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NUWC-NPT Technical Document 10,419
2 July 1993

Procedure to Derive Submarine Sonar Operational PNB NRDs Against Continuous Wave and Gaussian Signals (U)

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~~Classified by: OPNAVINST S5513.5A-44~~
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PREFACE (U)

(U) This report was funded under NUWC assignment No. SS0201, "AN/BQQ-5 Sonar System Engineering, Performance Predictions", principal investigator, T.O. Sypher (Code 2111). The sponsoring activity id is PMO 425 , program manager W. Johnson.

(U) Technical reviewer for this document was J. Pratt, Chief Program Engineer, Engineering and Advanced Development Program Office (Code 2191).

(U) The authors gratefully acknowledge the support and assistance of R. Maynard of Analysis & Technology, Inc. in producing this document.

REVIEWED AND APPROVED: 2 JULY 1993

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE 2 July 1993	3. REPORT TYPE AND DATES COVERED Final

4. TITLE AND SUBTITLE

Procedure to Derive Submarine Sonar Operational PNB NRDs
Against Continuous Wave and Gaussian Signals (U)

5. FUNDING NUMBERS

SS0201

6. AUTHOR(S)

E. B. Siborg and T. O. Sypher

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Undersea Warfare Center Detachment
39 Smith Street
New London, Connecticut 06320-5594

8. PERFORMING ORGANIZATION REPORT NUMBER

TD 10,419

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Program Management Office (PMO 425)
Navy Department
Washington, DC 20362

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution authorized to the Department of Defense and U.S. DoD contractors only; Critical Technology; 2 July 1993. Other requests for this document shall be referred to the Naval Undersea Warfare Center.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

(U) This document provides a procedure to derive operational recognition differentials (NRDs) for submarine sonars/processors that use Fast Fourier Transforms (FFTs), against signals of varying duration and and bandwidth.

14. SUBJECT TERMS

Passive Narrowband Operational Recognition Differentials (PNB NRDs)
ORing

15. NUMBER OF PAGES

52

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Confidential	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18

TABLE OF CONTENTS (U)

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1.0 INTRODUCTION (U)

1.1 Background (U)

(U) Two types of signals are examined in the following procedure to derive PNB operational NRDs, Continuous Wave (CW) and Gaussian. The amplitude of the envelope of Gaussian signals varies from cycle to cycle, while CW signals have a constant envelope amplitude. CW signals are sinusoidal, with a fixed amplitude (and possible slow frequency modulation), while the amplitudes of Gaussian signals are random variables with Gaussian probability density functions.

(U) In the frequency domain the CW and Gaussian signals look similar but their probability density functions (PDFs) are different. The probability density function (p(x)) is a real-valued, non-negative function which describes the probability density that random data will assume a value within some defined range at any given instant of time. Figure 1-1 presents the PDFs for CW and Gaussian Signals. The PDF of the Gaussian signal is the classical normal (i.e., Gaussian) random process shape.

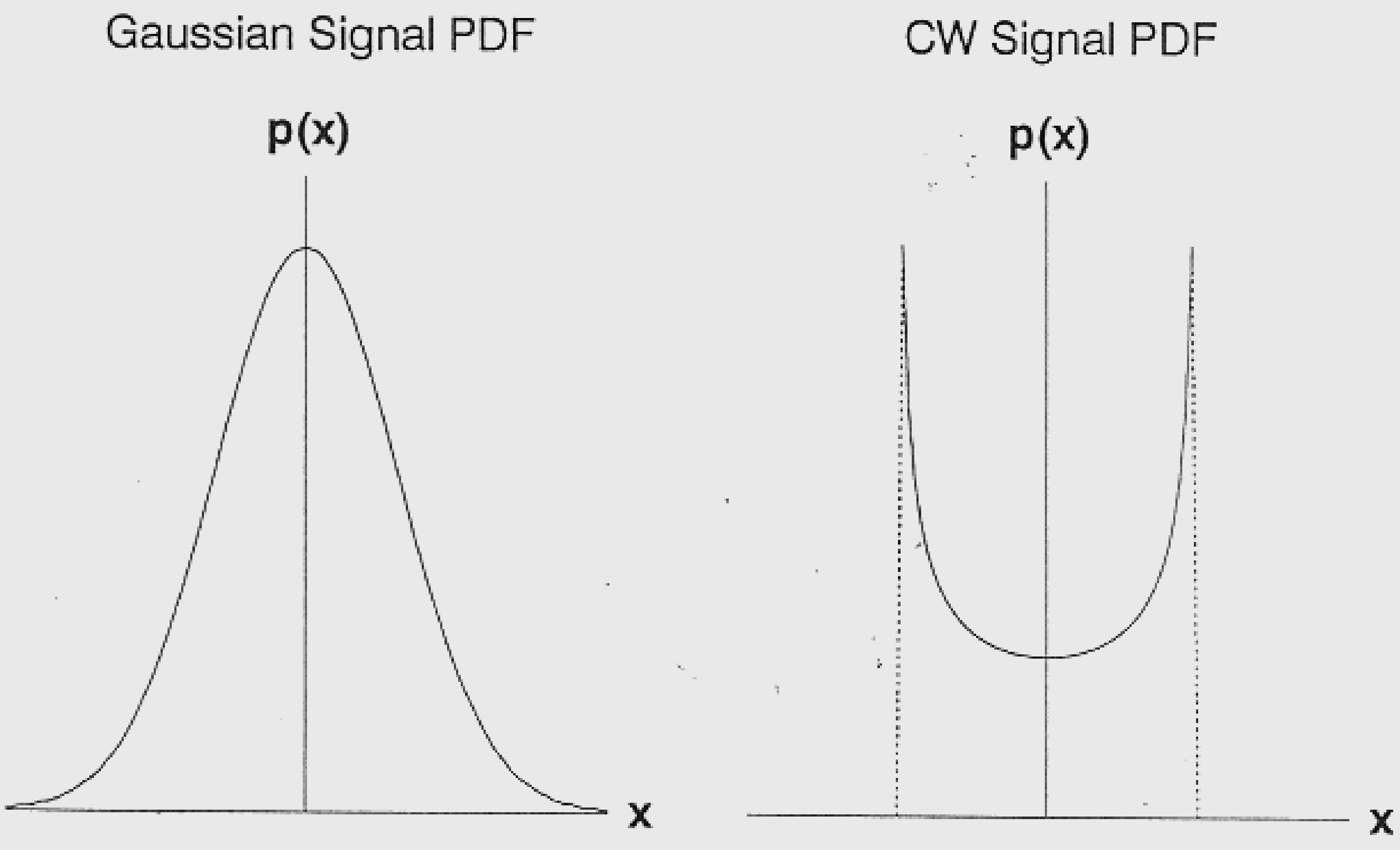

Figure 1-1 (U). Signal PDFs (U)

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1.2 Purpose (U)

(U) This technical document provides a procedure to derive operational recognition differentials (NRDs) for submarine sonars/processors that use Fast Fourier Transforms (FFTs), against signals of varying duration and bandwidth. The procedure has been expanded from the procedures reported in reference [a]. This expanded procedure includes the following:

a. A combined procedure for both CW and Gaussian signals.

b. Theoretical NRDs for Gaussian signals are based on statistical noise bandwidth rather than signal bandwidth.

c. Theoretical NRDs for CW signals are based on statistical noise bandwidth rather than effective noise bandwidth.

d. ORing losses were selected for LOFARgram displays with observation times of 300 seconds. Losses include degradation due to frequency and/or beam ORing, either as individual stages or concatenated stages. ORing loss data is based on the analysis reported in reference [b].

e. Theoretical NRDs for signals with Gaussian amplitude characteristics, as well as for CW tones, were extended to allow calculations out to 10,000 independent samples. The NRDs for signals with Gaussian amplitude characteristics are based on theoretical NRD values presented in reference [c]. The NRDs for signals with CW amplitude characteristics are based on theoretical NRD values from work done by A.H. Nuttall (reference [d]), using a more precise approach than G.H. Robertson's approximate calculations (reference [e]).

f. Signal suppression loss associated with normalizers has been revised. Normalizer loss is based on the analysis reported in reference [f].

g. Signal energy loss that results when the observation time is less than the minimum of the processor integration time and the time of one independent sample is based on the analysis reported in reference [g].

h. Calculations were revised to determine the number of independent samples to account for correlated samples due to overlapping FFTs. This procedure was based on analysis reported in reference [h].

i. At-sea loss was revised based on a recalculation reported in reference [t].

(U) The procedure applies to search LOFARgrams and classification LOFARgrams. It does not apply to processors that employ exponential integrators (as in ALIT and FRAZ processors).

A procedure to determine NRDs for exponential integrators and to determine their ORing loss will be incorporated as soon as a procedure and ORing Loss values are developed. Section 2 consists of a step-by-step procedure, followed by examples for CW and Gaussian signals. Appendix A provides assumptions and detailed rational for the step-by-step procedure.

1.3 Application (U)

(U) The procedure is intended to be the NUWC standard for determining submarine sonar operational PNB NRDs. It also could be used to generate NRDs for in-plant performance if operator assurance and at-sea losses are not considered. There currently exists a computer program which will compute operational NRDs based on the steps defined in reference [a]. The program is coded in FORTRAN and runs on any 100% IBM compatible personal computer. It is planned to update the PC NRD program with the steps outlined in this document. The PC NRD program will allow for the determination of ORing Loss for:

1. Observation times other than 300 seconds or display update rates other than 12 seconds, and

2. ORing stages other than 2:1, 3:1, 4:1, 6:1, 8:1, and 16:1.

2.0 PROCEDURE TO DERIVE OPERATIONAL PNB NRDs

~~(C)~~ This procedure should be used to derive operational PNB NRDs by applying degradations and losses to theoretical NRDs for a probability of detection (Pd) of 0.5 and a stated probability of false alarm (Pfa). The procedure requires that signals for which NRDs are to be derived be defined in signal duration and bandwidth. These NRDs are to be used in the sonar equation for which signal levels are specified as total line (band) levels (dB//μPa^2) and background noise as spectrum levels (dB//μPa^2/Hz). They are NRD in dB//line or band level to noise spectrum level. [redacted] All other signals are CW with strengths defined as band levels.

> NOTE: In order to use the NRDs derived from this procedure, a correction is required to convert Gaussian signal source levels to band level. The source level should be adjusted by:
>
> $$10 * \log_{10}(B_{sig})$$
>
> where,
>
> B_{sig} = Displayed Gaussian signal bandwidth in Hertz
>
> Determination of the displayed bandwidth is included as part of Step 8 of the NRD procedure.

(U) Appendix A provides an expanded discussion of the rationale and procedures used to develop the following derivation of PNB NRD values.

2.1 STEP 1. DETERMINE ANALYZER EFFECTIVE NOISE BANDWIDTH (B_{eff}) AND STATISTICAL NOISE BANDWIDTH (B_{stat}) (U)

(U) The bandwidth of an FFT analyzer (B_{bin}) is broadened by the use of weighting on the time series. Determine the effective noise bandwidth (B_{eff}) by multiplying the unweighted analyzer resolution, which equals bin spacing, by a factor (K_e) dependent on the weighting scheme ($B_{eff} = B_{bin} * K_e$). The factors for several common weighting schemes are as follows:

Effective Noise Bandwidth

Weighting Scheme	(K_e)
Unweighted (rectangular)	1.00
Fejer (triangular)	1.33
Hamming (raised cosine)	1.36
Hanning (cosine squared)	1.50
Kaiser-Bessel	1.80

(U) Determine the statistical bandwidth (B_{stat}) by multiplying the unweighted analyzer resolution by a factor (K_s) dependent on the weighting scheme ($B_{stat} = B_{bin} * K_s$). The factors for several weighting schemes are as follows:

Statistical Noise Bandwidth

Weighting Scheme	(K_s)
Unweighted (rectangular)	1.50
Fejer (triangular)	1.86
Hamming (raised cosine)	1.89
Hanning (cosine squared)	2.09
Kaiser-Bessel	2.48

(U) Note that B_{eff} is used to determine the effective averaging time of the filter and to correct noise to 1 Hertz while B_{stat} is the processing gain bandwidth and is used to determine the bandwidth-time product.

(U) For other filter shapes (including those not associated with an FFT analyzer) the effective noise and statistical bandwidths should be determined by the formulas in Appendix A.

2.2 STEP 2. DETERMINE TIME (T) USED IN BT PRODUCT (U)

(U) The time used in the BT product is the time the signal is displayed and therefore is limited at one extreme by the total displayed history and at the other limit by the maximum of the processor integration time or the time for an independent sample.

$$T = \max\{ \min[T_{sig}, T_{obs}, T_{hist}], T_{min} \},$$
$$T_{min} = \max[T_{int}, 1/B_{eff}]$$

where,

T_{sig} = Signal duration in seconds
T_{obs} = Observation time in seconds
T_{hist} = Total display history in seconds
T_{int} = Processor integration time in seconds (display update rate for LOFARgrams)
$1/B_{eff}$ = 1/STEP 1 (time in seconds for an independent sample)

2.3 STEP 3. DETERMINE NUMBER OF EFFECTIVE INDEPENDENT SAMPLES (N) (U)

(U) If the number of samples used in an FFT is overlapped with the samples of successive FFTs then the samples are correlated. The number of effective independent samples can be determined by multiplying the Bandwidth-Time product by the factor $K_{overlap}$.

Factors for several Weighting Schemes and percentage of FFT overlap are as follows:

$K_{overlap}$				
Weighting Scheme	50.00%	75.00%	87.50%	93.75%
Unweighted (rectangular)	0.982	1.043	1.053	1.051
Fejer (triangular)	0.908	0.921	0.910	0.903
Hamming (raised cosine)	0.906	0.928	0.915	0.908
Hanning (Cosine squared)	0.861	0.920	0.908	0.900
Kaiser-Bessel	0.757	0.937	0.925	0.917

NOTE: Figure A-1 in Appendix A provides factors ($K_{overlap}$) for additional FFT overlaps not presented in the table above.

(U) The effective number of independent samples (N) is computed by taking the product of the bandwidth (B_{stat}), time (T), and the appropriate $K_{overlap}$.

$$N = B_{stat} * T * K_{overlap}$$

where,

B_{stat} = Statistical Noise Bandwidth in Hertz (STEP 1)
T = Time in seconds (STEP 2)
$K_{overlap}$ = Overlap Correction Factor

2.4 STEP 4. DETERMINE THE THEORETICAL NRD (U)

(U) For a CW signal, use figure 2-1 to determine the theoretical NRD for the number of effective independent samples (N) (from STEP 3) and the Pfa of the processor. Figure 2-1a presents theoretical NRDs for independent sample sizes (N) from 1 to 100. Figure 2-1b presents theoretical NRDs for independent sample sizes (N) from 100 to 10,000.

(U) For a Gaussian signal, use figure 2-2 to determine the theoretical NRD for the number of independent samples (N) and the Pfa of the processor. Figure 2-2a presents theoretical NRDs against Gaussian signals for independent sample sizes (N) from 1 to 100. Figure 2-2b presents Gaussian signal theoretical NRDs for independent sample sizes (N) from 100 to 10,000.

2.5 STEP 5. CORRECT NRD TO A ONE HERTZ NOISE BANDWIDTH (U)

(U) A correction is required to convert the NRD to a one Hertz noise bandwidth. Assess a bandwidth correction as follows.

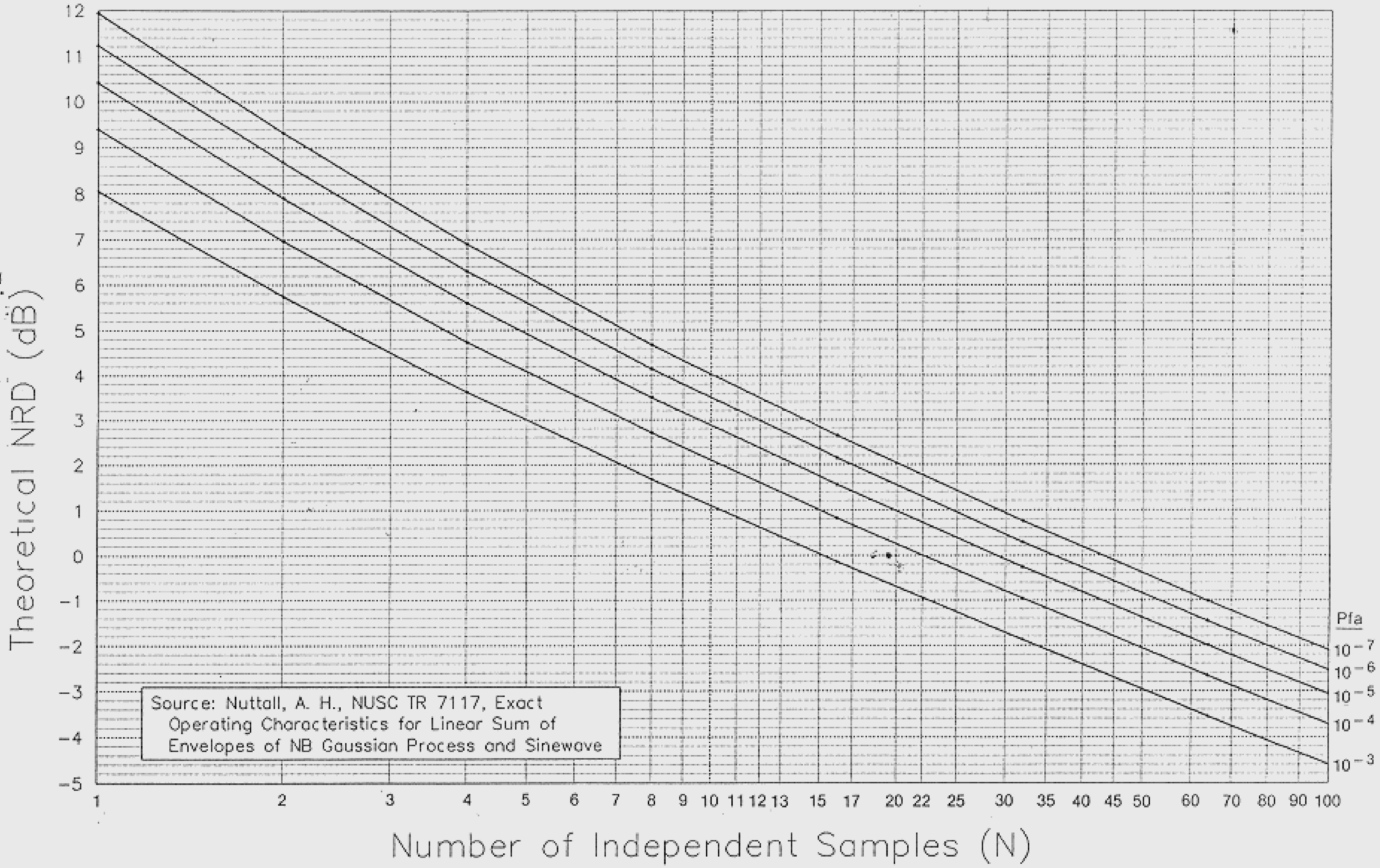
$$10 * \log_{10}(B_{eff})$$

where,

B_{eff} = Effective Noise Bandwidth in Hertz (STEP 1).

