Substituting equation (?3) into equation (17) yields, after some manipulations,

$$\mu_{Y1} = m_o + \sigma C_N(d_I) \quad , \tag{25}$$

where

$$C_N(d_I) = (N - 1)\int x\phi(x)\Phi^{N-2}(x)\ \Phi(x - d_I)\ dx$$

$$+\int x\Phi^{N-1}(x)\ \phi(x - d_I)\ dx$$

$$d_I = \frac{m_1 - m_o}{\sigma} \quad .$$

It remains to determine σ_{Y0}, the standard deviation of the noise-only case after ORing.

The standard deviation of the noise-only case, σ_{Y0}, was defined previously by equation (18). The variance, σ_0^2 , in equation (18) is defined in accordance with equation (26):

$$\sigma_{yo}^2 = \overline{Y_o^2} - \mu_{Yo}^2$$

$$= \int y^2\ f_o(y)\ dy - \mu_{Yo}^2 \quad . \tag{26}$$

Employment of equations (10), (23), and (24) reduces equation (26) to

$$\sigma_{Y0}^2 = m_o^2 + 2m_o\ \sigma A_N + \sigma^2 B_N - (m_o + \sigma A_N)^2$$

$$= \sigma^2(B_N - A_N^2) \quad , \tag{27}$$

where

$B_N = N\int x^2\ \phi(x)\ \Phi^{N-1}(x)\ dx$

A_N = constant for a fixed N, defined previously in equation (24)

σ = standard deviation of the noise at the input to the ORing device.

Therefore, insertion of equation (27) into equation (18) yields the standard deviation of the noise-only case, σ_{Y0}:

$$\sigma_{Y0} = \sigma\left(B_N - A_N^2\right)^{\frac{1}{2}} . \tag{28}$$

The deflection coefficient at the accumulator output, d_{OZ}, is now obtained by substituting equation (24), (25), and (28) into equation (22):

$$d_{OZ} = \sqrt{M} d_{OY} = \sqrt{M}\left(\frac{\mu_{Y1} - \mu_{Y0}}{\sigma_{Y0}}\right)$$

$$= \sqrt{M}\left[\frac{m_o + \sigma C_N(d_I) - (m_o + \sigma A_N)}{\sigma\left(B_N - A_N^2\right)^{\frac{1}{2}}}\right]$$

$$= \sqrt{M}\left[\frac{C_N(d_I) - A_N}{\left(B_N - A_N^2\right)^{\frac{1}{2}}}\right] . \tag{29}$$

The statistics of the accumulator output, Z, must be evaluated. Since the input statistics were assumed to be Gaussian distributed, the output, Z, will also be assumed to be Gaussian distributed. Therefore, the probability density functions of Z for the signal absent and signal present cases are governed by equation (30):

$$r_o(z) = \frac{1}{\sigma_{Z0}}\,\phi\left(\frac{z - \mu_{Z0}}{\sigma_{Z0}}\right) \qquad \text{(signal absent)}$$

$$r_1(z) = \frac{1}{\sigma_{Z1}}\,\phi\left(\frac{z - \mu_{Z1}}{\sigma_{Z1}}\right) \qquad \text{(signal present)}, \tag{30}$$

where $\phi(z)$ = Gaussian density function defined previously.

The detection probability, P_D and the false alarm probability, P_F, of the system in figure 2 is defined in accordance with equation (31):

$$P_D = \int_T^{\infty} r_1(z)\,dz = \Phi\left(\frac{\mu_{Z1} - T}{\sigma_{Z1}}\right)$$

$$P_F = \int_T^{\infty} r_o(z)\,dz = \Phi\left(\frac{\mu_{Z0} - T}{\sigma_{Z0}}\right) , \tag{31}$$

where

T = threshold shown in figure 2

$r_o(z)$, $r_1(z)$ = probability density functions defined previously by equation (30).

Consider the case of $T = \mu_{Z1}$. For this case,

$$P_D = \Phi(o) = 0.5$$

$$P_F = \Phi\left(\frac{\mu_{Z0} - \mu_{Z1}}{\sigma_{Z0}}\right) = \Phi(-d_{0Z}) \quad . \tag{32}$$

Solving equation (32) for the output deflection coefficient, d_{0Z}, gives

$$d_{0Z} = -\Phi^{-1}(P_F) \text{ for } P_D = 0.5. \tag{33}$$

Therefore, the output deflection coefficient, d_{0Z}, defined previously by equations (29) is equivalent to equation (33) for a detection probability of 0.5:

$$d_{0Z} = \sqrt{M}\left[\frac{C_N(d_I) - A_N}{\left(B_N - A_N^2\right)^{\frac{1}{2}}}\right] = -\Phi^{-1}(P_F) \quad \text{for } P_D = 0.5. \tag{34}$$

The output deflection coefficient for various false alarm probabilities is listed in table 1.

Table 1. Output Deflection Coefficient for P_D = 0.5

P_F	$d_{0Z} = -\Phi^{-1}(P_F)^*$
10^{-2}	2.33
10^{-3}	3.09
10^{-4}	3.75
10^{-6}	4.75

*This value is taken from reference 5.

