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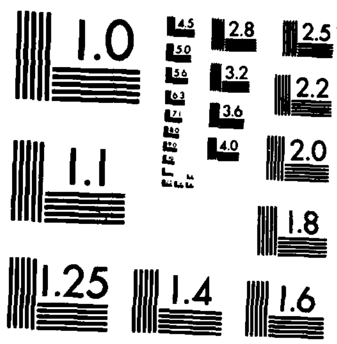
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TECHNICAL REPORT RE-82-20

DETECTION CRITERIA FOR A RADAR USING COINCIDENCE PROCESSING

Robert Boothe
Advanced Sensors Directorate
US Army Missile Laboratory

August 1982

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama ~~35809~~ 35898

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I. INTRODUCTION

The detection processes used in modern radars often do not lend themselves to straightforward calculations of the relationship between the desired false alarm criteria, the bias level, and the resulting detectability factor. Often, simple estimates are made as to the value of these detection parameters with the result that several decibels of error are introducted into performance calculations. One such detection process is that which uses a coincidence of events in which several related range-doppler channels must produce threshold crossings before a target is declared.

This report examines one such coincidence detection process of interest in modern radars that must use several coherent processing periods having different code rates (or pulses repetition frequencies) in order to resolve ambiguities during a single beam position. Specifically, two code rates periods are examined here, but the analysis approach can be extended to include processors which use more than two periods. The detection parameters examined include the average false alarm time, probability of false alarm, and detectability factor for a fluctuating target.

II. PROBABILITY OF FALSE ALARM

Consider the detection process whereby a target is declared as being detected only if (1) a threshold is exceeded during both code rate periods in the beam dwell time and (2) the second code period threshold crossing occurs in the doppler cell in which the threshold crossing occurred on the first code period, plus or minus one doppler cell on either side. The diagram of Figure 1 is useful for developing the false alarm probability for this form of a coincidence detector. Let P_{fa} denote the probability of a false alarm in a single range-doppler channel for each code period. Assume further that the thresholds are the same value for each of the two periods. The probability of the bias level on the second code period being exceeded by noise alone in a specific doppler cell, or in the doppler cell on either side of that one specified, is given by

$$P'_{fa} = 1 - (1-P_{fa})^{n_2} \qquad (1)$$

$$= 1 - (1-P_{fa})^{3r}$$

where r is the number of range cells. The probability of an incorrect target declaration due to noise alone, P_n, at the output of the coincidence circuit is then

$$Pn = P_{fa} P'_{fa}.$$

Referring to Figure 1, there are n_1 x N opportunities for a noise voltage to exceed the threshold for the first code rate within the average false alarm time, T_{fa}. Here, N is the number of beam positions contained within the average false alarm time, and n_1 is the number of range-doppler cells for the first code rate. Note that T_{fa} is the average time between false alarms and not that used by Marcum[1] where the false alarm time is defined as the time in