Theoretical NRDs for CW Signals at Pd=0.5

(Number of Samples from 1 to 100)



Source: Nuttall, A. H., NUSC TR 7117, Exact Operating Characteristics for Linear Sum of Envelopes of NB Gaussian Process and Sinewave

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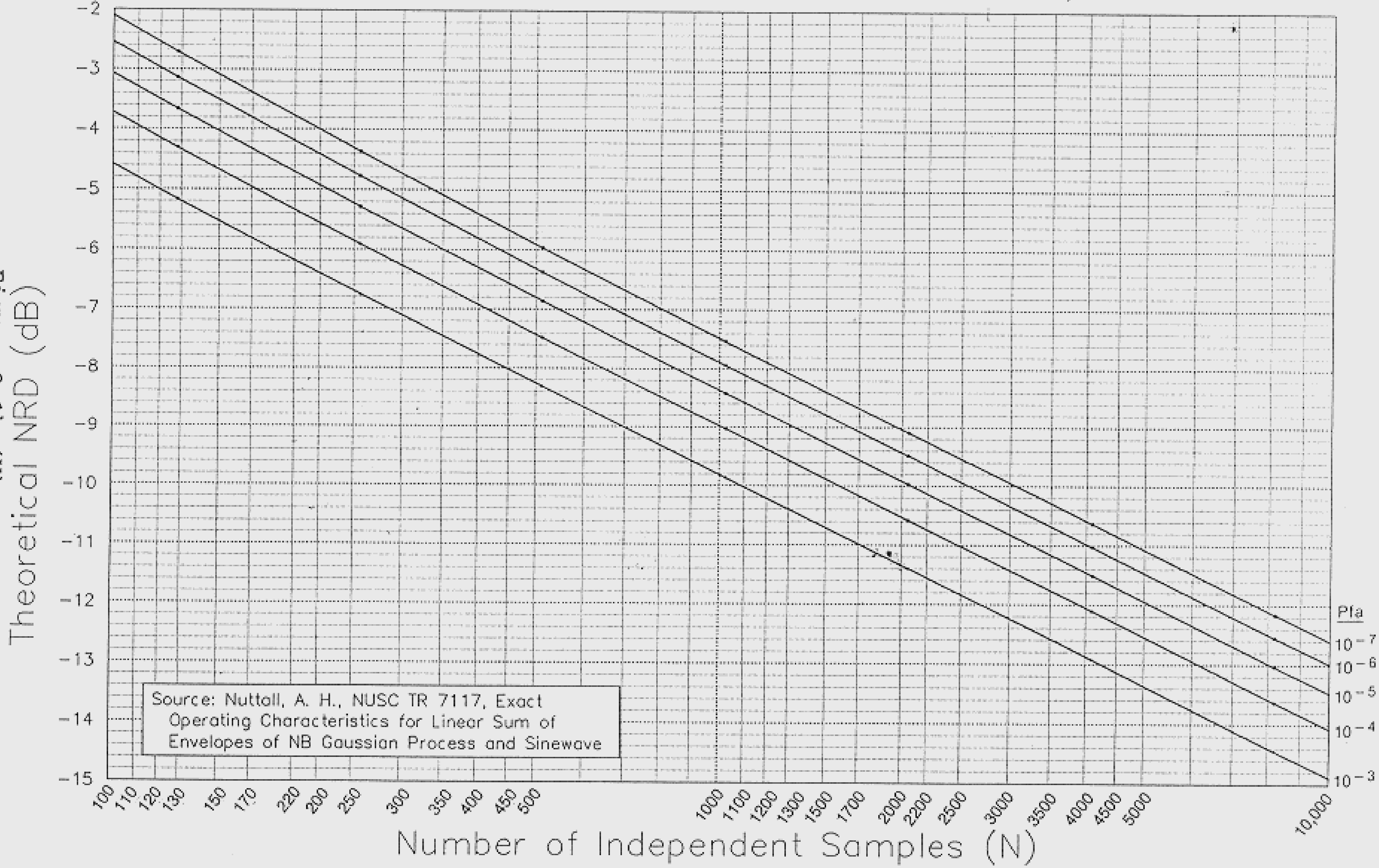
Figure 2-1a (U)

Theoretical NRDs for CW Signals at Pd=0.5

(Number of Samples from 100 to 10000)



Source: Nuttall, A. H., NUSC TR 7117, Exact Operating Characteristics for Linear Sum of Envelopes of NB Gaussian Process and Sinewave

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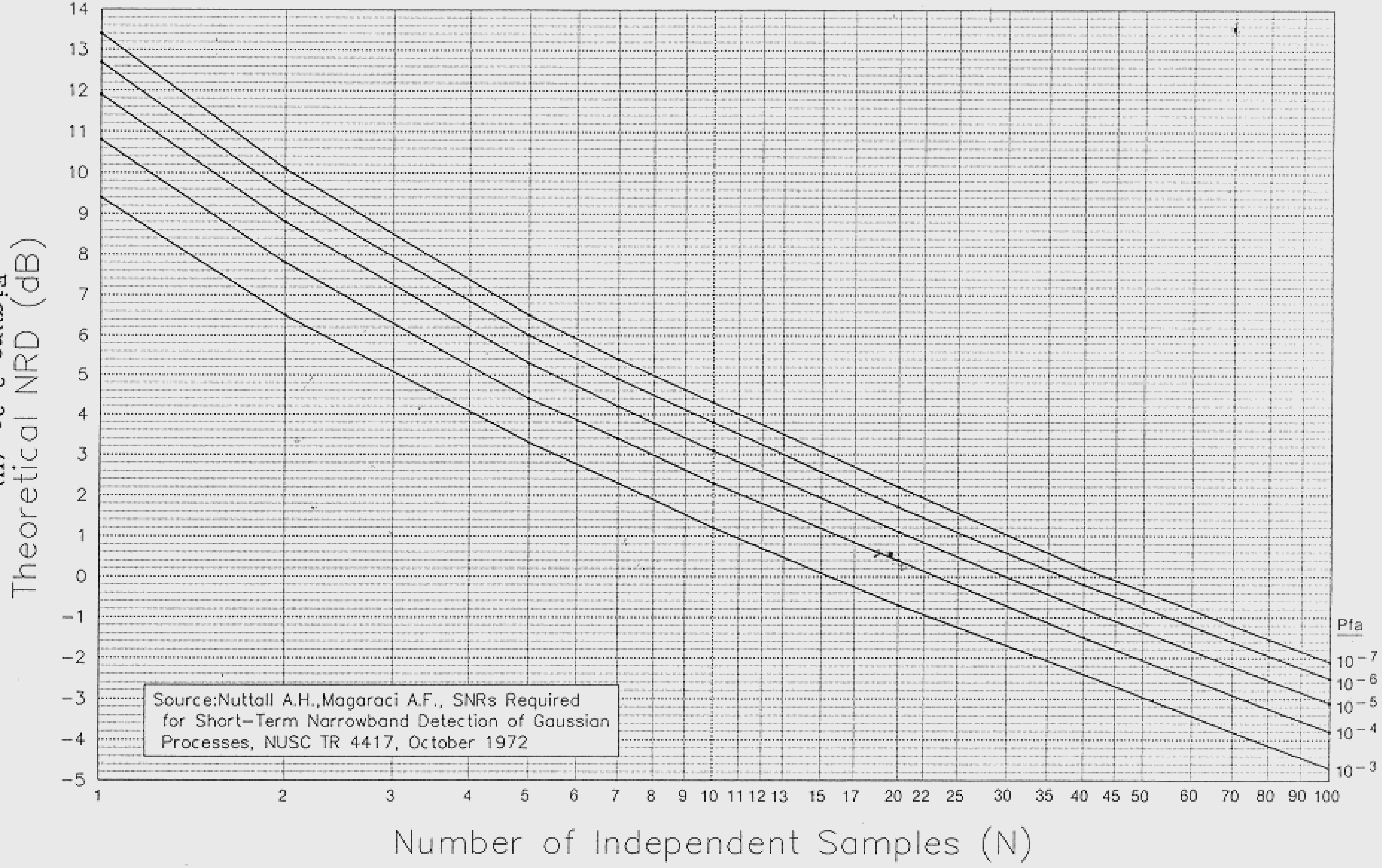
Figure 2-1b (U)



Theoretical NRDs for Gaussian Signals at Pd=0.5
(Number of Samples from 1 to 100)

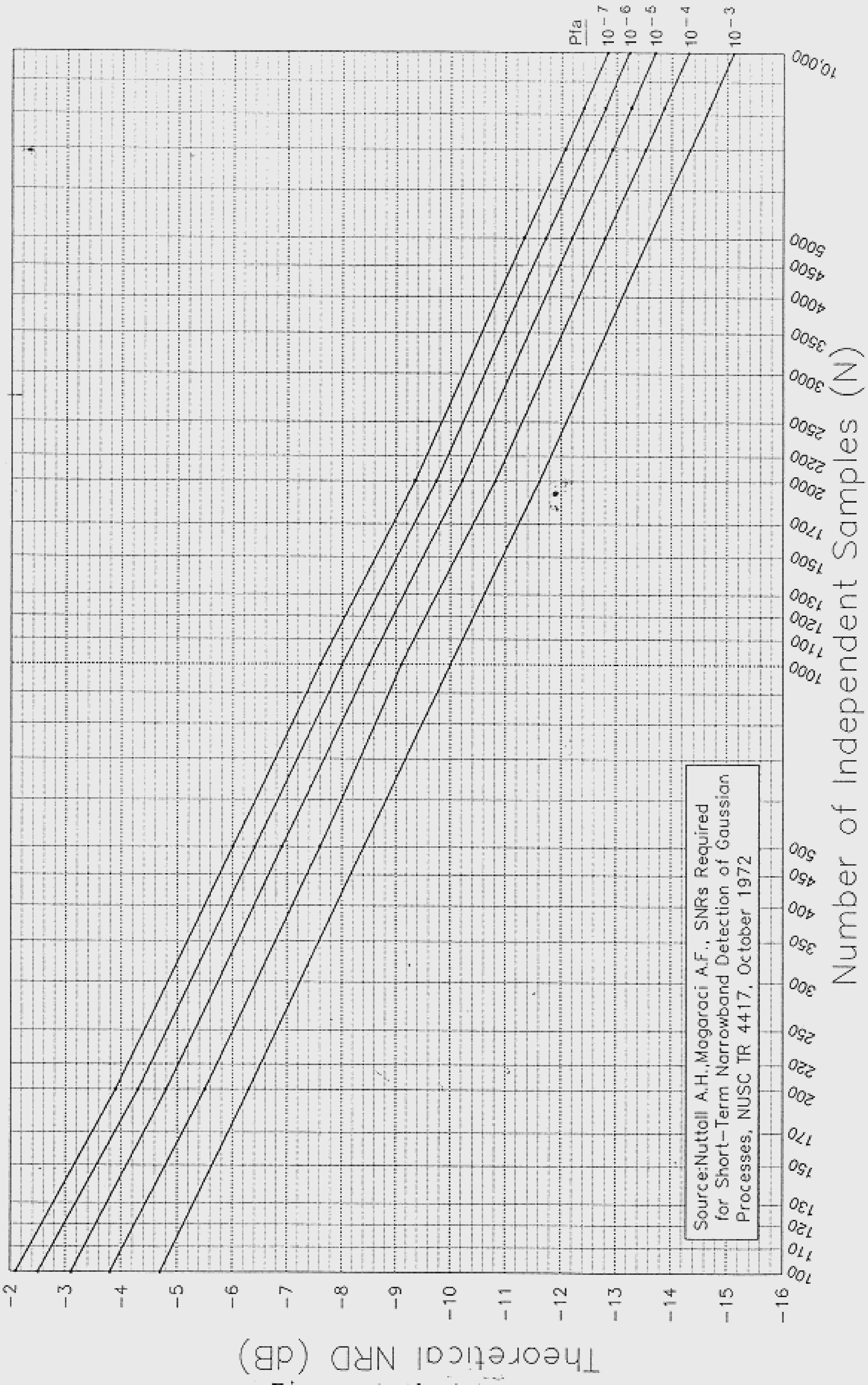
Source:Nuttall A.H.,Magaraci A.F., SNRs Required for Short-Term Narrowband Detection of Gaussian Processes, NUSC TR 4417, October 1972

(UNCLASSIFIED)

Figure 2-2a (U)

Theoretical NRDs for Gaussian Signals at Pd=0.5

(Number of Samples from 100 to 10000)



Source:Nuttall A.H.,Magaraci A.F., SNRs Required for Short-Term Narrowband Detection of Gaussian Processes, NUSC TR 4417, October 1972

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Figure 2-2b (U)

2.6 STEP 6. DETERMINE SIGNAL ENERGY LOSSES (U)

(U) If the signal duration is less than T_{min}, a signal energy loss should be assessed.

$$-10 * \log_{10}(T_{sig}/T_{min})$$

where,

T_{sig} = Signal duration in seconds (STEP 2)
T_{min} = Lower Time limit used in determining T (STEP 2)

(U) If the observation time is less then T_{min}, a signal energy loss should be assessed.

$$-10 * \log_{10}(T_{obs}/T_{min})$$

where,

T_{obs} = Observation time in seconds (STEP 2)
T_{min} = Lower time limit used in determining T (STEP 2)

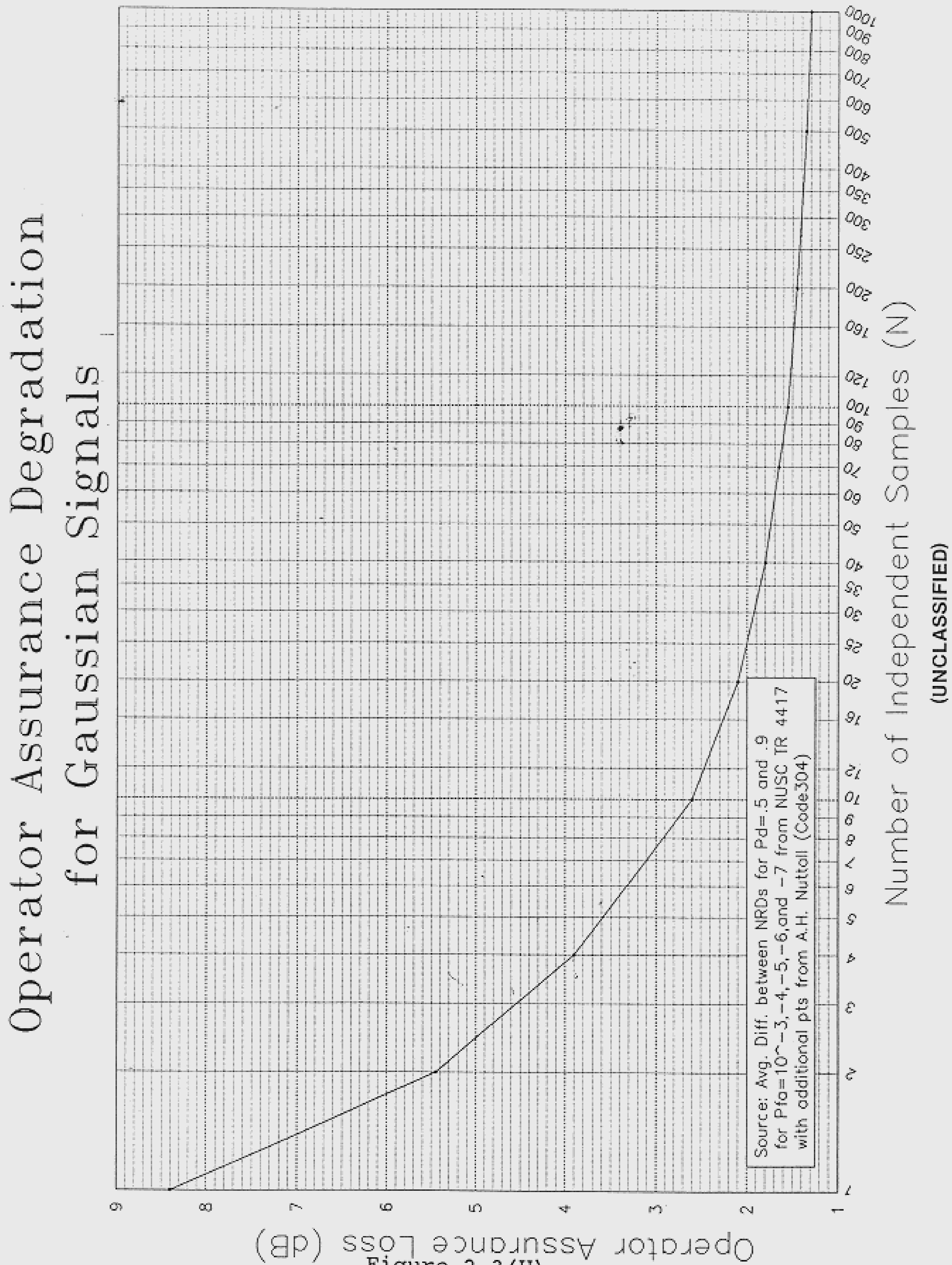
2.7 STEP 7. DETERMINE THE DEGRADATION FOR OPERATOR ASSURANCE (U)

~~(C)~~ For a CW signal, the degradation for operator assurance is dependent on the processing function.