Equation (34) can be rearranged in a more convenient form:

$$C_N(d_I) - A_N = -\Phi^{-1}(P_F)\left(\frac{B_N - A_N^2}{M}\right)^{\frac{1}{2}} \quad \text{for } P_D = 0.5. \tag{35}$$

This equation gives an expression for the input deflection coefficient, d_I, required for a specified P_F and $P_D = 0.5$ as a function of the number of channels ORed, N, and the number of samples in the accumulator, M. The left-hand side of equation (35) can be put in its proper mathematical form by inserting the appropriate expressions for $C_N(d_I)$ and A_N defined previously:

$$C_N(d_I) - A_N = \int x \left[(N - 1)\ \Phi^{N-2}(x)\ \phi(x)\ \Phi(x - d_I) + \Phi^{N-1}(x)\ \phi(x - d_I) - N\phi(x)\Phi^{N-1}(x)\right] dx\ . \tag{36}$$

The constants, A_N and B_N, given in equation (35) are a function only of the number of channels ORed, N. Their mathematical expressions, defined previously in equations(24) and (27), were programmed on a PDP-12 computer using OS/8 BASIC. The integration was performed using Simpson's one-third rule with automatic halving (reference 6). The numerical values obtained for the constants, A_N and B_N, are listed in table 2.

Table 2. Constants A_N and B_N

Number of Channels ORed, N	A_N	B_N
1	0.00000	1.00000
2	0.56418	1.00000
3	0.84627	1.27566
4	1.02936	1.55132
5	1.16295	1.80000
6	1.26719	2.02172
7	1.35216	2.22028
8	1.42357	2.39951
9	1.48499	2.56258
10	1.53872	2.71207

The input deflection coefficient for N = 1, d_{I_1}, can be derived manually from equations (35) and (36) and table 2. The result is

$$d_{I_1} = \frac{-\Phi^{-1}(P_F)}{\sqrt{M}}\ , \tag{37}$$

where M = number of samples in the accumulator.

The input deflection coefficient for N = 1, d_{I_1}, for a specified P_F and M is listed in table 3.

Table 3. Input Deflection Coefficient (N = 1) for a Specified P_F and M

M	$d_{I_1}(P_F = 10^{-2})$	$d_{I_1}(P_F = 10^{-3})$	$d_{I_1}(P_F = 10^{-4})$	$d_{I_1}(P_F = 10^{-6})$
8	0.82261	1.09280	1.32582	1.68044
16	0.58167	0.77250	0.93750	1.18825
32	0.41131	0.54624	0.66291	0.84022
64	0.29084	0.38625	0.46875	0.59412
128	0.20565	0.27312	0.33146	0.42011
256	0.14542	0.19312	0.23437	0.29706

The input deflection coefficient for N > 1, d_{I_N}, is also obtained from equations (35) and (36) and table 2. Equation (36) was programmed on a PDP-12 computer using OS/8 BASIC. The value of the output deflection coefficient was set equal to d_{0Z} = 2.33, 3.09, 3.75, or 4.75. The right-hand side of equation (35) was computed manually for a specified number of channels ORed, N, and M = 8, 16, 32, 64, 128, and 256. Equation (36) was then used to obtain the required value of the input deflection coefficient for each N and M. The integration in equation (36) was performed using Simpson's one-third rule with automatic halving (reference 6). Finally, equation (3) and table 3 were used to compute the ORing loss.

SUMMARY

The graphical results are presented in figures 3 through 10. The following conclusions can be drawn from an examination of these figures:

1. The greater the number of channels ORed, the greater the ORing loss.

2. The lower the false alarm probability, the lower the ORing loss.

3. The more samples in the accumulator following the ORing device, the greater the ORing loss.

4. Exclusive ORing at point B in figure 1 considerably decreases the amount of data that must be displayed. However, there will be a large SNR loss if integration is performed following ORing.

5. The overall system gain produced by the integrator in figure 1 is reduced by an amount equal to the ORing loss.

Finally, the analytical results for ORing at point C (after integration) in figure 1 are equivalent to the M=1 curves in figures 3 through 6.