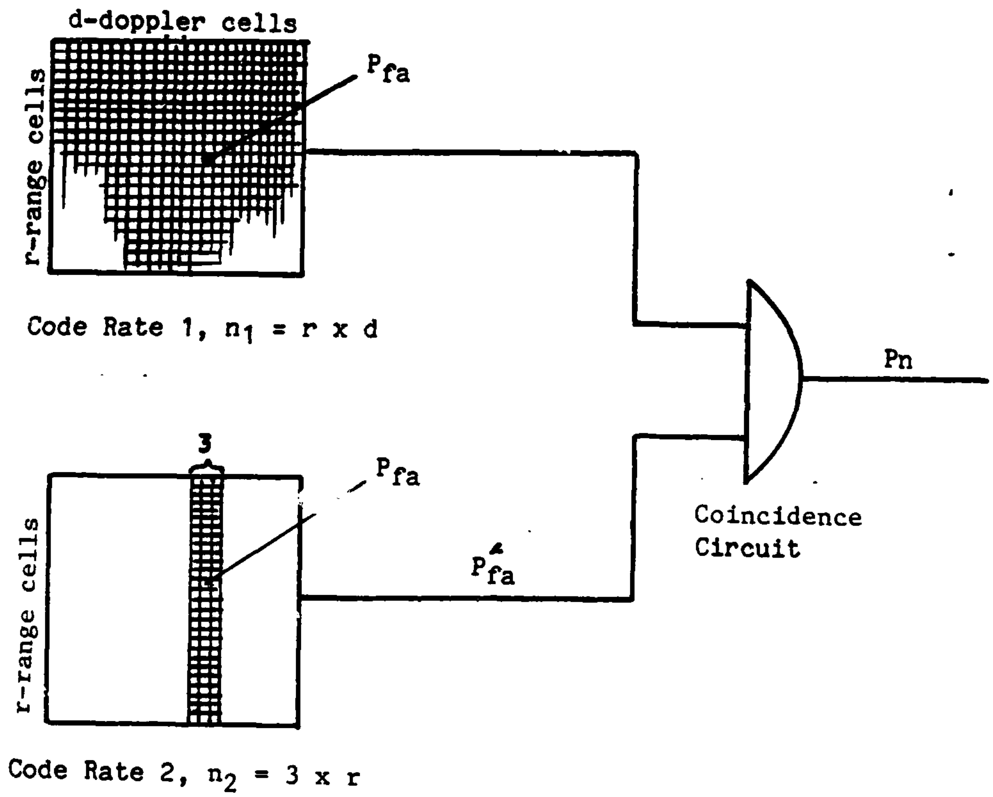

Figure 1. The coincidence detection process

which the probability is 50 percent that a false alarm will not occur. The cumulative probability of experiencing at least one false alarm within T_{fa} at the output of the coincidence circuits is then

$$\begin{aligned} P_{fa} &= 1 - [1 - P_n]^{n_1 N} \\ &= 1 - \left[1 - P_{fa}\,(1-(1-P_{fa})^{n_2})\right]^{n_1 N} . \end{aligned} \tag{3}$$

Here, $n_2 = 3 \times r$, the number of acceptable range-doppler possibilities within the second code rate period.

The binomial distribution can be used to determine the probability that k (k = 0,1,2,...) false alarms will occur during the average false alarm time, T_{fa}. Since the false alarm probability, P_{fa}, is so small and the number of chances to obtain a false alarm is large, the limiting form of Poisson's distribution is more suitable for this purpose. The Poisson distribution is given by

$$P(k) = \frac{m^k e^{-m}}{k!} \tag{4}$$

where P(k) is the probability of obtaining k false alarms within T_{fa} and m is the average number of false alarms expected within T_{fa}. Since T_{fa} has been defined here as the average time between false alarms, the value of m is unity. Thus, for this purpose, Equation (4) becomes

$$P(k) = \frac{e^{-1}}{k!} . \tag{5}$$

The probability of obtaining no false alarms within T_{fa} is found by setting k = 0 in Equation (5). This results in $P(0) = e^{-1}$. P(0) can then be set equal to $1 - P_{FA}$ (P_{FA} given in Equation (3)) to obtain

$$[1 - P_{fa}(1-(1-P_{fa})^{n_2})]^{n_1 N} = e^{-1} . \tag{6}$$

Manipulation of Equation (6) and solving for the number of beams, N, in the average false alarm time yields

$$N = \frac{-1}{rd\ \ln[1-P_{fa}(1-(1-P_{fa})^{n_2})]} . \tag{7}$$

Consider a signal processor with r=31 range cells (resulting from a 31 bit code) and d=32 (correspondig to 32 doppler filters). The resulting value of

n_1 is 31 x 32, or 992, cells. Furthermore, let the 32 doppler filters be separated into approaching and receding doppler frequencies with an interval between the lowest frequency approaching and receding filters to permit rejection of low frequency doppler signals resulting from clutter. The value of n_2 is not simply 3 x r, or 91, as stated earlier because it does not take into account the fact that four doppler cells do not have adjacent doppler cells on both sides. These are the lowest and highest doppler cells for both approaching and receding target velocities. There are twenty-eight other doppler cells that have adjacent doppler cells on both sides. The effective number of channels for n_2 can be found by averaging the number of possibilities over the 32 doppler channels. The average value of n_2 is then