~~(C)~~ For a Gaussian signal, use Figure 2-3 to determine the degradation for operator assurance for the number of independent samples (N from STEP 3).

2.8 STEP 8. DETERMINE IMPLEMENTATION LOSSES (U)

(U) **Analyzer Scalloping Loss** - For a CW signal, analyzer scalloping loss is dependent on the weighting scheme. For the following weighting schemes, determine the appropriate analyzer scalloping loss.



Source: Avg. Diff. between NRDs for Pd=.5 and .9 for Pfa=10^-3,-4,-5,-6,and -7 from NUSC TR 4417 with additional pts from A.H. Nuttall (Code304)

(UNCLASSIFIED)

Figure 2-3(U)

Weighting Scheme	Scalloping loss (dB)
Unweighted (rectangular)	1.2
Fejer (triangular)	0.7
Hamming (raised cosine)	0.6
Hanning (cosine squared)	0.5
Kaiser-Bessel	0.4

(U) For other weighting schemes, the average of the square of the normalized filter response should be computed. The frequency range of the average should be between the crossover points of adjacent bins.

(U) For a Gaussian signal, do not assess any scalloping loss.

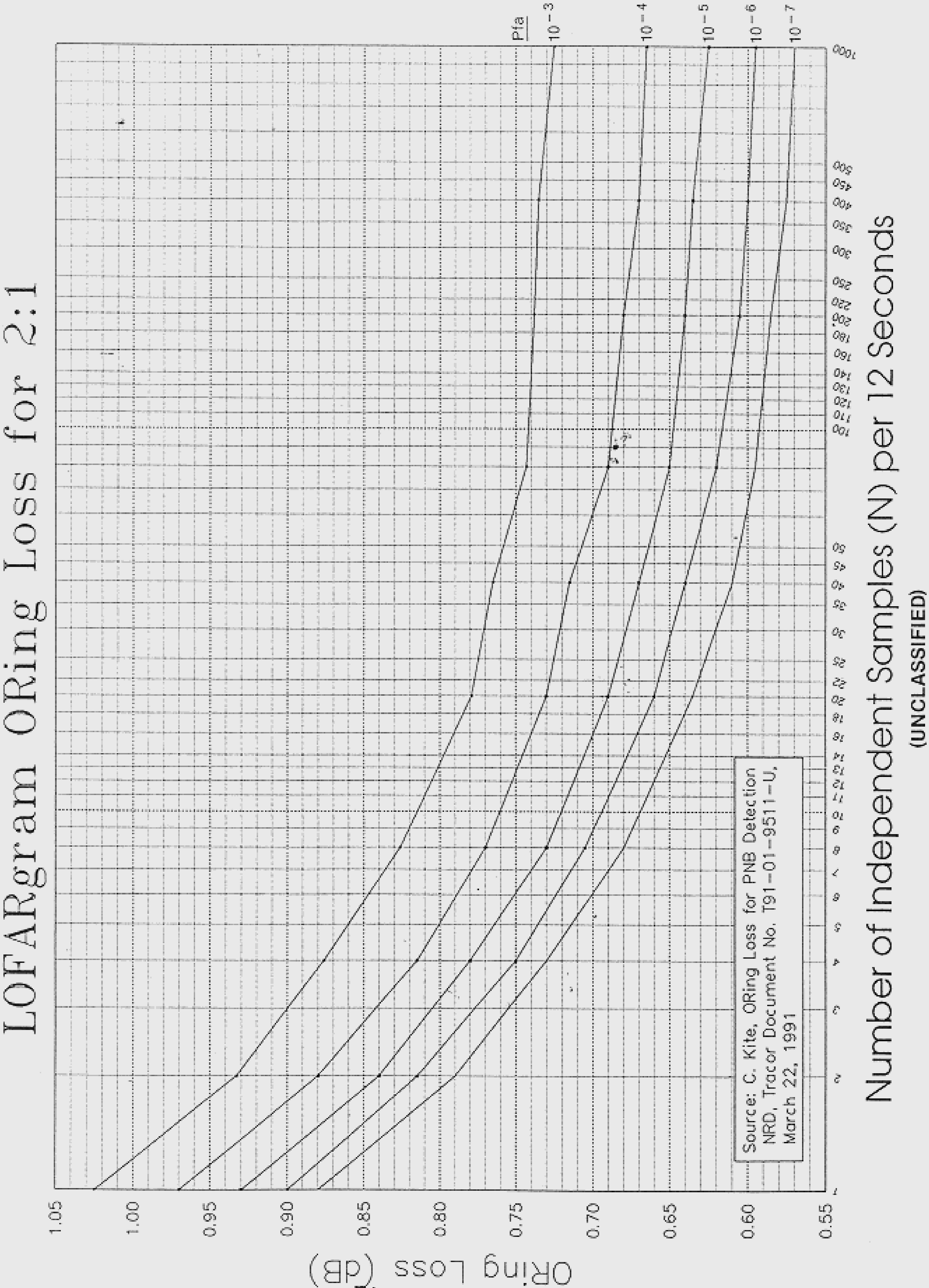
(U) **ORing Loss** - If the processor uses frequency and/or beam ORing, then the degradation due to lost information from taking the largest value of N adjacent beams (or bins) should be assessed. To determine the loss associated for a processor with a display update of 12 seconds first locate the appropriate figure for the given configuration from below.

ORing Ratio	Figure Number
2:1	2-4
3:1	2-5
4:1	2-6
8:1	2-7
16:1	2-8
3:2	2-9
2:1 + 3:2	2-10
3:1 + 3:2	2-11
4:1 + 3:2	2-12
8:1 + 3:2	2-13
16:1 + 3:2	2-14

NOTE: Figures 2-4 thru 2-14 are ORing losses for a 12 second display update rate and an observation time of 5 minutes. If either of these is not true, the figures should not be used. The PC NRD procedure should be used for other display updates or observation times.

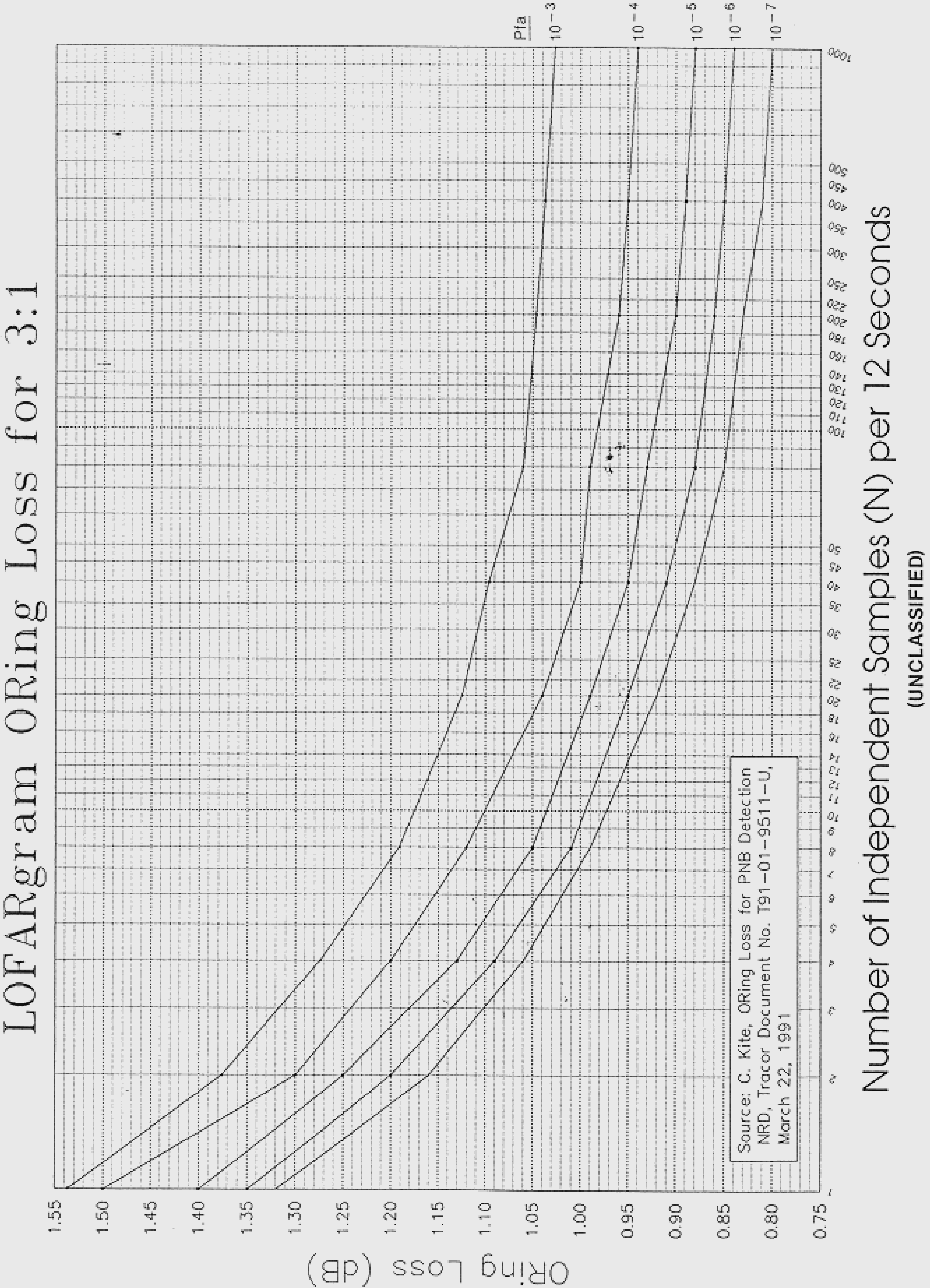
(U) From the appropriate figure, determine the ORing loss using the Pfa of the processor and the effective number of independent samples divided by 12 (N/12) (where N is computed in STEP 3).

(U) Concatenated ORing stages can be treated as a product of the individual stage ORing ratios on either side of a 3:2 ORing ratio. A 3:2 ORing ratio breaks the string. The 3:2 ORing can be combined with prior N:1 ORing. Example, if an ORing string is 2:1, 2;1, 3:2, and 3:1, then total ORing loss should be based on the loss of: 4:1 + 3:2 ORing loss added to 3:1 ORing loss.



Source: C. Kite, ORing Loss for PNB Detection NRD, Tracor Document No. T91-01-9511-U, March 22, 1991

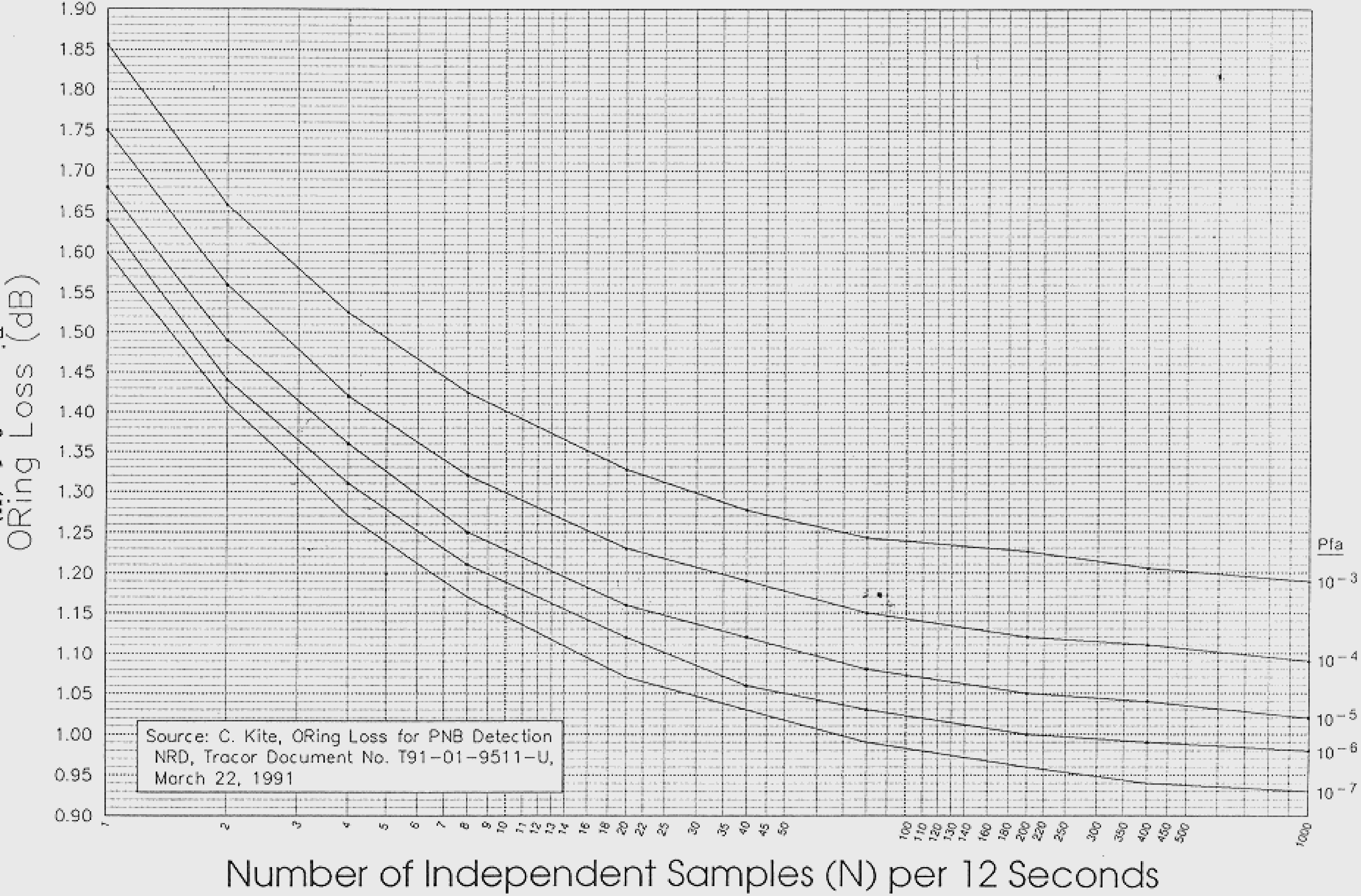
Figure 2-4 (U)



Source: C. Kite, ORing Loss for PNB Detection NRD, Tracor Document No. T91-01-9511-U, March 22, 1991

Figure 2-5 (U)

LOFARgram ORing Loss for 4:1



Source: C. Kite, ORing Loss for PNB Detection NRD, Tracor Document No. T91-01-9511-U, March 22, 1991

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Figure 2-6 (U)

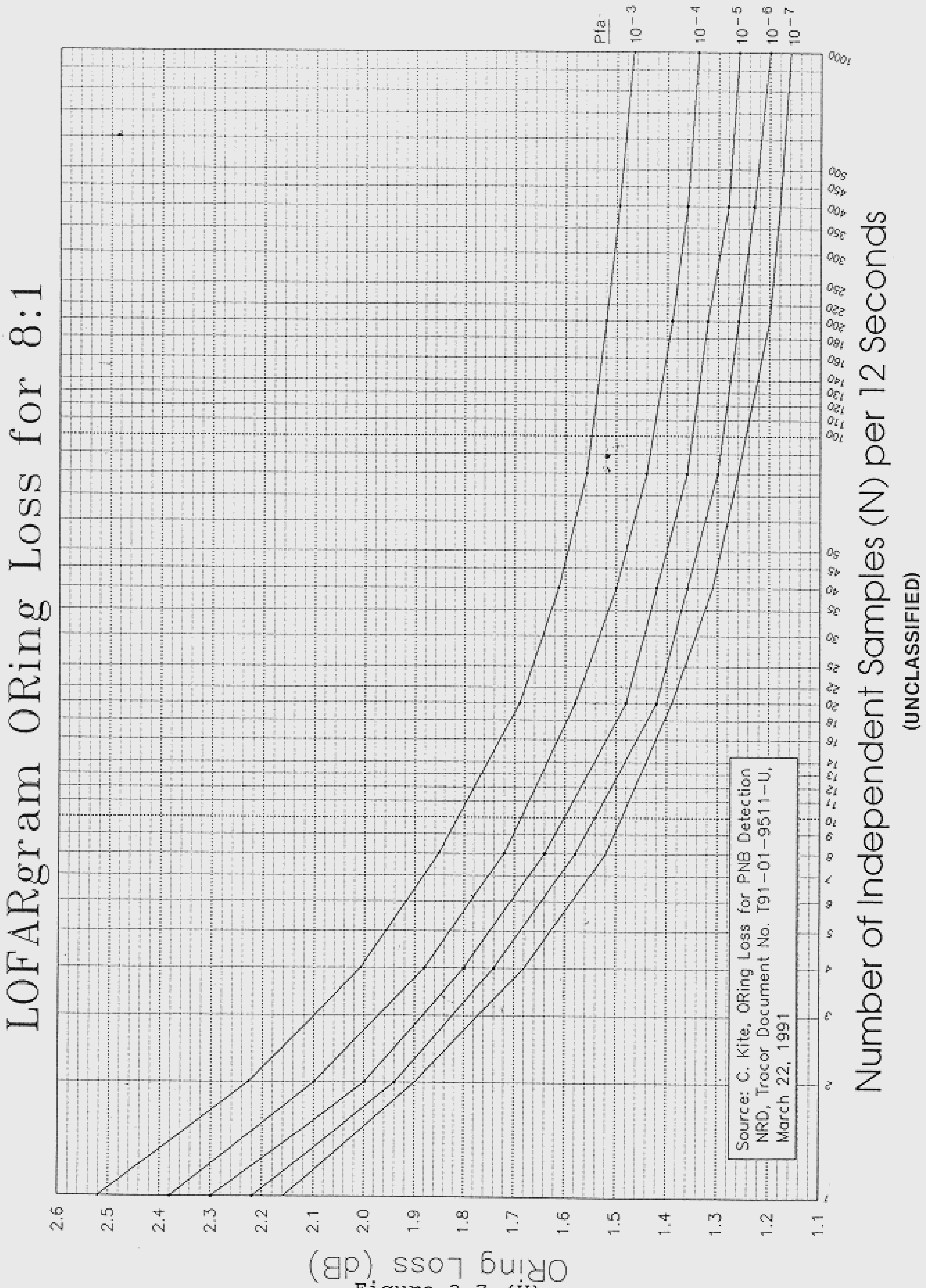

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Figure 2-7 (U)