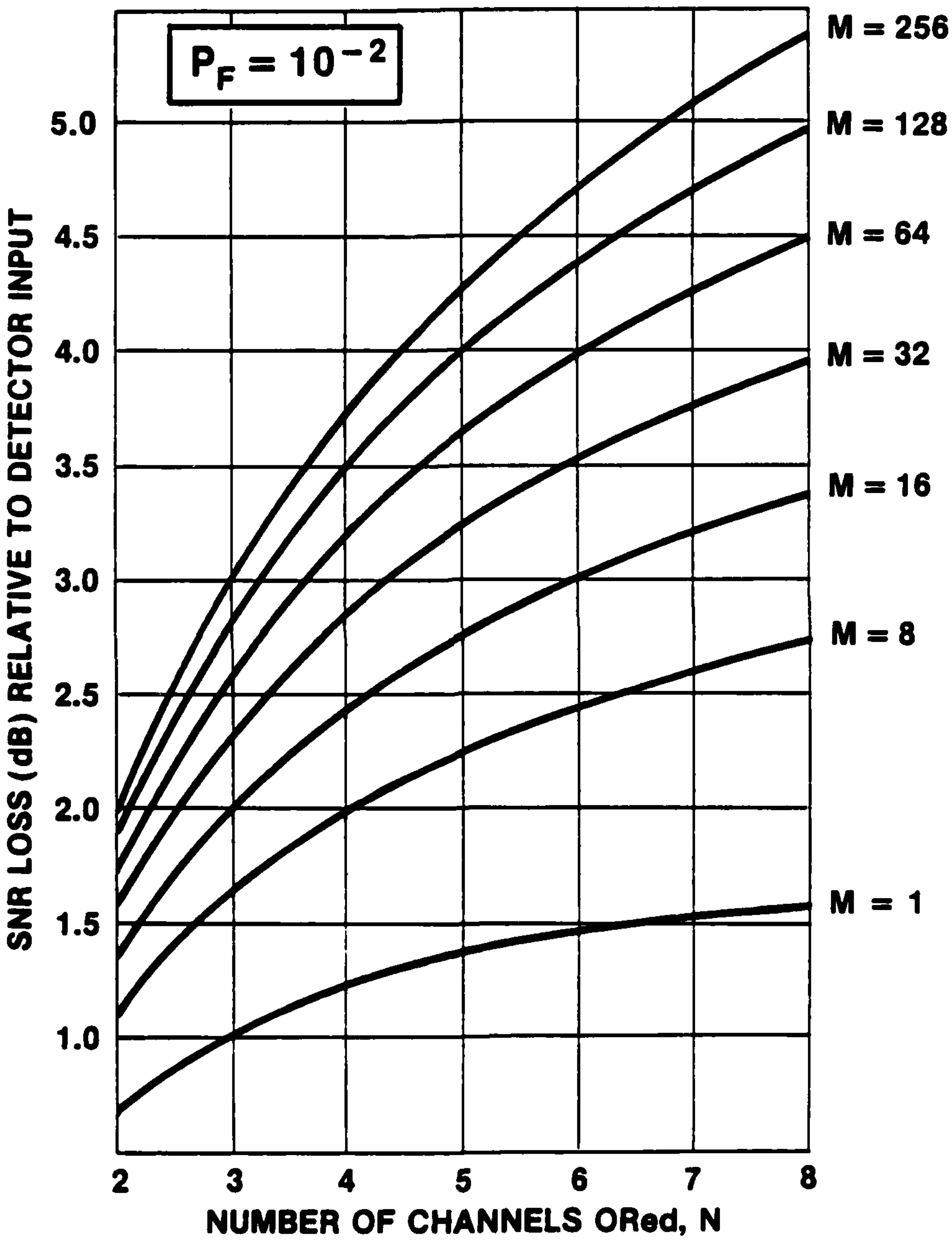

Figure 3. SNR Loss Due to ORing for $P_D = 0.5$ and $P_F = 10^{-2}$

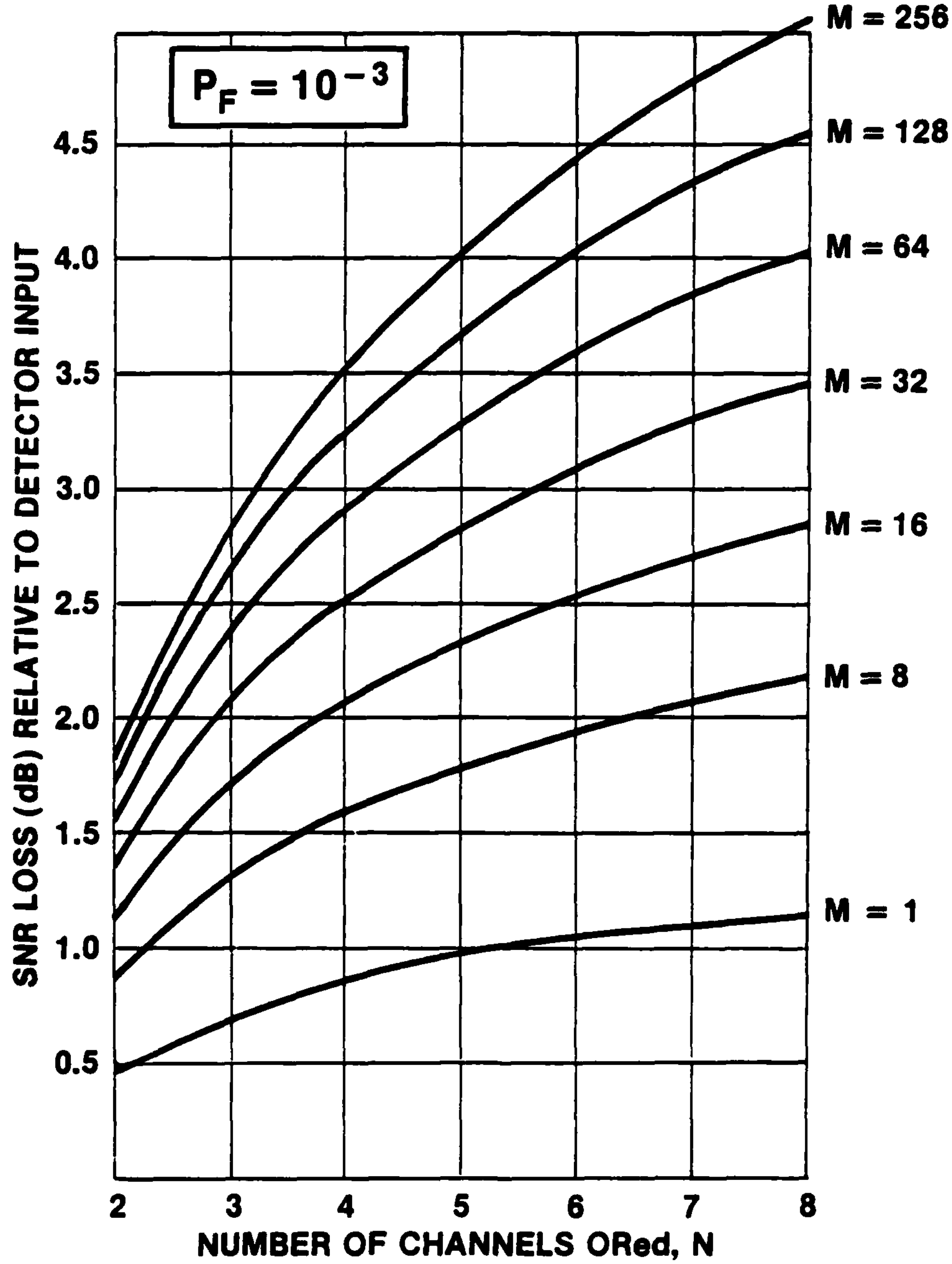