$$\bar{n}_2 = \frac{(28x3) + (4x2)}{32} \times 31 = 89.125. \quad (8)$$

Having determined the effective value for n_2 as 89.125, the relationship between the number of beams (N) contained within the false alarm time (T_{fa}) and the false alarm probability given by Equation (7) can be calculated. The results of this calculation are shown in Figure 2. Assume a requirement calls for an average of one false alarm per rotation during which time there are 670 beam positions. Referring to Figure 2, an N of 670 beams gives

$$P_{fa} = 1.3 \times 10^{-4} \ .$$

For false alarm probabilities very much less than unity, Equation (7) can be simplified by using Taylor's expansions for the expressions $(1-X)^n$ and $\ln(1-X)$. Application of these to Eq. (7) yields the simplified expression

$$P_{fa} = (n_1 \, n_2 N)^{-1/2}. \quad (9)$$

III. Detectability Factor

Having determined the false alarm probability for the two code rate waveform, the detectability factor can now be found. Detectability factors may include various effects or losses to the system such as target fluctuation and correlation, bandwidth mismatch, integration loss, statistical losses, etc. For the purpose of this report, the detectability factor will include the effect of noncoherent integration of the two dwells that make up each of the two code intervals, target fluctuation, and the correlation of the target's radar cross section between the two code rates.

Each of the two code rate periods contained within the beam dwell time is composed of two dwells. The envelope detector outputs of these two dwells are noncoherently integrated to produce the output for each code rate period. The probability of detection for a Swerling Case 1 target[2] on a single code rate with noncoherent integration of the two dwells following square law detection is determined from the expression