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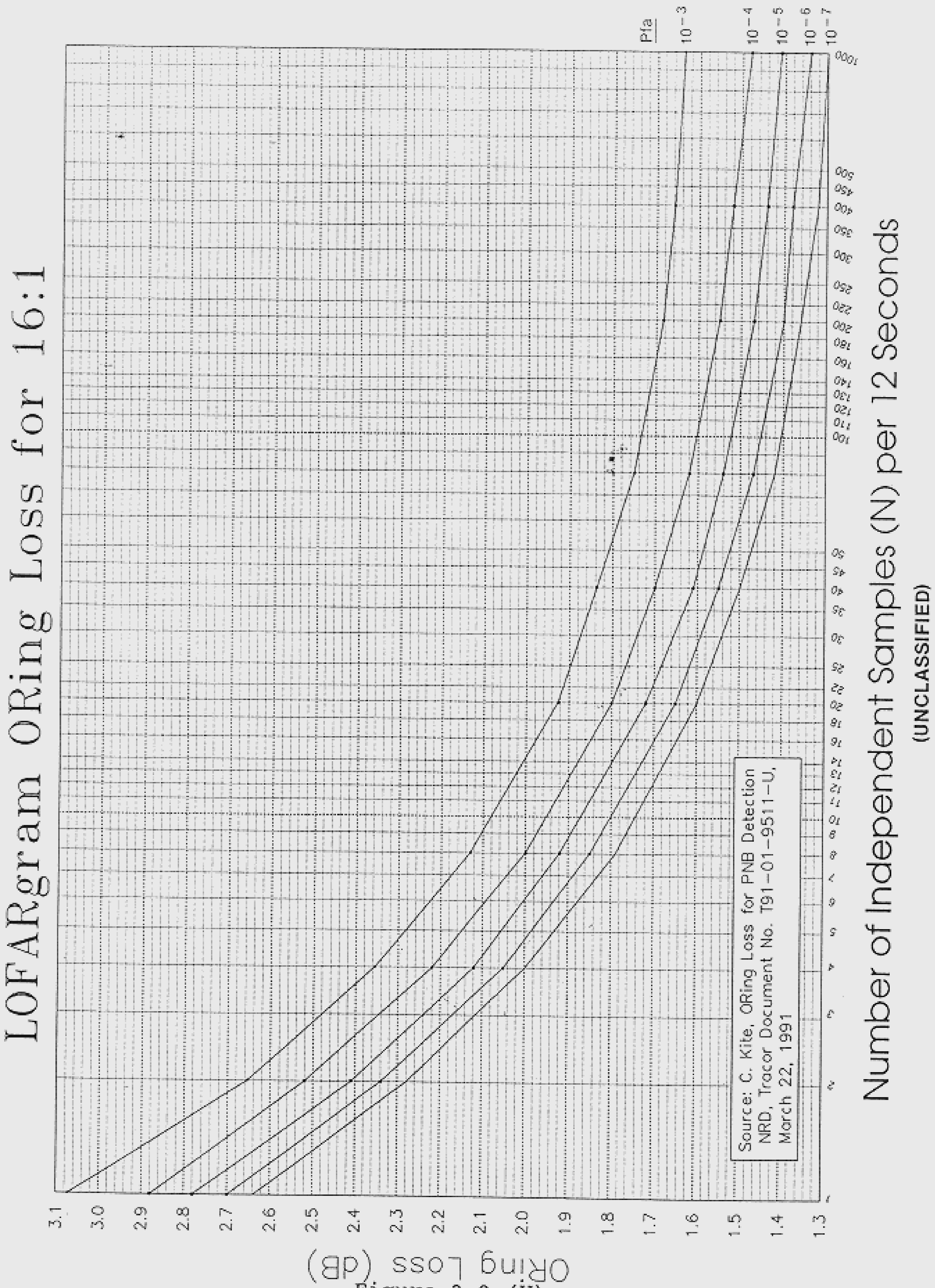
LOFARgram ORing Loss for 16:1

Source: C. Kite, ORing Loss for PNB Detection NRD, Tracor Document No. T91-01-9511-U, March 22, 1991

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Figure 2-8 (U)

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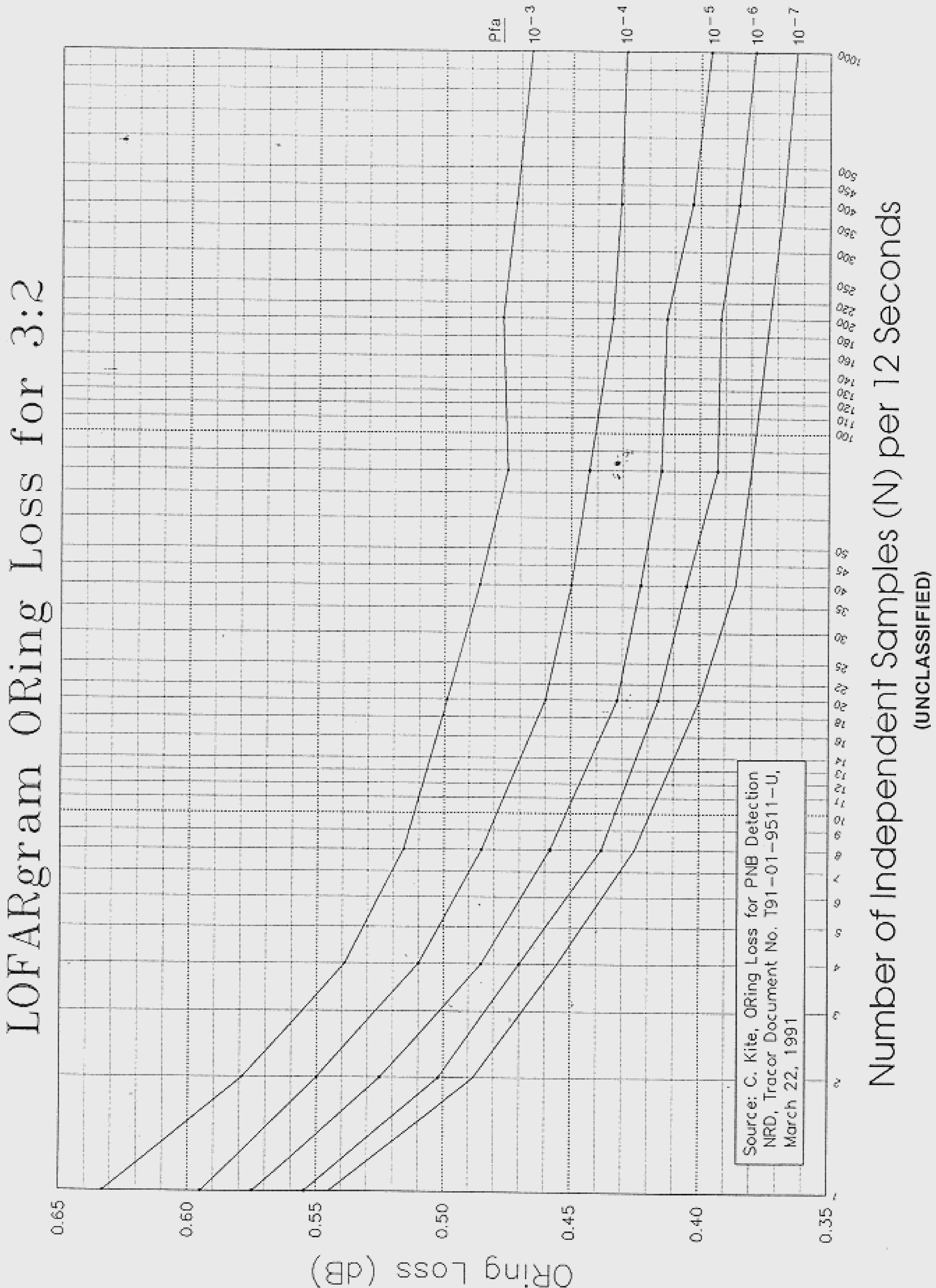

LOFARgram ORing Loss for 3:2

Source: C. Kite, ORing Loss for PNB Detection
NRD, Tracor Document No. T91-01-9511-U,
March 22, 1991

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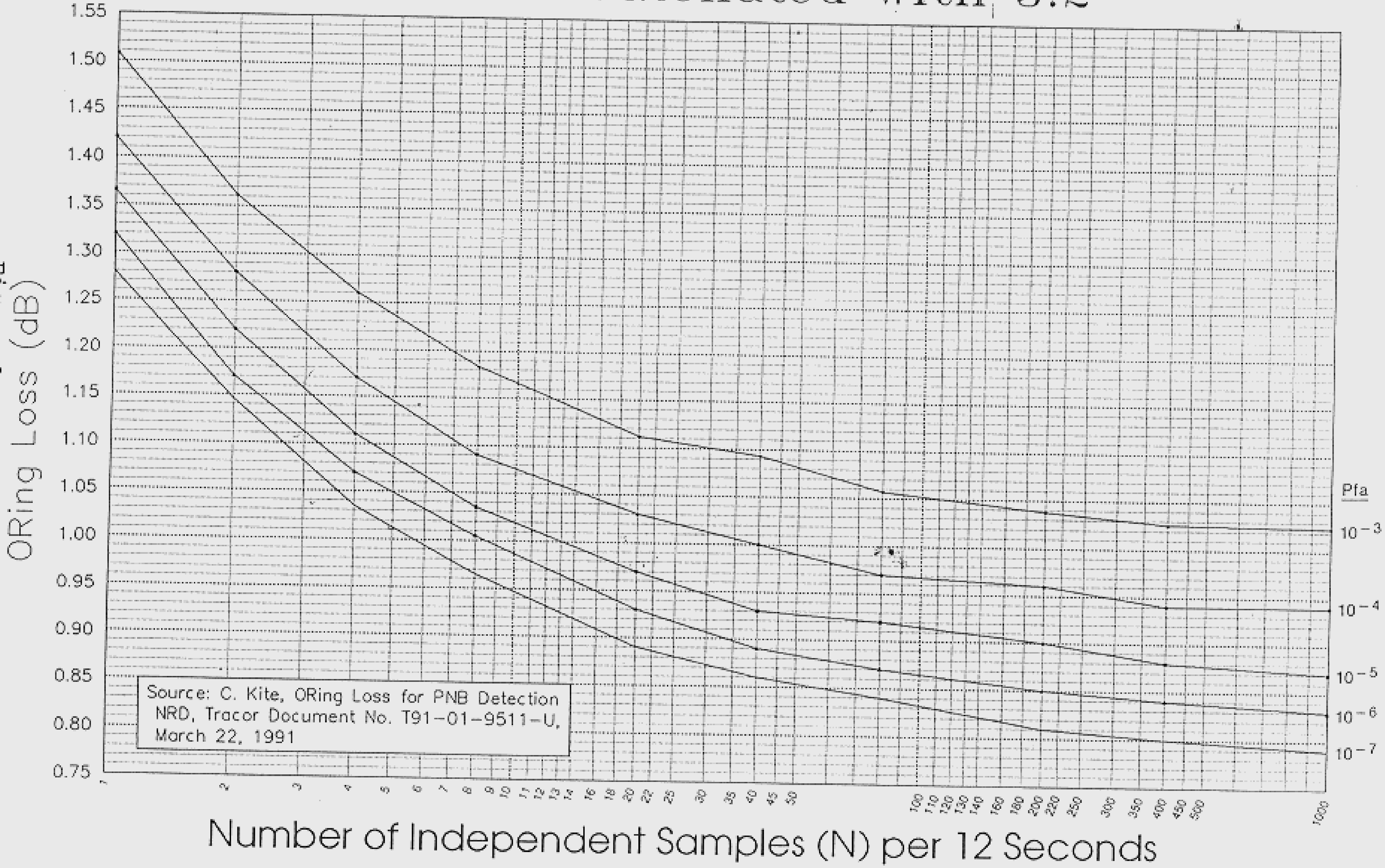
Figure 2-9 (U)

LOFARgram ORing Loss
for 2:1 concatenated with 3:2



Source: C. Kite, ORing Loss for PNB Detection NRD, Tracor Document No. T91-01-9511-U, March 22, 1991

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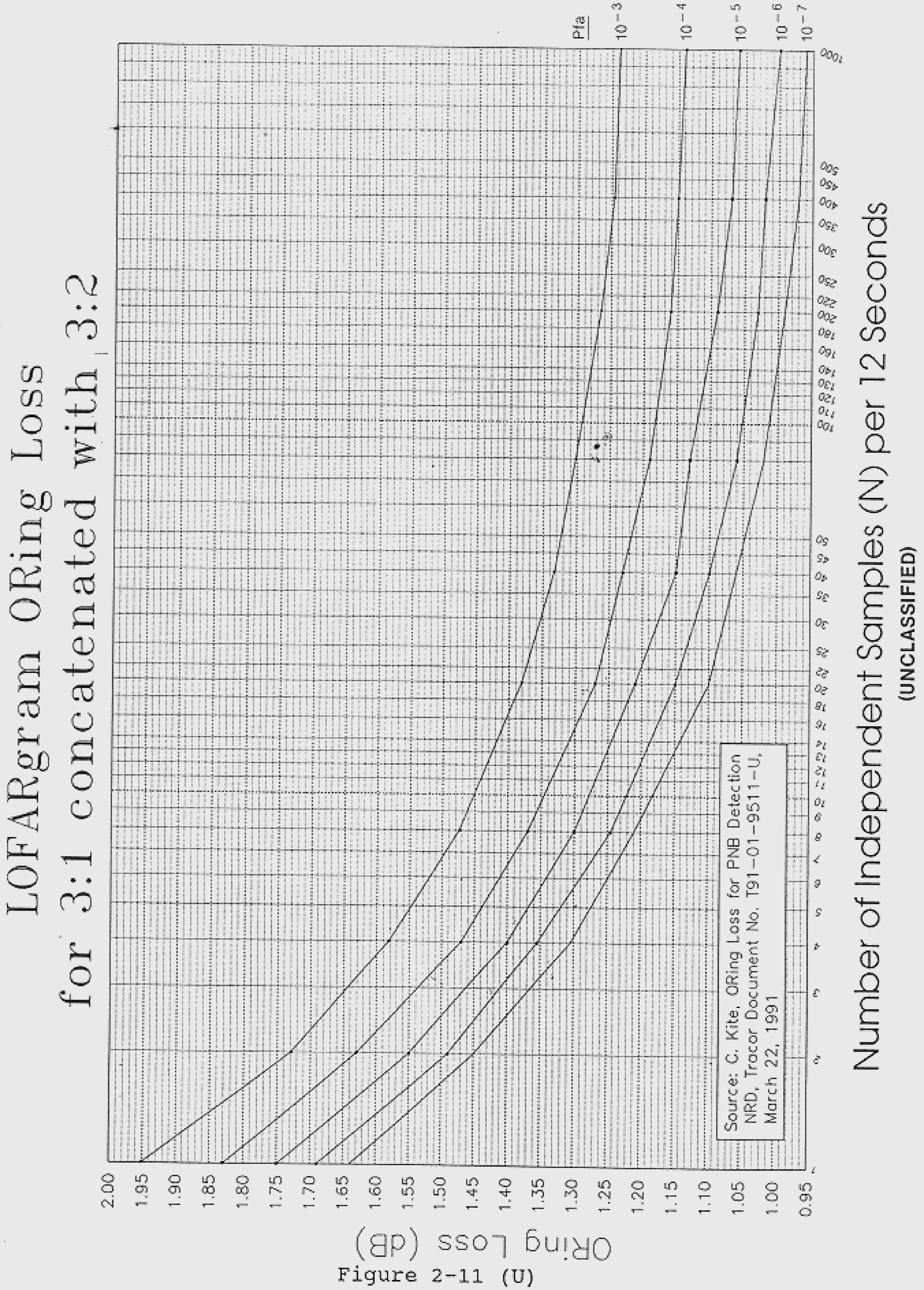
Figure 2-10 (U)