Figure 4. SNR Loss Due to ORing for $P_D = 0.5$ and $P_F = 10^{-3}$

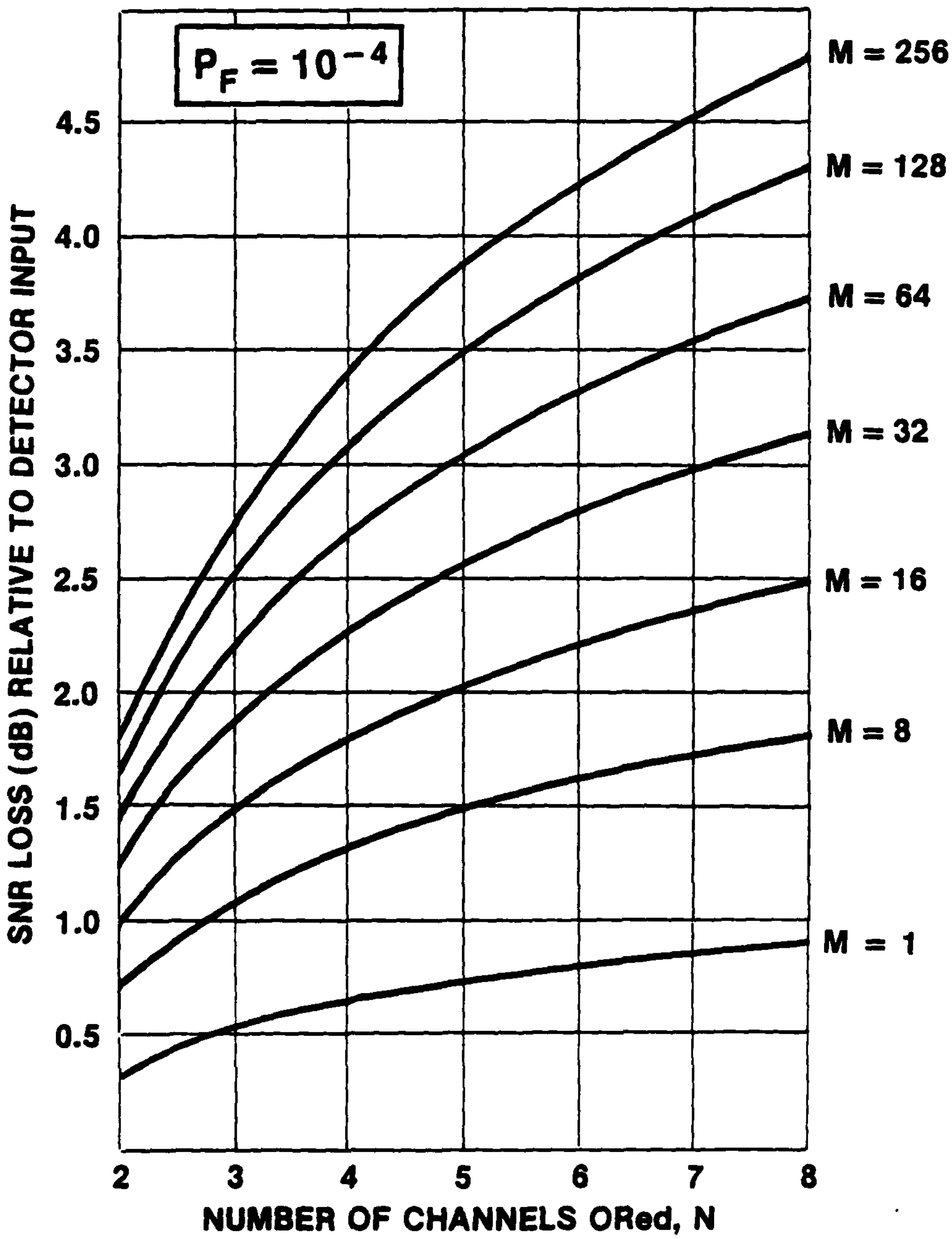

Figure 5. SNR Loss Due to