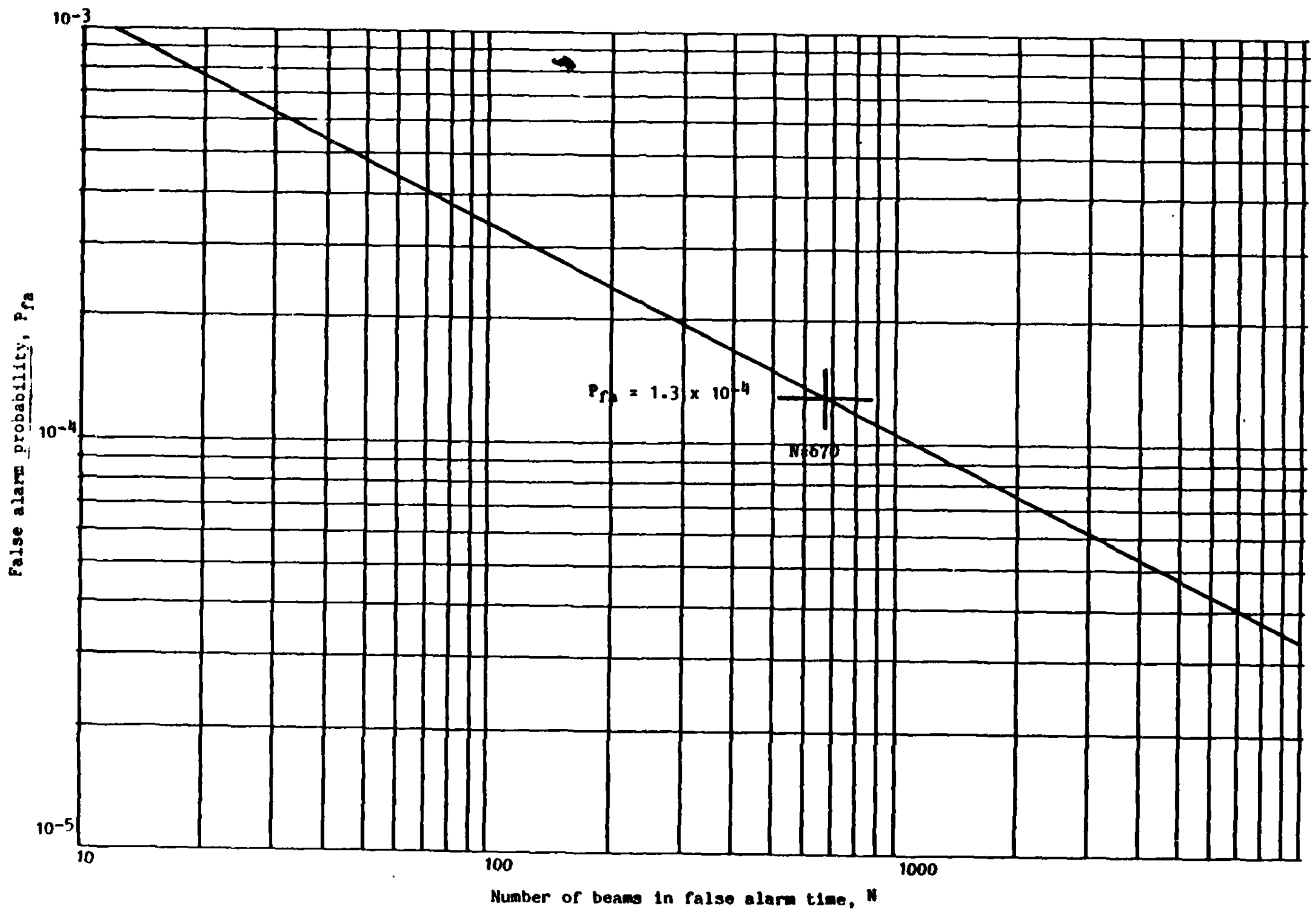

Figure 2. False alarm probability vs number of beams in false alarm time

$$P_d = \left(1 + \frac{1}{2\bar{\chi}}\right) \exp(-Y_b/(1 + 2\bar{\chi})) - \frac{1}{2\bar{\chi}} \exp(-Y_b) \qquad (10)$$

where $\bar{\chi}$ is the average signal-to-noise ratio of one of the dwells and Y_b is the normalized bias level. The bias level for two integrated samples is determined from the expression

$$P_{fa} = (1 + Y_b) \exp(-Y_b). \qquad (11)$$

Square law detection is used here for mathematical convenience. For a linear detection process, the relationship between false alarm probability and β, the bias level normalized to the standard deviation of the noise, has been shown by Marcum [1,3] to be

$$P_{fa} = \exp(-\beta/2) + \frac{\sqrt{\pi}\beta}{2} \exp(-\beta^2/4) \operatorname{erf}(\beta/2). \qquad (12)$$

The resulting performance between both types of detectors is essentially the same.

Equation (11) has been evaluated, and the results are shown in Figure 3. For the false alarm probability of 1.3×10^{-4} that is of interest here,

$$Y_b = 11.471.$$

The probability of detection given by Equation (10) has been evaluated using this value of Y_b and is shown as curve A in Fig. 4. This curve gives the probability of detection only for a single code rate. A S/N of 8.47 dB per dwell is required to achieve a 50 percent probability of detection for the two-dwell period. In order to achieve target detection during a beam dwell, a target must be detected on both code rate periods within that beam dwell time. If the target were completely decorrelated between each code rate, each would require an individual probability of detection of 0.707 in order to achieve a 0.5 probability of detection for the beam. This would require an additional 3.17 dB of S/N for each dwell above the 8.47 dB required for a single code rate.

For a Swerling Case 1 fluntuating target model, it can be properly assumed that the target radar cross section is very highly correlated over the beam dwell time of approximately two milliseconds. Thus, it would be expected that the increase in S/N required to achieve the 0.5 probability of detection for a beam dwell would be less than the 3.17 dB increase required for the uncorrelated case.