LOFARgram ORing Loss for 3:1 concatenated with 3:2

Source: C. Kite, ORing Loss for PNB Detection NRD, Tracor Document No. T91-01-9511-U, March 22, 1991

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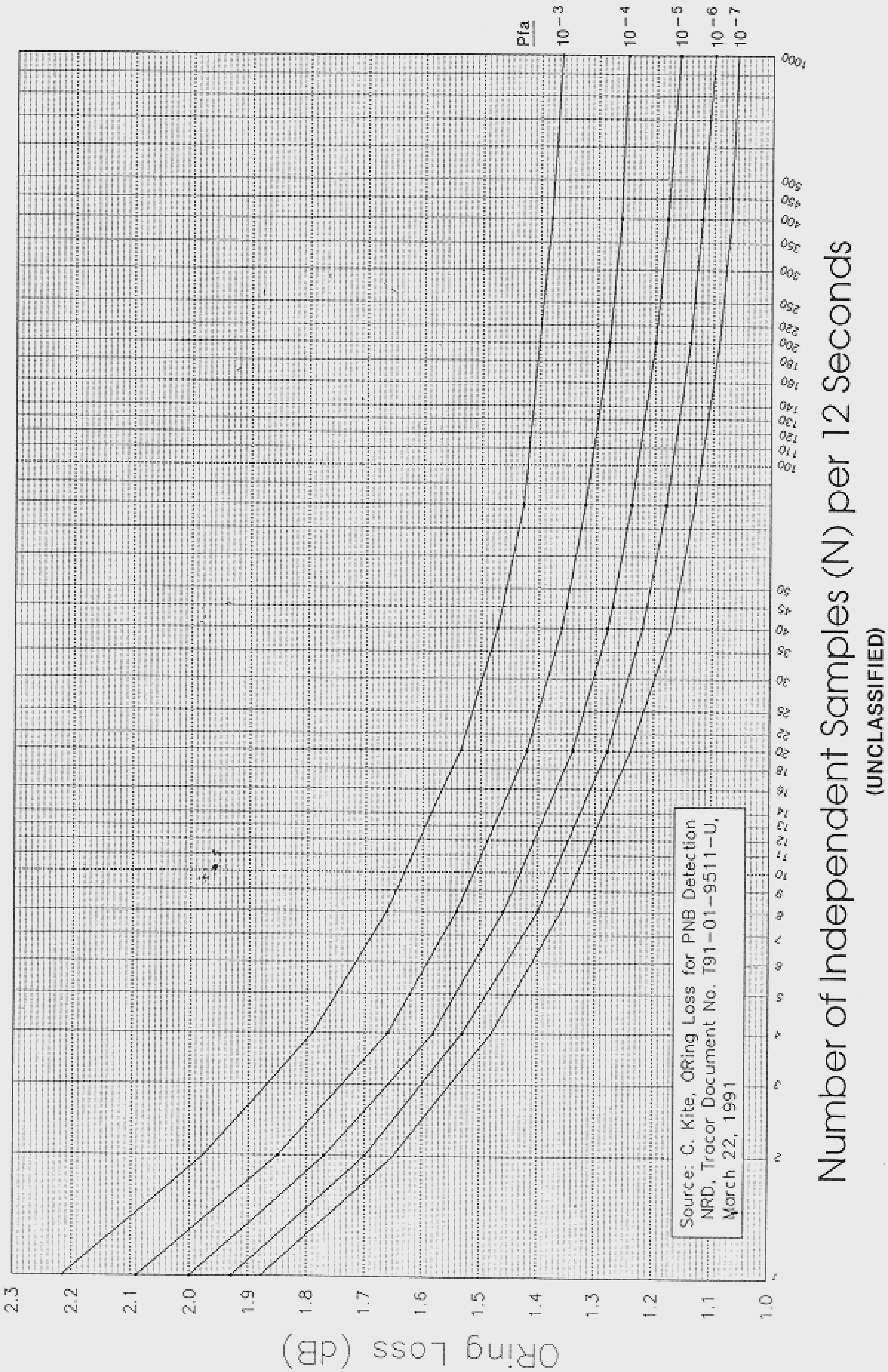
Figure 2-11 (U)

LOFARgram ORing Loss
for 4:1 concatenated with 3:2



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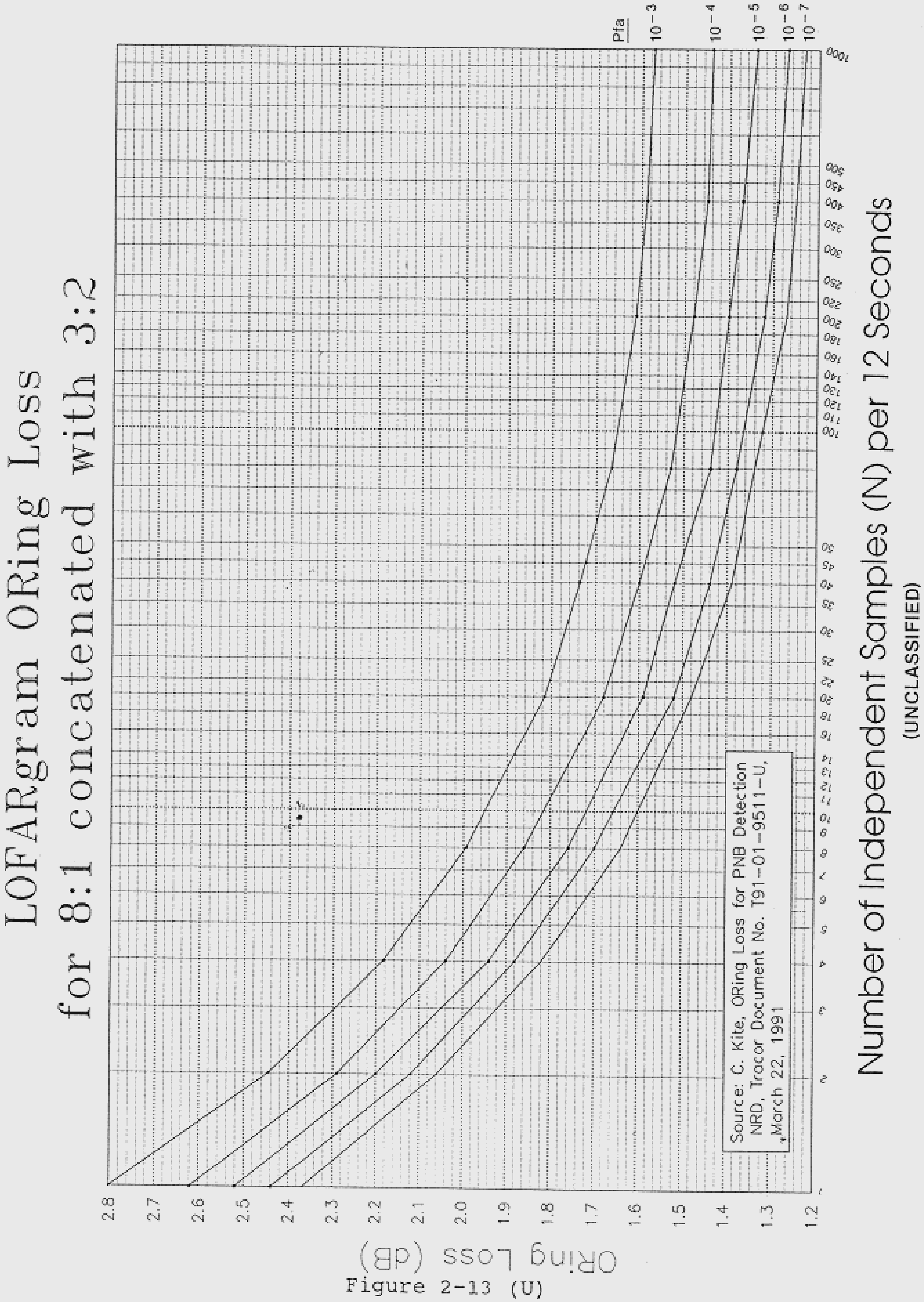
Source: C. Kite, ORing Loss for PNB Detection
NRD, Tracor Document No. T91-01-9511-U,
March 22, 1991

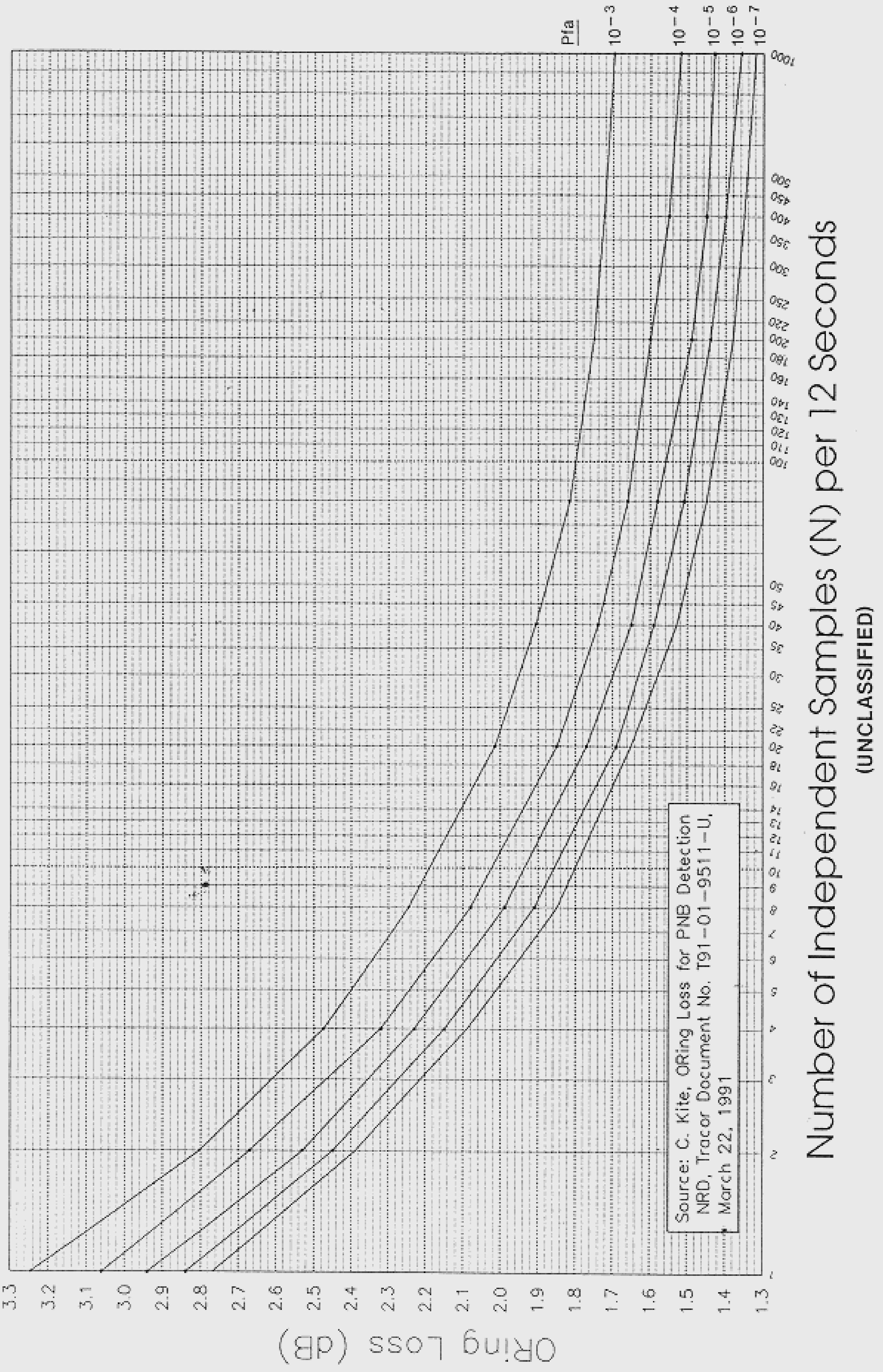
Figure 2-12 (U)



Source: C. Kite, ORing Loss for PNB Detection NRD, Tracor Document No. T91-01-9511-U, March 22, 1991

Figure 2-13 (U)

LOFARgram ORing Loss for 16:1 concatenated with 3:2



Source: C. Kite, ORing Loss for PNB Detection NRD, Tracor Document No. T91-01-9511-U, March 22, 1991

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Figure 2-14 (U)

~~(C)~~ **Normalization Loss** - To assess normalization loss proceed as follows:

a) First determine the displayed signal bandwidth. The signal bandwidth used to calculate normalization and overresolution losses for both CW and Gaussian signals is the bandwidth of the displayed signal.

$$B_{sig} = \min[F_{maxsig}, F_{maxband}] - \max[F_{minsig}, F_{minband}]$$

where,

F_{maxsig} = Maximum signal frequency in Hertz
$F_{maxband}$ = Maximum frequency of processor band of interest in Hertz
F_{minsig} = Minimum signal frequency in Hertz
$F_{minband}$ = Minimum frequency of processor band of interest in Hertz

b) Determine the number of processor bins occupied by the signal, X.

$$X = B_{sig}/B_{bin}$$

where,

X = Width of signal in bin spacings
B_{sig} = Displayed signal bandwidth in Hertz
B_{bin} = Unweighted bin spacing (STEP 1)

c) If the processor [redacted] depending on the value of X and the signal type, determine the normalization loss from Figure 2-15.

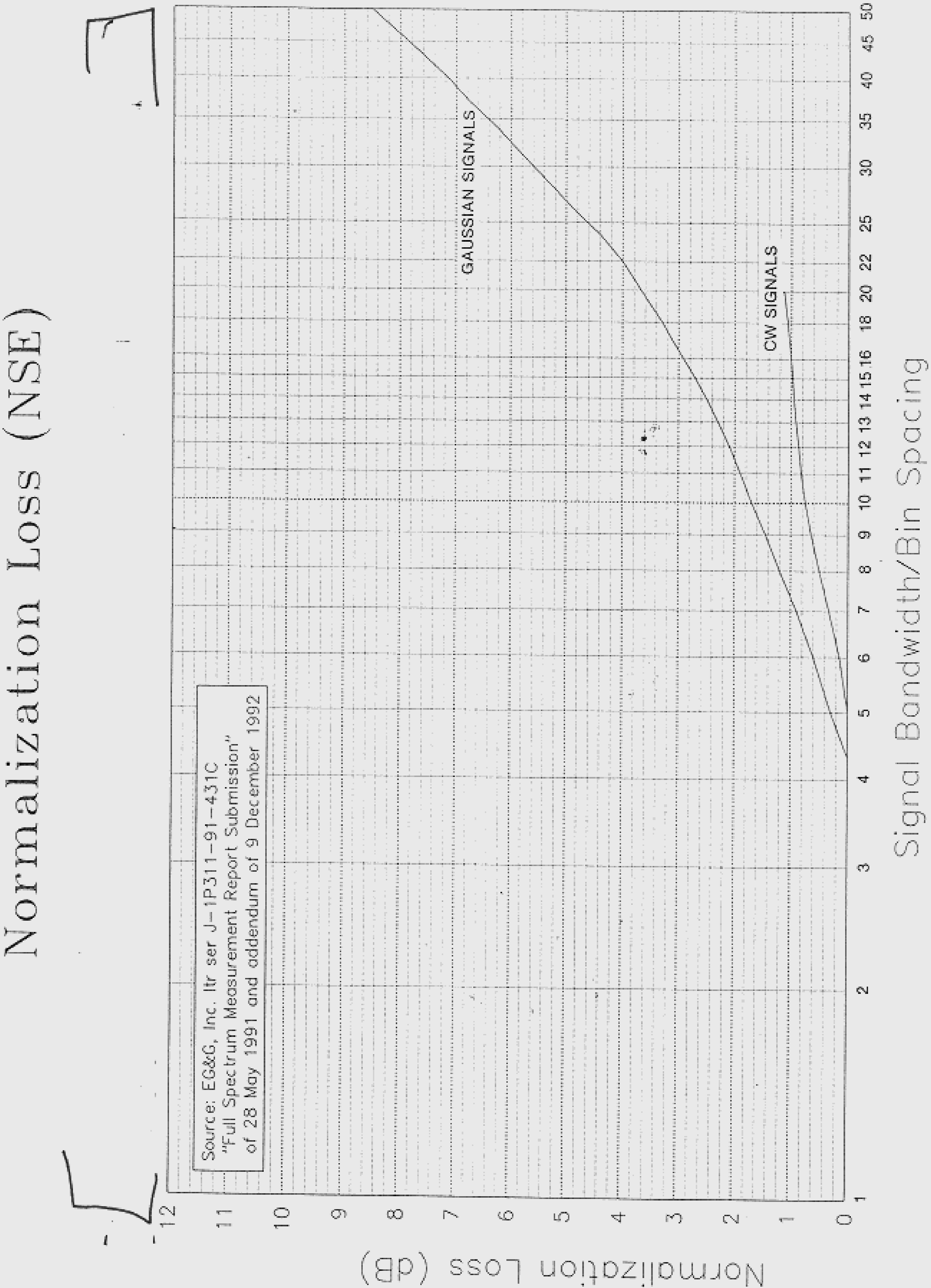
[redacted]

d) If the processor is [redacted] [redacted] depending on the value of X, the selected normalization setting, and the signal type, determine the normalization loss from Figure 2-16.

[redacted]

2.9 STEP 9. DETERMINE THE AT-SEA DEGRADATION (U)

~~(C)~~ At-sea degradation is based on comparison of predicted and at-sea measured NRDs, and is a function of array type and type of displayed data. For the following arrays, determine the appropriate at-sea degradation.