ORing for P_D = 0.5 and P_F = 10^{-4}

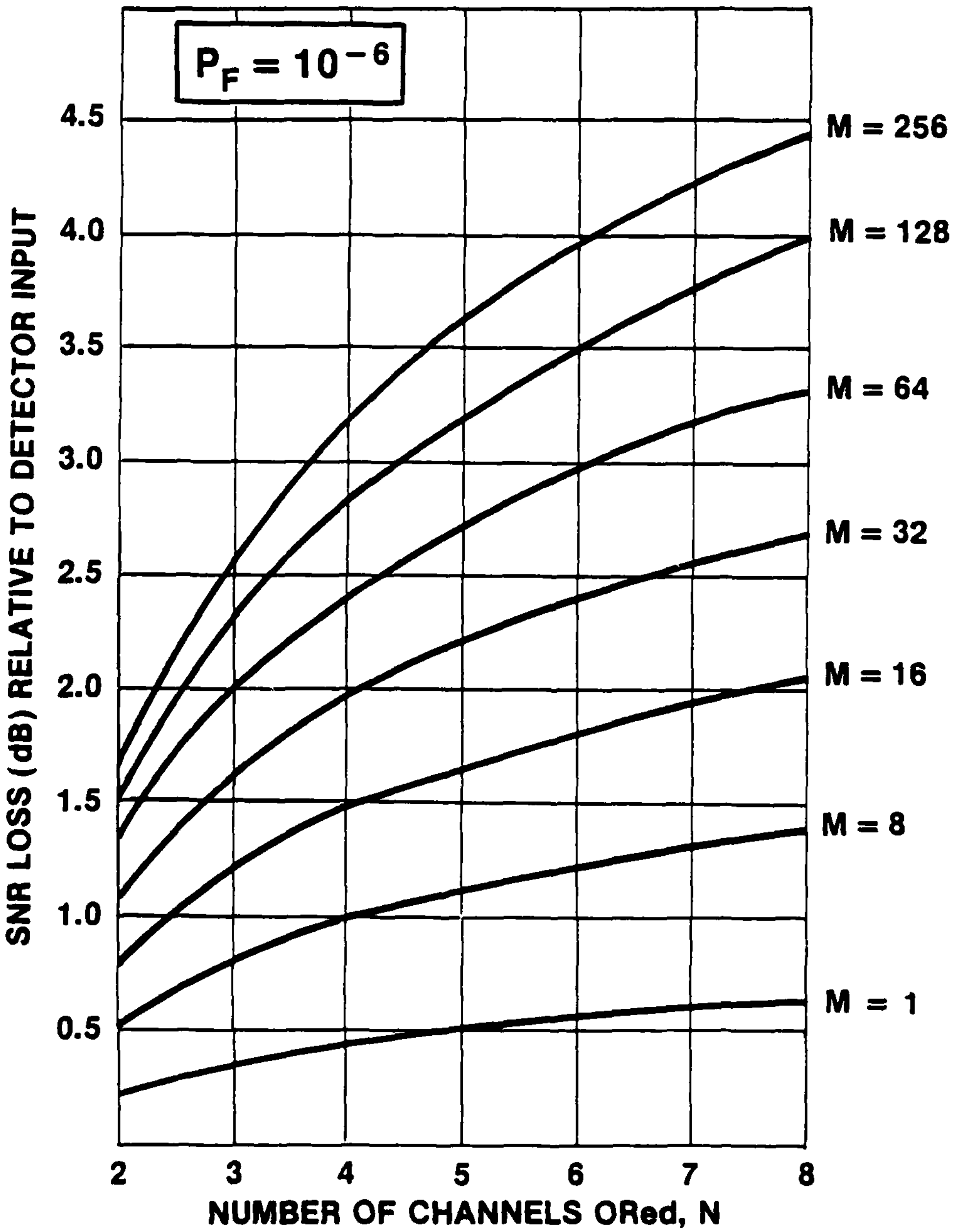

Figure 6. SNR Loss Due to ORing for $P_D = 0.5$ and $P_F = 10^{-6}$