Source: EG&G, Inc. ltr ser J-1P311-91-431C
"Full Spectrum Measurement Report Submission"
of 28 May 1991 and addendum of 9 December 1992

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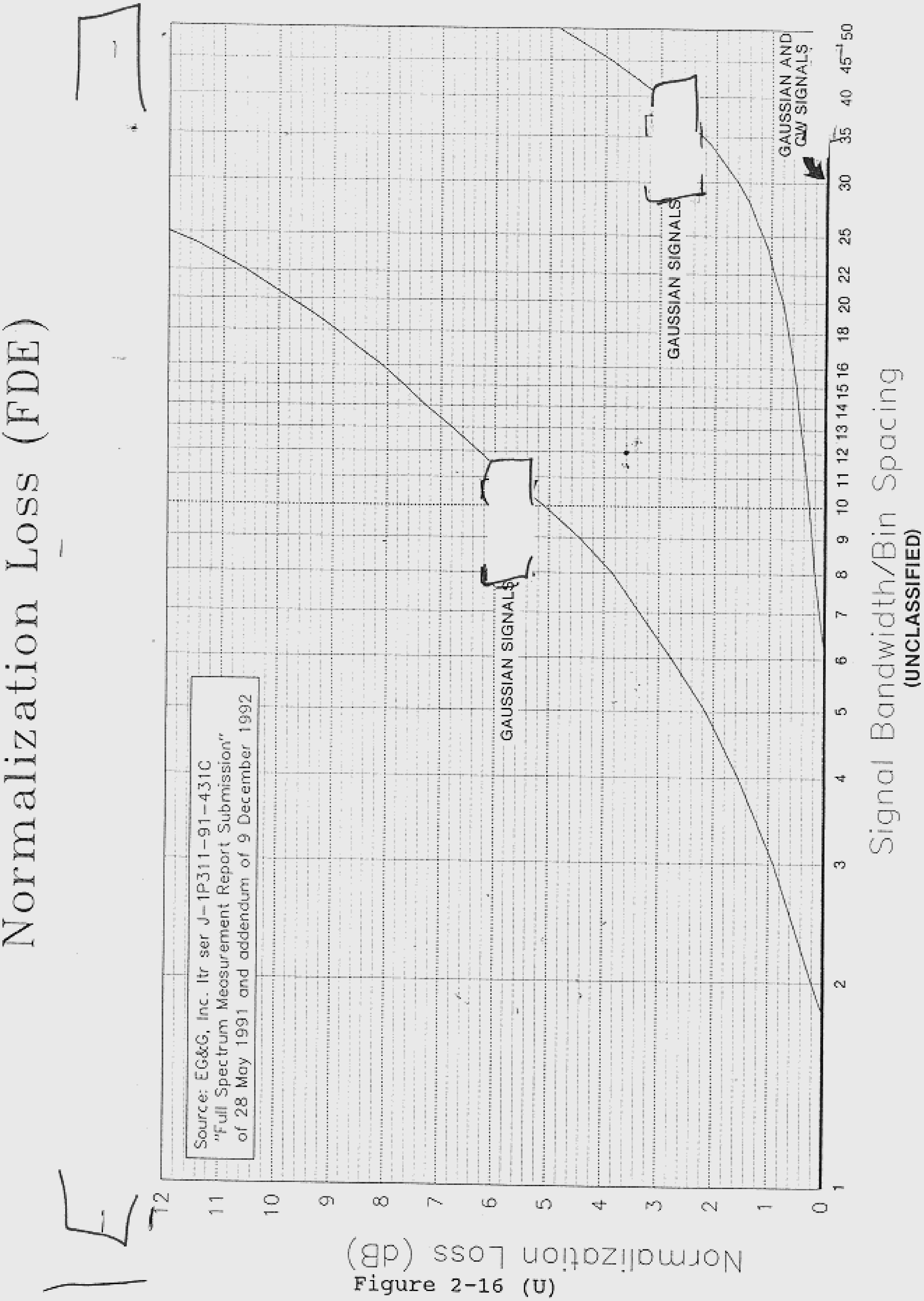
Figure 2-15 (U)



Source: EG&G, Inc. ltr ser J-1P311-91-431C
"Full Spectrum Measurement Report Submission"
of 28 May 1991 and addendum of 9 December 1992

Figure 2-16 (U)

[redacted]

~~(C)~~ Further degradation should be assessed in an environment [redacted] that has high contact density because of increased display clutter. This additional degradation is also array dependent. For the following arrays, determine the additional at-sea degradation that should be assessed while operating in [redacted]

[redacted]

2.10 STEP 10. DETERMINE OVERRESOLUTION LOSS (U)

~~(C)~~ Calculate the ratio (R_{res}) of [redacted]

R_{res} = [redacted]

where,

R_{res} = [redacted]

B_{eff} = Effective noise bandwidth in Hertz (STEP 1)

B_{sig} = Displayed signal bandwidth in Hertz (STEP 8)

~~(C)~~ If the ratio X (STEP 8 - NORMALIZATION LOSS) is [redacted] then assess the following overresolution loss.

[redacted]

(U) If the ratio X (STEP 8 - NORMALIZATION LOSS) is [redacted] then assess the following overresolution loss.

[redacted]

2.11 STEP 11. CALCULATE NET OPERATIONAL NRD (U)

~~(C)~~ Calculate the operational NRD by adding the degradations and losses to the theoretical NRD. Losses raise the threshold and are therefore added. Note that the noise bandwidth correction is negative if $B_{eff} < 1$.

Theoretical NRD (STEP 4)	:
Noise Bandwidth Correction (STEP 5)	+:
Signal Energy Losses (STEP 6)	
Signal Duration	+:
Observation Time	+:
Operator Assurance (STEP 7)	+:
Implementation Losses (STEP 8)	
Scalloping	+:
ORing	+:
Normalization	+:
At-sea Degradation (STEP 9)	+:
Overresolution Loss (STEP 10)	+:
PNB Operational NRD	:

2.12 EXAMPLE CALCULATION FOR A CONTINUOUS WAVE (CW) TONE (U)

open ocean.

STEP 1. DETERMINE ANALYZER EFFECTIVE NOISE BANDWIDTH (B_{eff}) AND STATISTICAL NOISE BANDWIDTH (B_{stat}) (U)

(U) $B_{eff} = B_{bin} * K_e =$

where,

$B_{bin} =$ (unweighted processor resolution)
$K_e = 1.36$ (Hamming weighting factor)

(U) $B_{stat} = B_{bin} * K_s =$ 1.89 $=$

where,

$K_s = 1.89$ (Hamming weighting factor)

STEP 2. DETERMINE TIME (T) USED IN BT PRODUCT (U)

(U) $T = \max\{ \min$ $=$ sec,
$T_{min} = \max$ $=$ sec

where,

T_{sig} = [

T_{obs} =

T_{hist} =

T_{int} =

$1/B_{eff}$ =]

STEP 3. DETERMINE NUMBER OF EFFECTIVE INDEPENDENT SAMPLES (N) (U)

(U) $N = B_{stat} * T * K_{overlap}$ = [ ] [ ]

where,

B_{stat} = [ ] (STEP 1)

T = [ ] (STEP 2)

$K_{overlap}$ = [ ]

STEP 4. DETERMINE THE THEORETICAL NRD (U)

(U) Using Figure 2-1a with [ ] the theoretical NRD is [ ] dB

STEP 5. CORRECT NRD TO A ONE HERTZ NOISE BANDWIDTH (U)

(U) Bandwidth correction $= 10 * \log_{10}(B_{eff})$

$= 10 * \log_{10}$ [ ]

[ ]

STEP 6. DETERMINE THE SIGNAL ENERGY LOSSES (U)

(U) Because signal duration is greater than T_{min} [ ] there is no signal energy loss due to signal duration. Because the observation time (T_{obs}) is greater than T_{min} ([ ] there is no signal energy loss due to observation time

STEP 7. DETERMINE THE DEGRADATION FOR OPERATOR ASSURANCE (U)

(~~C~~) The degradation for operator assurance is [ ] [ ]

STEP 8. DETERMINE IMPLEMENTATION LOSSES (U)

(U) Analyzer Scalloping Loss is (Hamming weighting).

(U) Using Figure 2-9 [ ] [ ] the ORing loss is dB to the nearest tenth of a dB.

B_{sig} = min [ ] max [ ] = [ ] Hertz

where,

F_{maxsig} = [ ] Hertz

$F_{maxband}$ = Hertz

F_{minsig} = Hertz

$F_{minband}$ = Hertz

(U) The width of the signal in bin spacings is

X = [redacted]

where,

B_{sig} = [redacted] Hertz
B_{bin} = [redacted] Hertz

Therefore, the signal suppression loss associated with the normalizer is 0.0 dB from figure 2-15.

STEP 9. DETERMINE THE AT-SEA DEGRADATION (U)

~~(C)~~ The at-sea degradation is [redacted]

STEP 10. DETERMINE OVERRESOLUTION LOSS (U)

(U) Because signal bandwidth [redacted] is not greater than [redacted] the processor bandwidth [redacted], no overresolution loss should be assessed.

STEP 11. CALCULATE NET OPERATIONAL NRD (U)

~~(C)~~ The operational PNB NRD is:

Theoretical NRD (STEP 4)	:	[redacted]
Noise Bandwidth Correction (STEP 5)	+:	
Signal Energy Losses (STEP 6)		
Signal Duration	+:	
Observation Time	+:	
Operator Assurance (STEP 7)	+:	
Implementation Losses (STEP 8)		
Analyzer Scalloping	+:	
ORing	+:	
Normalization	+:	
At-sea Degradation (STEP 9)	+:	
Overresolution Loss (STEP 10)	+:	
Operational PNB NRD	:	[redacted]

2.13 EXAMPLE CALCULATION FOR A GAUSSIAN SIGNAL (U)

~~(C)~~ [redacted]

open ocean. Determine an NRD against this signal/processor combination.

NOTE: Adjust the source level by 10 times the log of the signal bandwidth (B_{sig} = [redacted] as determined in STEP 8 of the procedure).

Source Level Correction = $10 * \log_{10}(B_{sig})$
=
= [redacted]

STEP 1. DETERMINE ANALYZER EFFECTIVE NOISE BANDWIDTH (B_{eff}) AND STATISTICAL NOISE BANDWIDTH (B_{stat}) (U)

(U) $B_{eff} = B_{bin} * K_e =$ [redacted]

where,

[redacted]

$K_e = 1.36$ (Hamming weighting factor)

(U) $B_{stat} = B_{bin} * K_s = \quad * 1.89 =$ [redacted]

where,

[redacted]

$K_s = 1.89$ (Hamming weighting factor)

STEP 2. DETERMINE TIME (T) USED IN BT PRODUCT (U)

(U) T = max{min[[redacted]
T_{min} = max [

where,

T_{sig} =
T_{obs} =
T_{hist} =
T_{int} =
$1/B_{eff}$ =
[redacted]

STEP 3. DETERMINE NUMBER OF EFFECTIVE INDEPENDENT SAMPLES (N) (U)

(U) $N = B * T * K_{overlap} =$ [redacted]

STEP 4. DETERMINE THE THEORETICAL NRD (U)

(U) Using Figure 2-2a with N = [redacted] and Pfa of [redacted] the theoretical NRD is [redacted]

STEP 5. CORRECT NRD TO A 1 HERTZ NOISE BANDWIDTH

(U) Bandwidth Correction = $10 * \log_{10}(B_{eff})$
= $10 * \log_{10}$ [redacted]

STEP 6. DETERMINE THE SIGNAL ENERGY LOSSES (U)

(U) Because signal duration [redacted] is greater than T_{min} there is no signal energy loss due signal duration.

(U) Because the observation time [redacted] is greater than T_{min} [redacted] there is no signal energy loss due to observation time.

STEP 7. DETERMINE THE DEGRADATION FOR OPERATOR ASSURANCE (U)

(~~C~~) Using Figure 2-3 and N equal to [redacted] (STEP 3) the degradation for operator assurance is [redacted]

STEP 8. DETERMINE IMPLEMENTATION LOSSES (U)

(U) Using Figure 2-6 for 4:1 ORing, a Pfa of [redacted] independent samples per display update rate [redacted] the ORing loss is [redacted] the nearest tenth of a dB.

B_{sig} = min [redacted] -max [redacted]

where,

F_{maxsig} =
$F_{maxband}$ =
F_{minsig} =
$F_{minband}$ = [redacted]

(U) The width of the signal in bin spacings (X) is calculated as follows:

X = [redacted]

where,

B_{sig} =
B_{bin} = [redacted]

Therefore, the signal suppression loss associated with the normalizer is [redacted] from Figure 2-15.

STEP 9. DETERMINE THE AT-SEA DEGRADATION

(~~C~~) The at-sea degradation is [redacted]

STEP 10. DETERMINE OVERRESOLUTION LOSS

(U) R_{res} = [redacted]

where,

B_{sig} =
B_{eff} = [redacted]

(U) Because R_{res} [redacted] overresolution loss equals:

[redacted]

STEP 11. CALCULATE NET OPERATIONAL NRD (U)

(U~~C~~) The operational PNB NRD is:

Theoretical NRD (STEP 4)	:
Noise Bandwidth Correction (STEP 5)	+:
Signal Energy Losses (STEP 6)	
Signal Duration	+:
Observation Time	+:
Operator Assurance (STEP 7)	+:
Implementation Losses (STEP 8)	
Analyzer Scalloping	+:
ORing	+:
Normalizer	+:
At-sea Degradation (STEP 9)	+:
Overresolution Loss (STEP 10)	+:
Operational NRD	:

APPENDIX A (U)
Rational Foundation used to develop Operational PNB NRDs

(U) This appendix provides details and references for the step-by-step procedure to derive operational PNB NRDs. Discussion is keyed to the steps of the procedure.

> NOTE: In order to have a common procedure for both Gaussian and CW signals it is required to convert Gaussian signal source levels to band levels.

STEP 1. DETERMINE ANALYZER EFFECTIVE NOISE BANDWIDTH (B_{eff}) AND STATISTICAL BANDWIDTH (B_{stat}) (U)

(U) The B_{eff} factors given in the step-by-step procedure for the common weighting schemes are from reference [i]. For a non-rectangular filter, the factor should be computed. The noise bandwidth formula that follows should be used:

$$B_{eff} = [\int \{H(f)\}^2 \, df]/[H_m]^2$$

where,

B_{eff} = Equivalent noise bandwidth
$H(f)$ = Frequency filter response function at any frequency f
H_m = Maximum value of the frequency filter response function

(U) The B_{stat} factors given in the step-by-step procedure for the common weighting schemes were computed based on the formula below.

$$B_{stat} = [\int \{H(f)\}^2 \, df]^2/[\int \{H(f)\}^4 \, df]$$

where,

B_{stat} = Statistical Noise Bandwidth
$H(f)$ = Frequency filter response function at any frequency f

STEP 2. DETERMINE TIME (T) USED IN BT PRODUCT

(U) The time (T), for use in computing the BT product, is the length of signal, with the following limitations. The minimum observable time is the greater of the single display point internal averaging time (T_{int}), or the time between independent samples ($1/B_{eff}$). The maximum is the minimum of signal length (T_{sig}), the maximum observable time on the display (T_{hist}), or an externally entered maximum observation time (T_{obs}). Thus,

$$T = \max\{ \min[T_{sig}, T_{obs}, T_{hist}], T_{min}\}$$
$$T_{min} = \max\{T_{int}, 1/B_{eff}\}$$

STEP 3. DETERMINE EFFECTIVE NUMBER OF INDEPENDENT SAMPLES (N) (U)

(U) If a window and FFT are applied to nonoverlapping partitions of a time sequence a significant portion of the series is ignored due to the window's exhibiting small values near the boundaries. For instance, if the transform is being used to detect short duration CW signals, the nonoverlapped analysis could miss the event if it occurred near the boundaries. To avoid this loss of data (and increase the stability of the spectral estimation), the transforms are usually applied to overlapped partition sequences. The overlap is usually 50 percent or greater.

(U) In U.S. Combat Systems, FFTs for all bands are processed simultaneously. The lowest frequency band (finest frequency resolution) is usually processed at 50% overlap. Since the rate at which samples are taken is proportional to the coarseness of the frequency resolution, the overlap becomes higher and higher as frequency increases. For instance, if octave bands are processed (bin widths also doubling), and if the lowest octave band has 50% overlap, the next octave will have 75%, the next 87.5%, etc..

(U) By overlapping the partition sequences, the random components in successive transforms become correlated. The degree to which the successive transforms are correlated depends on the fractional overlap and the type of window. For "good" windows, transforms taken with a 50 percent overlap are essentially independent.

(U) The effective number of samples in some references refer to the overlap effect as a "loss" and others refer to it as a "gain". This is due to whether the method fixes the number of samples averaged ("loss") or fixes the time length ("gain") for a given fractional overlap. This step-by-step procedure is based on fixing the total time length and therefore overlap is treated as a "gain".

(U) Fixing the number of samples averaged reduces the effective number of independent samples due to the increase in correlation between samples as the overlap is increased.

(U) Fixing the time length for which N samples are taken allows a larger number of samples to be averaged as the overlap is increased. However, there is a point at which the additional samples do not provide any more additional effective samples (for most "good" windows this usually occurs at fractional overlaps of 50 to 75 percent) as the number of samples averaged become highly correlated.

(U) Reference [h] provides equations to determine correlation coefficients and the degree of variance reduction. Reference [j] provides the time weighting schemes for various data windows used for calculating sample correlations.

(U) Figure A-1 presents the overlap factors for various weighting schemes and percentages of FFT overlap.

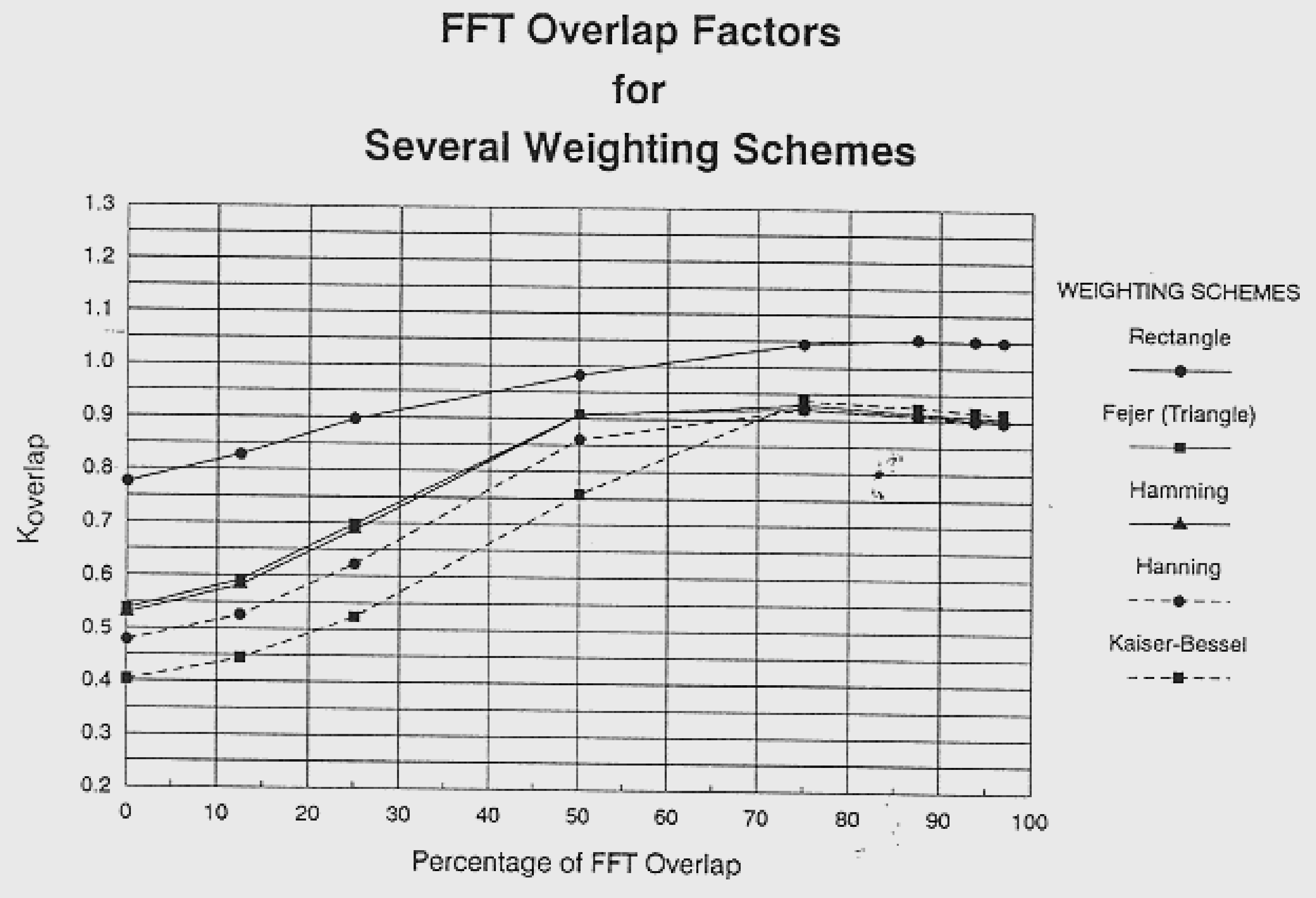


Figure A-1.

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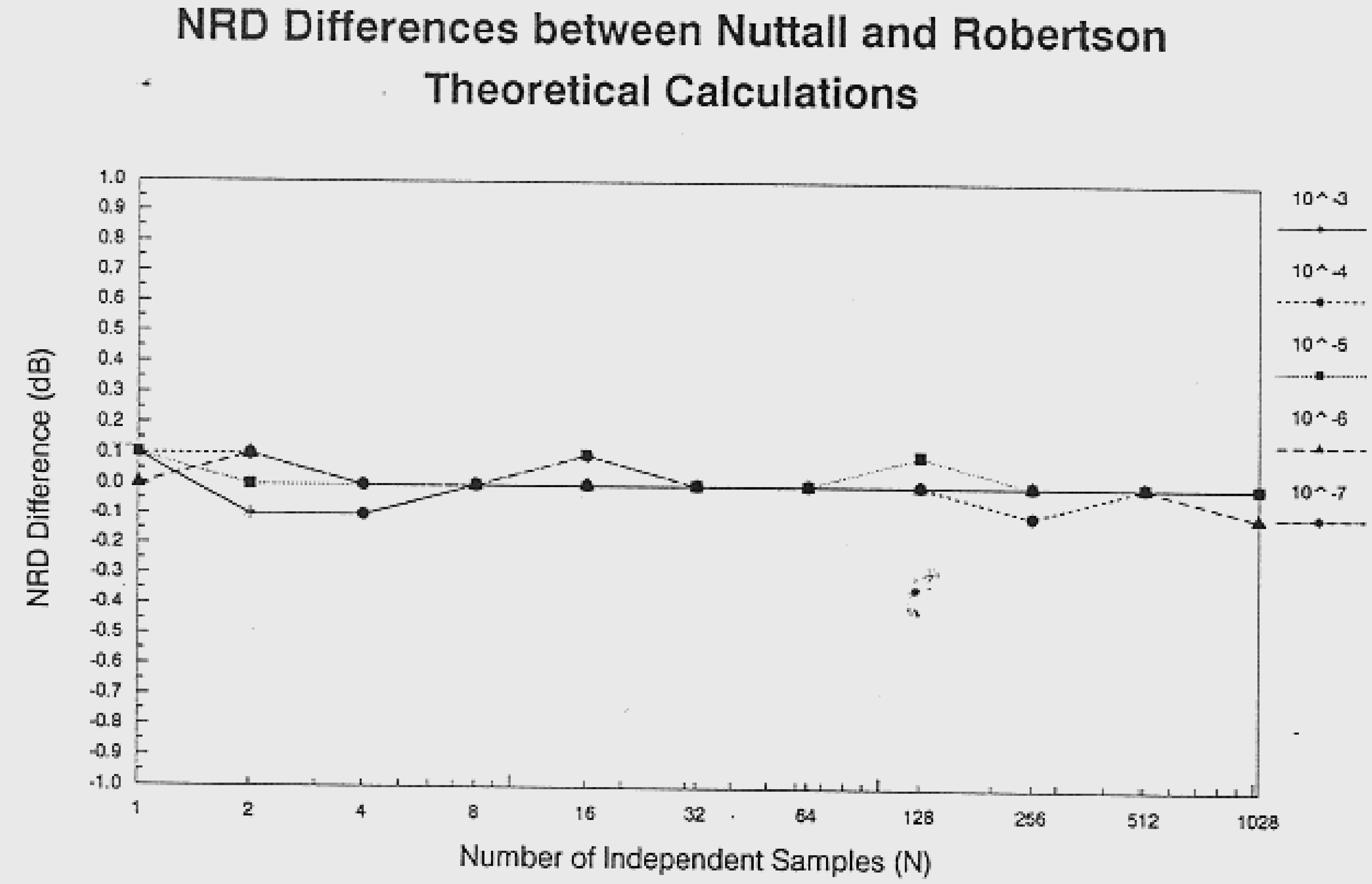
STEP 4. DETERMINE THE THEORETICAL NRD (U)

(U) For CW signals, Figure 2-1 provides NRDs referenced to SNR in the filter band versus the number of independent samples (N), extracted from reference [d].

(U) Reference [a] based NRDs on Robertson's curves (reference [e]), this version of the procedure uses Nuttall's calculations (reference [d]) to allow determination of NRDs for larger number of independent samples (greater than 1000).

(U) Figure A-2 presents the differences in theoretical NRDs between Nuttall's calculations versus Robertson's calculations. Figure A-2 shows that the differences are very small between the two methods. Nuttall's work is based upon evaluation of the



NRD Differences between Nuttall and Robertson Theoretical Calculations

The NRD Difference was calculated as Nuttall's NRDs minus Robertson's NRDs

Nuttall's NRDs from NUSC TR 7117 Jan 1984,
Robertson's NRDs from Bell System Tech. Journal
April 1967, Pg 755-774

Figure A-2.

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characteristic function of the envelope detector output, from which the exceedance distribution function can be precisely evaluated numerically, whereas, Robertson used an approach based upon evaluation of the first 31 moments of the envelope variate and their use in a type A Gram-Charlier series approximation, or in modified approximations involving averages over different terms in the series.

(U) For Gaussian signals, Figure 2-2 provides NRDs references to SNR in the filter band versus the effective number of independent samples, (N), extracted from reference [c].

(U) As shown in reference [c], for large sample sizes (greater than 1000) the NRDs were determined by the following steps:

a) Compute the effective number of independent samples (N) as defined in step 3.

b) Look up dt as a function of probability of false alarm (Pfa) in table A-1 (from reference [c] Table 1).

Determine dt for a given Pfa					
Pfa	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
dt	4.90	5.70	6.30	6.77	7.16

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Table A-1 (U). NRD dt Values (U)

c) Compute NRD using the following formula:

$$\text{NRD} = dt - 5 * \log_{10}(N)$$

(U) The steps outlined above are based on a random variable z (defined as a multiple of a chi-square variate with 2N degrees of freedom) being approximated by a Gaussian random variable for large number of independent samples (N). Maximum error is 0.23 dB at N = 1000, Pfa = 10^{-7} and decreases with increasing sample size. Figure 2-2b uses the Gaussian approximation for N greater then 1000. Figure A-3 presents the differences in NRD between the chi-square ("exact") probability density function and the Gaussian ("approximate") probability density function for several Pfas and N=1000. It should be noted that this procedure is only valid for Probability of detection equal to 50 percent.

STEP 5. CORRECT NRD TO A ONE HERTZ NOISE BANDWIDTH (U)

The NRDs are converted from SNR in the processor band to a 1 Hz band by adding a bandwidth correction ($10 * \log_{10}(B_{eff})$).

STEP 6. DETERMINE THE SIGNAL ENERGY LOSSES (U)

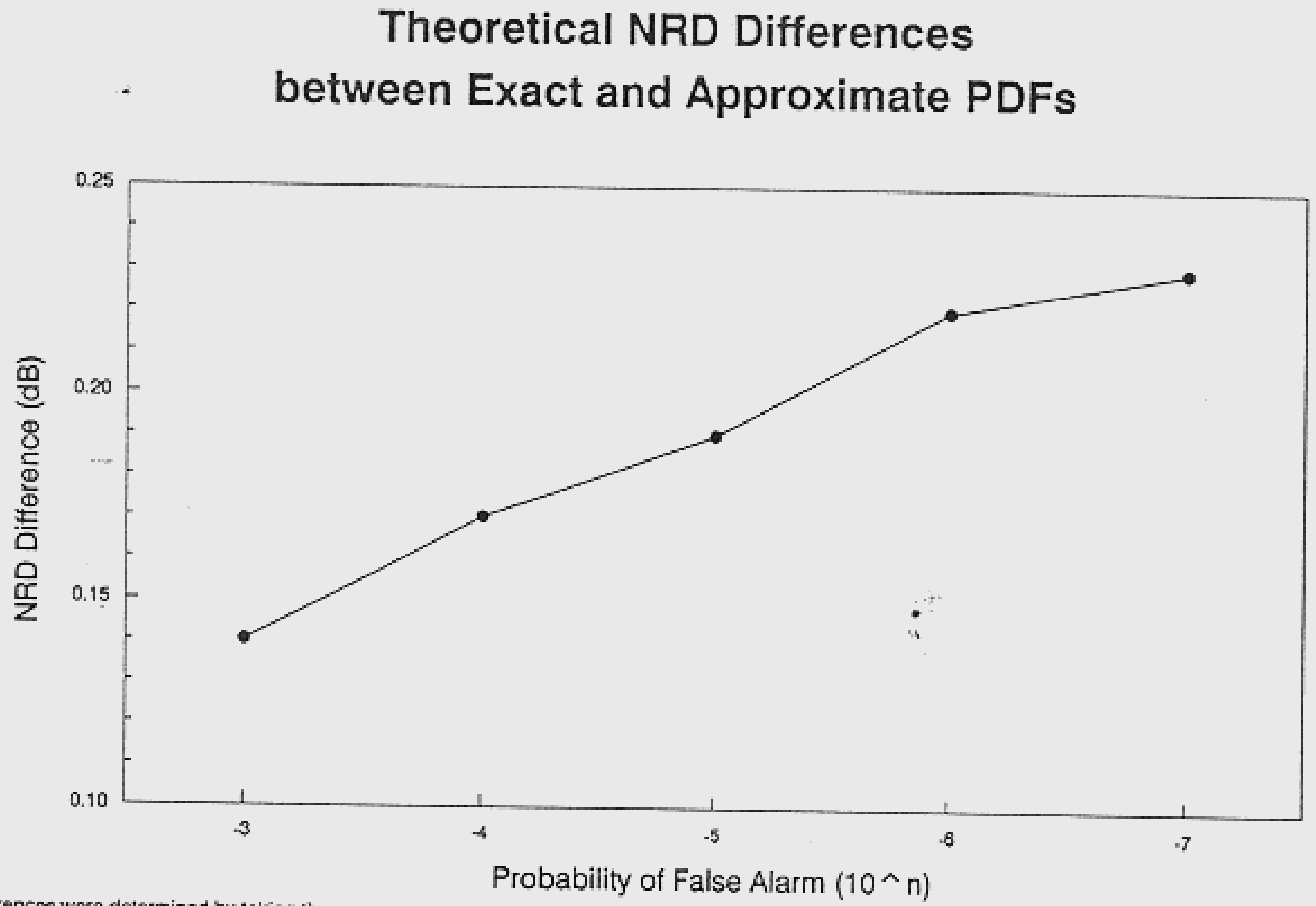
(U) If the signal exists for less than a single independent time interval on the display, then it accumulates proportionally less energy than does noise, which exists continuously. The signal to noise power ratio required is raised by the amount by which signal energy is lowered.

$$- 10 * \log_{10}(T_{sig}/T_{min});\ T_{sig} < T_{min}$$

(U) Since the signal's power is expressed as a single power over all frequency, it does not accumulate over power spectral density (or, equivalently, the accumulation has already been done). Thus, any losses in signal energy across frequency are already taken. Therefore, there is no basis for assessing an energy loss in frequency.

(U) If the observation time is less than a single independent display interval on the display, then it accumulates proportionally less signal energy. The signal to noise power ratio required is raised by the amount by which the signal energy is lowered

$$- 10 * \log_{10} (T_{obs}/T_{min});\ T_{obs} < T_{min}$$



Differences were determined by taking the "approximate" NRDs minus the "exact" NRDs using a sample size (N) of 1000.

Figure A-3.

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STEP 7. DETERMINE THE DEGRADATION FOR OPERATOR ASSURANCE (U)

(~~C~~) Operator assurance represents the additional probability of detection above the 0.5 value, required by the PNB search operator before "calling" a detection

Compared with CW signals, Gaussian signals require much more additional signal to noise ratio at low BT products than at high,

Figure 2-3 is a plot of the average difference between 50% and 90% NRDs for Pfa's of 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, and 10^{-7}, for a Gaussian signal.

STEP 8. DETERMINE IMPLEMENTATION LOSSES (U)

(U) Implementation losses represent the losses associated with design tradeoffs concerning constraints in technology, space, weight, complexity, and cost. They consist of such things as (1) analyzer scalloping loss, (2) ORing loss due to decimating data by choosing the largest value from among a group of adjacent frequency bins or acoustic beams and (3) losses from other compromises such as internal and digitization noise, and bin output normalization schemes. The most prevalent sources of degradation are analyzer scalloping, ORing loss, and Normalization loss. There will be no degradation assessed for the other compromises.

~~(C)~~ **Analyzer Scalloping Loss** - Analyzer scalloping losses are associated with misalignment of the incoming signal with the center of the bin, which is the most sensitive portion. The detection will appear with equal probability anywhere within the bin's frequency response.

Scalloping loss is the average loss in frequency.

(U) Gaussian and CW signals are effected by scalloping loss. The loss should based on the ratio of signal bandwidth to binwidth and is a function of the weighting scheme. The calculation of scalloping loss requires the solving of integrals. It is planned to implement this calculation in the PC NRD procedure. The next version of this procedure will attempt to address this loss in detail. Until the time scalloping loss is investigated, apply scalloping loss to CW signals and not to Gaussian signals. Typically CW signals are much narrower than Gaussian signals.

(U) Frequency bin scalloping is a loss in NRD, and is included in this procedure. Beam scalloping loss, on the other hand, is an expected loss to SNR at the analyzer input. Beam scalloping loss is handled as a separate "adjustment to SNR" and is not included in this procedure.

~~(C)~~ **ORing Loss** - ORing consists of

integration or display.

(U) Acoustic signal processing systems generate large quantities of data which are displayed on a display surface where visual detections can be made. Often the display surface is not large enough to display all the data simultaneously. Consequently, ORing operation is performed to reduce the amount of data. An N:1 ORing operation merely takes the largest value of N-adjacent values (bins or beams). Since the standard duration of the noise is higher and the threshold must be raised to maintain the same Pfa, the minimum detection level must increase, so a larger signal-to-noise ratio target is required. This loss in detection capability is known as ORing loss.