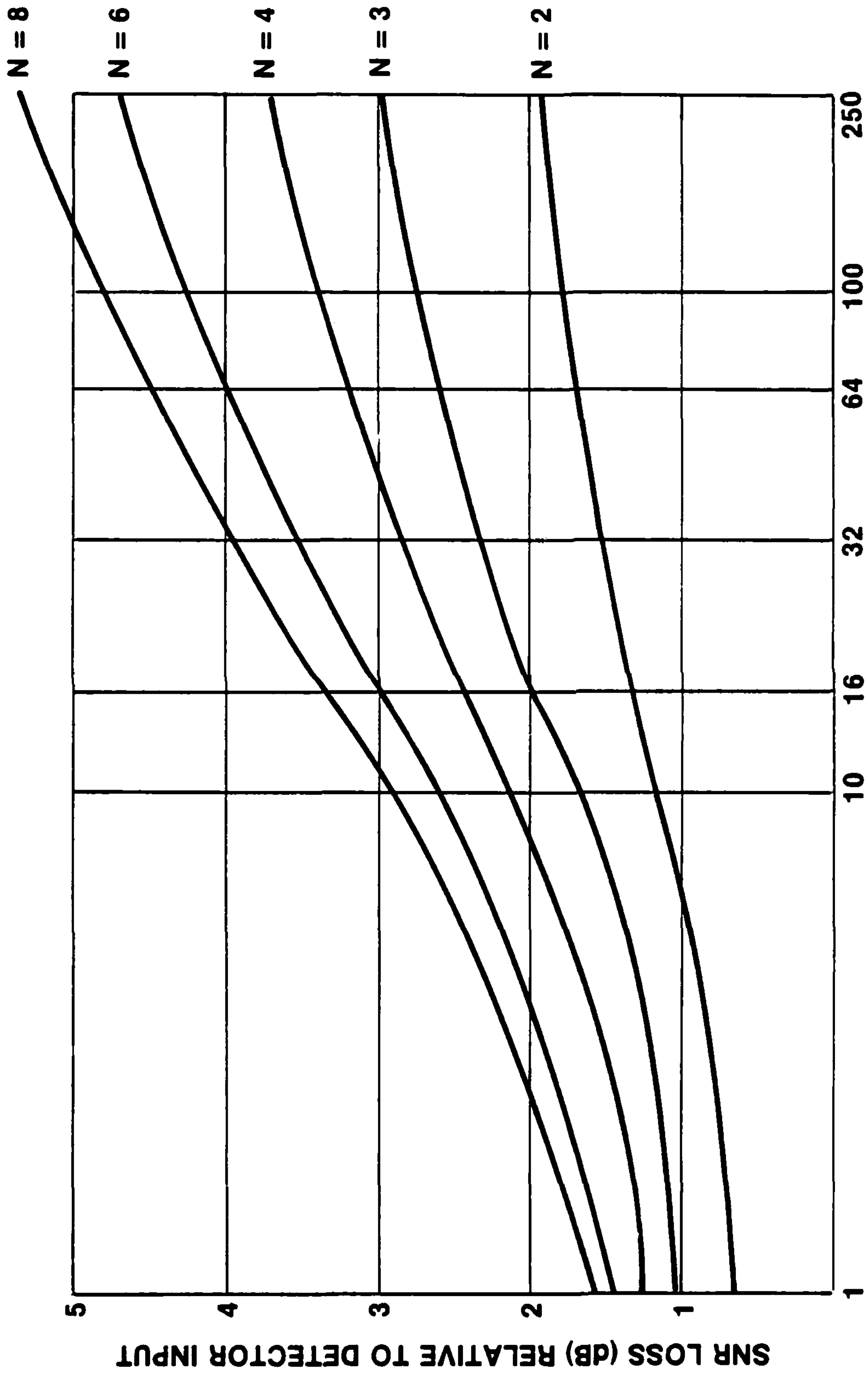

Figure 7. SNR Loss Versus Number of Samples in Accumulator for $P_D = 0.5$ and $P_F = 10^{-2}$