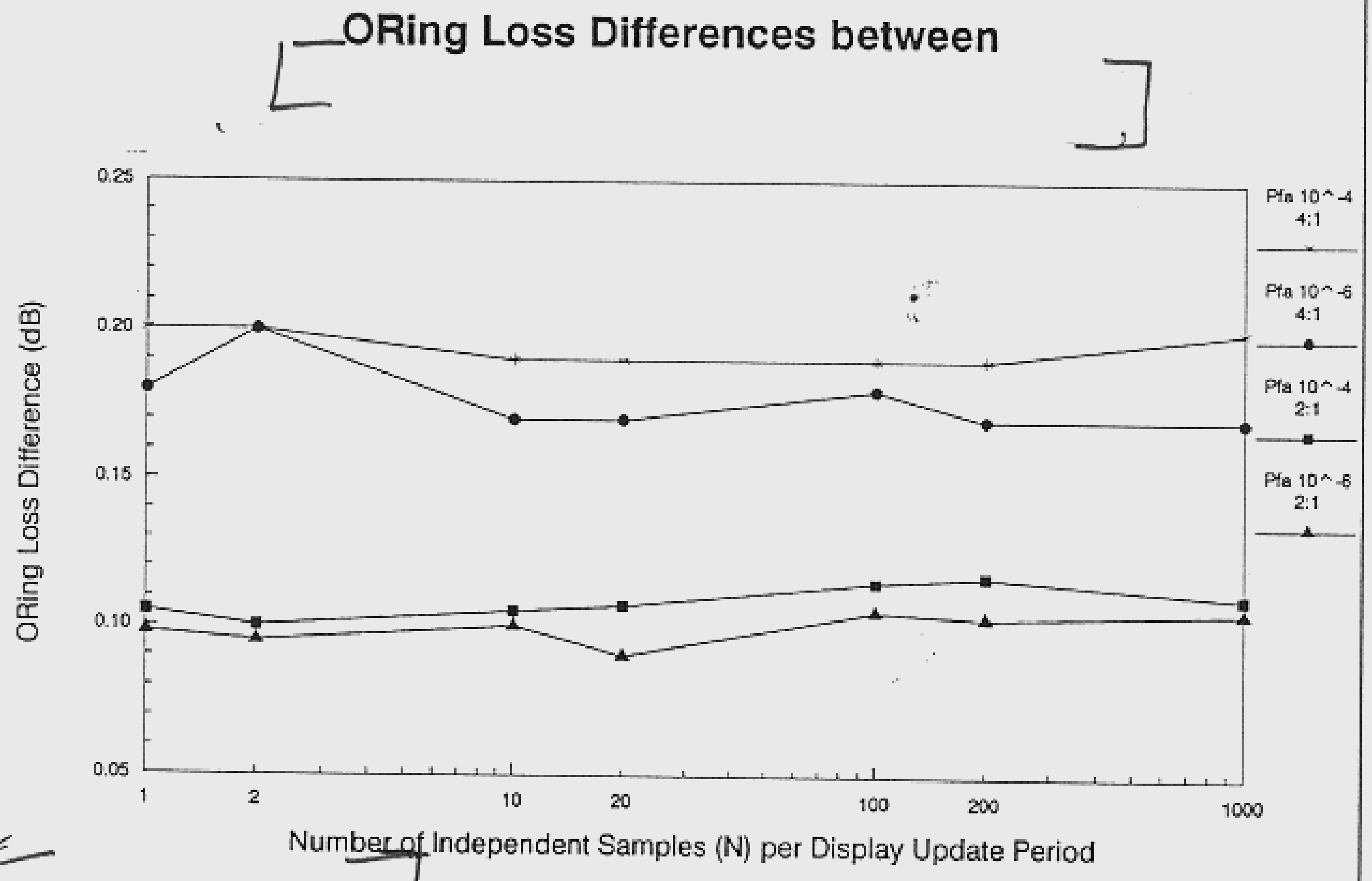
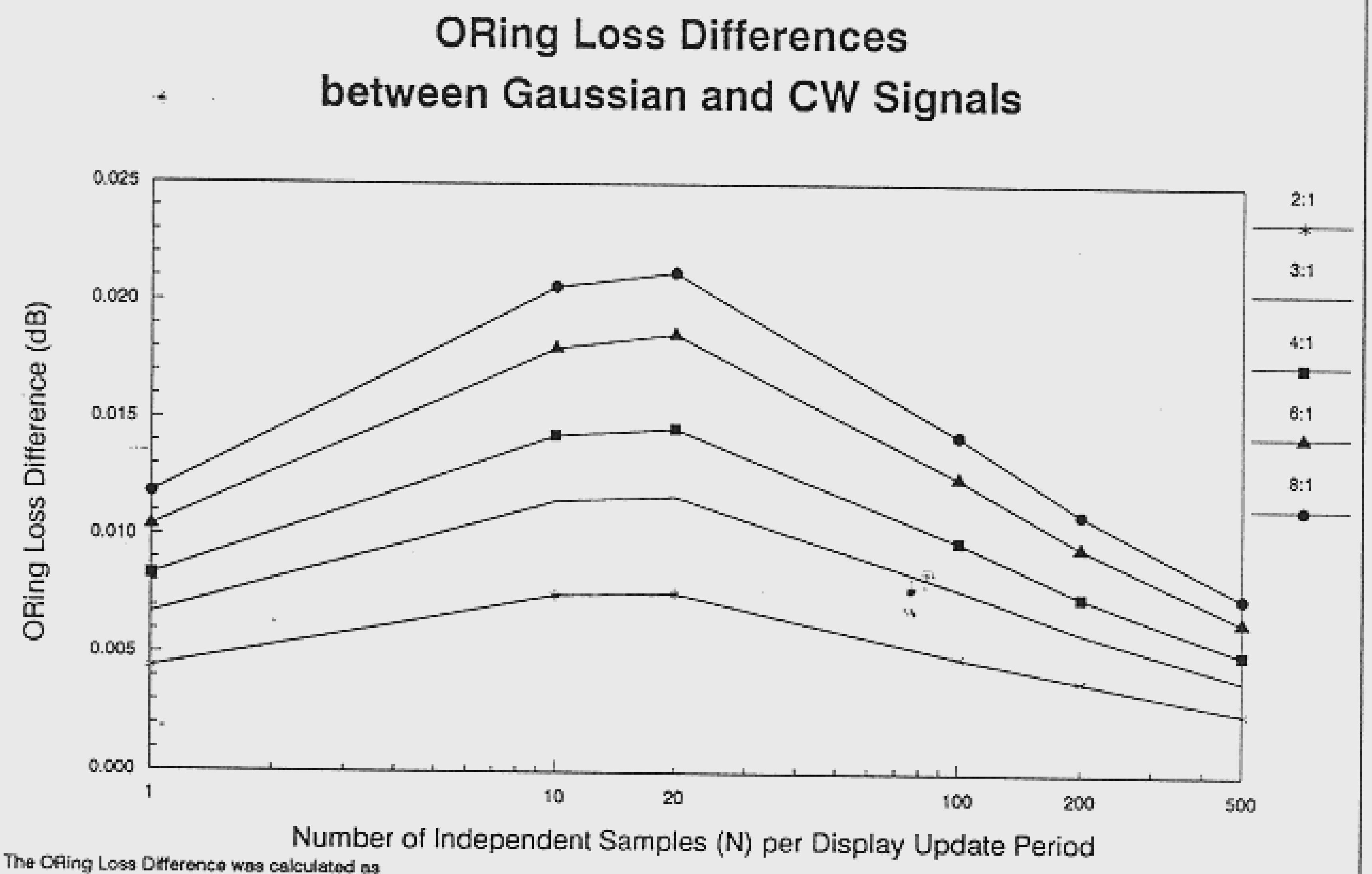


Figure A-4.

(U) The ORing loss curves provided in this report apply to both continuous Wave (CW) and Gaussian signals in Gaussian noise. The difference in ORing loss for the two signal types is negligible (on the order of a hundredth of a dB difference). Figure A-5 presents ORing Loss differences between Gaussian signals and CW signals for various ORing ratios and independent sample sizes for a probability of false alarm of 10^{-5}.



The ORing Loss Difference was calculated as the Gaussian Signal ORing Loss minus the CW Signal ORing Loss.

Figure A-5.

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(U) **Normalization Loss** - A series of in-plant measurement have occurred to quantify overresolution and normalization losses associated with LOFARgram processing.

~~(C)~~ The first measurements of overresolution loss are documented in reference [k]. Overresolution loss was measured to start when the signal bandwidth was [redacted] Processor resolution is the same as effective noise bandwidth. The first quantification of normalization loss was based on a theoretical analysis (reference [l]). Normalization loss was quantified for a generic normalization scheme that contained a "dead zone". Normalization loss was calculated for the [redacted] normalization scheme. Normalization for the [redacted] The overresolution and normalization characterizations were incorporated into reference [m] with the exception that a theoretical variation [redacted] was used [redacted] Overresolution loss against Gaussian signals was assumed to start as soon as the signal was [redacted]

[redacted] The normalization loss was applied equally against CW and Gaussian signals.

(~~C~~) A second set of overresolution and normalization measurements were conducted [redacted] the results of which were reported in reference [n]. The results of the testing against a CW signal agreed with the normalization and overresolution losses contained in the procedure in reference [m] with the one limitation [redacted] Against a Gaussian signal, there were two deviations from the procedure in reference [m]. Normalization loss [redacted] deviated considerably [redacted] overresolution against Gaussian signals started at 2 times the effective noise bandwidth. The results of this testing were incorporated into a revised NRD procedure (reference [o]).

(~~C~~) Additional in-plant testing of LOFARgram normalization and overresolution losses occurred in April 1991 and again in October 1992 [redacted] The results of the testing are provided in the addendum to reference [f]. A meeting was held (reference [p]) that agreed to the characterizations of the measured losses. Overresolution loss against CW and Gaussian signals should be modeled as starting at 2 times the effective noise bandwidth. The loss should be a 5 log function up to a ratio of signal bandwidth to analyzer bin spacing of 10. Above the ratio of 10, the overresolution loss should be modeled as a 10 log function. The deviation from the 5 log characterization for overresolution loss at ratios above 10 [redacted] Normalization loss should be modeled as the difference between overresolution loss and measured data. [redacted] normalization loss against CW and Gaussian signals is shown in figure 2-15. [redacted]

(U) The bandwidth of the signal used in determining normalization and overresolution loss should be based on the width of the displayed signal. This same bandwidth should also be used as the basis for adjusting a Gaussian source level to a band level.

STEP 9. DETERMINE THE AT-SEA DEGRADATION (U)

(X) When at-sea NRD measurements are made, there is a difference between expected and observed values. Since this loss represents a number of factors [redacted] these losses are grouped together and referred to as "at-sea losses". They [redacted]

(X) Reference [q] provides the initial source for at-sea loss. [redacted]

(X) A recent recalculation of at-sea loss resulted in a slight revision [redacted]

STEP 10. DETERMINE OVERRESOLUTION LOSS (U)

(X) When the received signal has a bandwidth larger than the resolution of the analyzer in which it is processed, some of the signal's power is lost to the analyzer. The resultant loss of detectability of signal is called overresolution loss. Reference [u] provided standards for overresolution loss [redacted] The loss [redacted] was further refined by reference [v]. Overresolution loss was further refined when normalization measurements were made (reference [f]) [redacted] This latest set of measurements indicate a [redacted] Above the [redacted] the overresolution loss should be modeled as a [redacted]

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b. Kite, C., "ORing Loss for PNB NRD Detection NRD", TRACOR Document T91-01-9511-U, 22 March 1991.

c. Nuttall, A.H., "Signal-to-Noise Ratios Required for Short-term Narrowband Detection of Gaussian Processes", NUSC Technical Report 4417, 20 October 1972.

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e. Robertson, G. H., "Operating Characteristics for a linear Detector of Signals in Narrowband Gaussian Noise", The Bell System Technical Journal. April 1967.

f. EG&G ltr Ser J-1P311-91-431C "Full Spectrum Measurement Report Submission" of 28 May 1991 and addendum of 9 Dec 1992.

g. Personal notes of E. Siborg.

h. Nuttall, A.H., "Spectral Estimation by Means of Overlapped Fast Fourier Transform Processing of Windowed Data", NUSC Report No. 4169, 13 October 1971.

i. Spectral Dynamics Corporation DSP-011 of 7/76.

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l. NUSC ltr Ser 92102/C52 "Signal Suppression by Noise Spectral Equalizers" of 6 Sept 1989

m. NUSC ltr Ser 02111/C27 "Revised Procedure to Derive Submarine Sonar Operational PNB NRDs" of 29 March 1990

n. NUSC ltr Ser 02111/C47 "Results of In-plant PNB NRD Testing" of 20 June 1990

o. NUSC ltr Ser 02111/C49 "Revised Procedure to Determine Submarine Sonar Operational PNB NRDs" of 1 July 1990

p. Meeting between 2111 (T. Sypher), 2191 (J. Pratt) and EG&G (S. Kessler) on 24 Nov 1992

q. NUSC ltr Ser 43202-C2 of 25 Jan 1984, Subj: AN/BQQ-5/6 PNB and CLASS Recognition Differential.

r. NUSC ltr Ser 53202/C43 of 8 October 1985, Subj: Change to Q-5, SUBACS and SSN21 FRAZ NRDs.

s. Meeting between E. Siborg, J. Brown and J. Pratt on 23 June 1987.

t. NUWC ltr Ser 22111/C23 of 11 June 1992, Subj: Comparison of Dr. Pryor's NRDs with Code 2111 NRD Standards.

u. NUSC ltr Ser 43202-C17 of 9 April 1984, Subj: AN/BQQ-5/6 PNB and CLASSIFICATION Over Resolution Loss.

v. TRACOR, Inc. Report of 17 Dec 1982, "Evaluation of the Effects of Over-resolution in the detection of Difar-like Signals".

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

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NEWPORT RI 02841-1708

IN REPLY REFER TO:
5720
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Mr. John Greenewald, Jr.
8512 Newcastle Avenue
Northridge, CA 91325

Dear Mr. Greenewald:

This is in response to your Freedom of Information Request dated 09 May 1998 for a copy of the Naval Undersea Warfare Center Division, Newport (NUWC) Technical Document 10419, dated 02 July 1993.

The document you have requested is classified, and not releasable in its present form.

You may request that the document be reviewed, and classified portions removed You may find however, that the resultant document will be of no use to you because it will not fully cover the information that you seek.

At your earliest convenience, please advise me if you want us to proceed with the review and release, or whether you wish to withdraw your request. To date, there are no fees associated with your request.

To expedite matters, please feel free to contact me by phone at (401) 832-3611, or e-mail at steigerwald@npt.nuwc.navy.mil with your decision..

Sincerely,

G.A. STEIGERWALD
Public Affairs Officer
By direction of
the Commander

To: steigerwald@npt.nuwc.navy.mil
From: "John Greenewald, Jr." <greeney@primenet.com>
Subject: Ser 800BC(PA)/74
Cc:
Bcc:
Attached:

Dear Mr Steigerwald,

This is in response to your letter undated, postmarked June 16, 1998, with the serial above.

I please respectfully request that the document be reviewed and classified portions be BLACKED OUT, and the document then sent back to me.

Thank you very much for your time, and I look forward to your response.

Sincerely,

John Greenewald, Jr.

Printed for "John Greenewald, Jr." <greeney@primenet.com> 1

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE NAVY
NAVAL UNDERSEA WARFARE CENTER DIVISION
1176 HOWELL STREET
NEWPORT RI 02841-1708

IN REPLY REFER TO

5720
Ser 800BC(PA)/83
30 JUL 1998

Mr. John Greenewald, Jr.
8512 Newcastle Avenue
Northridge, CA 91325

Dear Mr. Greenewald:

This is in response to your Freedom of Information (FOIA) request dated 09 May 1998 in which you request a copy of the Naval Undersea Warfare Center Division , Newport (NUWC) Technical Document 10419 dated 02 July 1993. The requested document was located, but sections of the document are believed to be exempt from mandatory disclosure under (b)(1) of the FOIA. Specifically, the records contain information the release of which may be construed as causing a threat to national security..

Insofar as the Naval Undersea Warfare Center Division, Newport does not have denial authority, this document has been forwarded to Headquarters, Naval Sea Systems Command for a release determination and direct response to you.

If you have any questions, feel free to contact me at (401) 832-3611.

Sincerely,

G. A. STEIGERWALD
Public Affairs Officer
By direction of
the commander

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

5720
Ser 09T33C/98-622

OCT 30 1998

Mr. John Greenewald, Jr.
8512 Newcastle Avenue
Northridge, CA 91325

Dear Mr. Greenewald:

This is a final response to your May 9, 1998, Freedom of Information Act (FOIA) request for a copy of the document entitled, "Procedure to Derive Submarine Sonar Operational PNB NRDs Against Continuous Wave and Gaussian Signals." You addressed your request to the Naval Undersea Warfare Center (NUWC), New London, Connecticut. In an electronic mail response to Mr. Steigerwald of NUWC, you indicated that you would accept the documents, minus the portions that are considered classified.

NUWC referred the responsive document to us for review and direct response to you. We reviewed the document and removed all portions that are considered classified, as this information is likely exempt from public disclosure pursuant to FOIA subsection (b)(1).

This is not a denial of information under the FOIA, as you agreed to accept clearly releasable portions of the document.

Fees associated with processing your request are minimal and have therefore been waived. However, I consider fee waivers on a case-by-case basis and you may be charged fees on future requests.

Please contact Ms. Stephanie L. Carr if you have any questions about the processing of your request.

Sincerely,

Judy Wise

JUDY P. WISE
Head, Freedom of Information
And Privacy Program Division
By Direction of the Commander