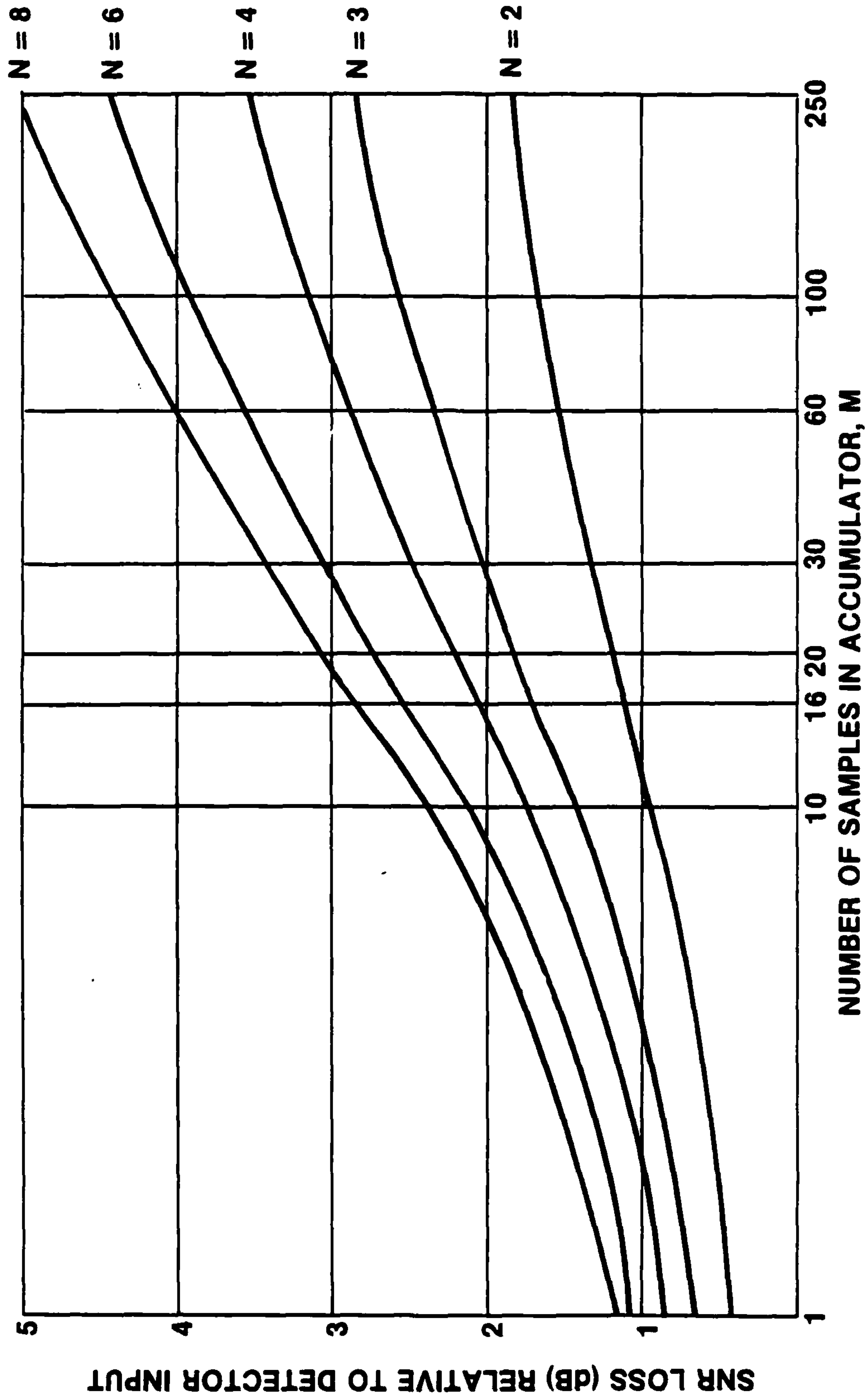

Figure 8. SNR Loss Versus Number of Samples in Accumulator for $P_D = 0.5$ and $P_F = 10^{-3}$

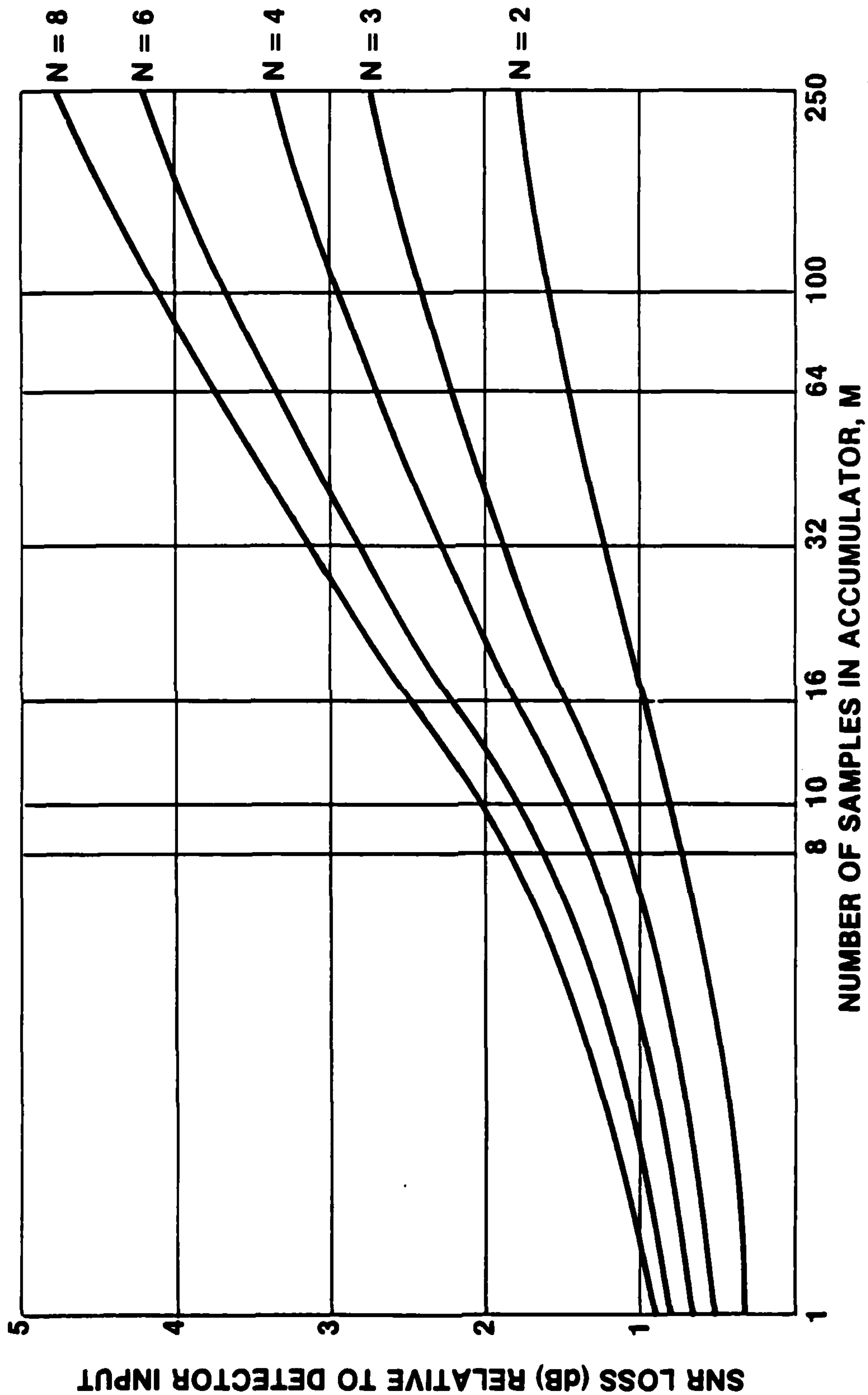

Figure 9. SNR Loss Versus Number of Samples in Accumulator for $P_D = 0.5$ and $P_F = 10^{-4}$

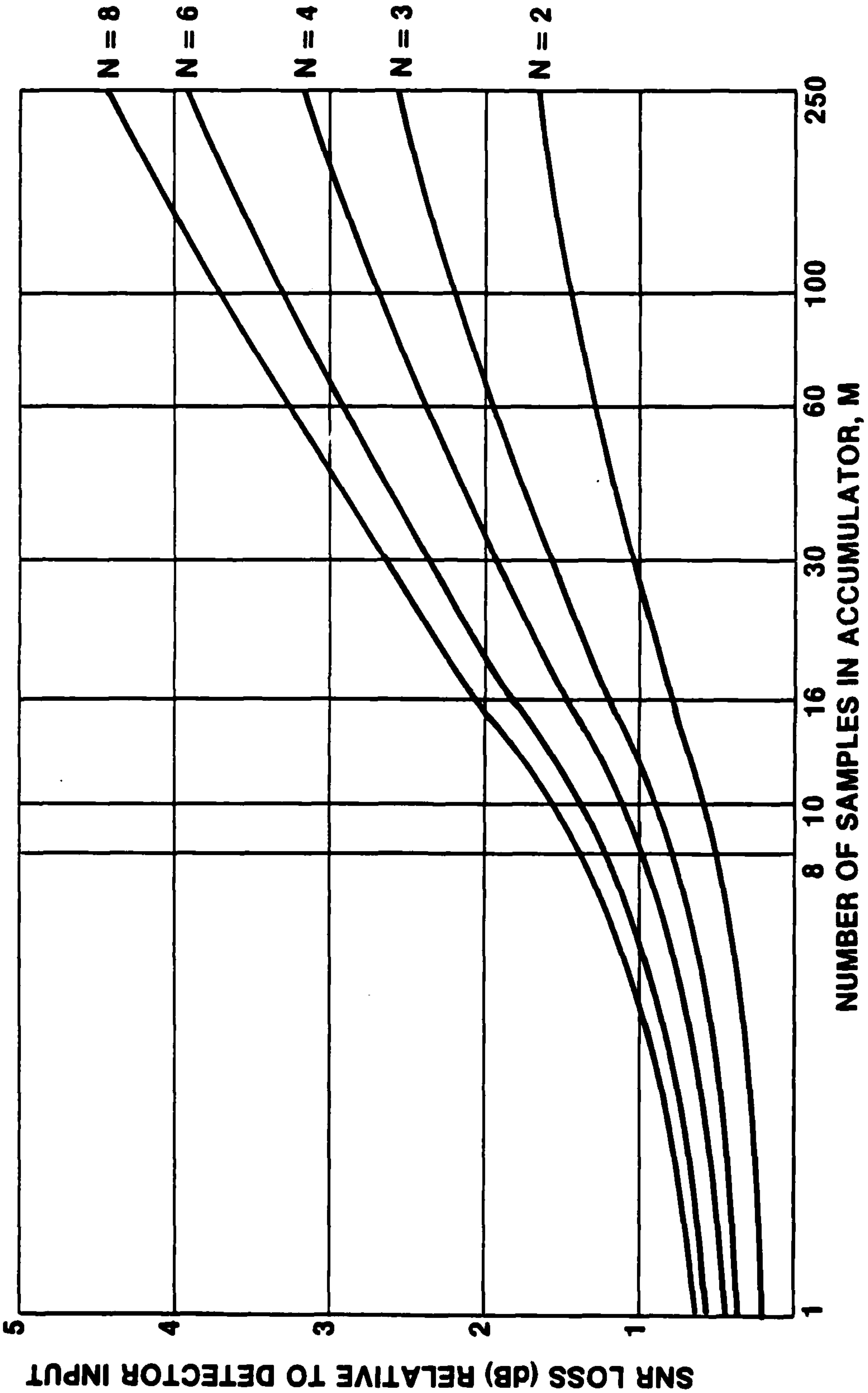

Figure 10. SNR Loss Versus Number of Samples in Accumulator for $P_D = 0.5$ and $P_F = 10^{-6}$

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