This condition (target completely correlated over a beam dwell time) has been simulated for a Swerling Case 1 fluctuation model where the target's radar cross section remains constant over the two code rate periods contained in the

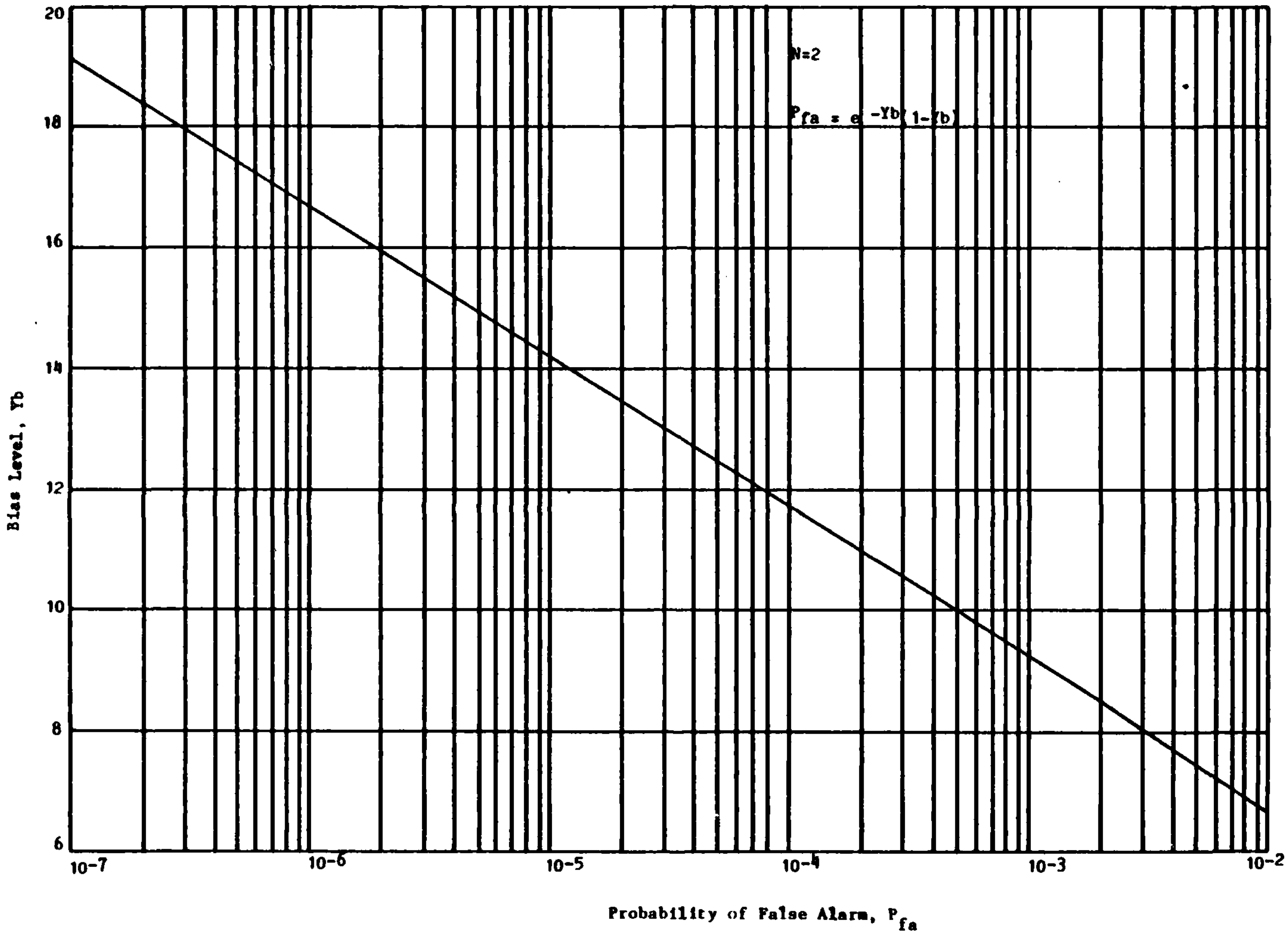

Figure 3. Normalized bias level vs probability of detection for two noncoherently integrated square law detected samples.

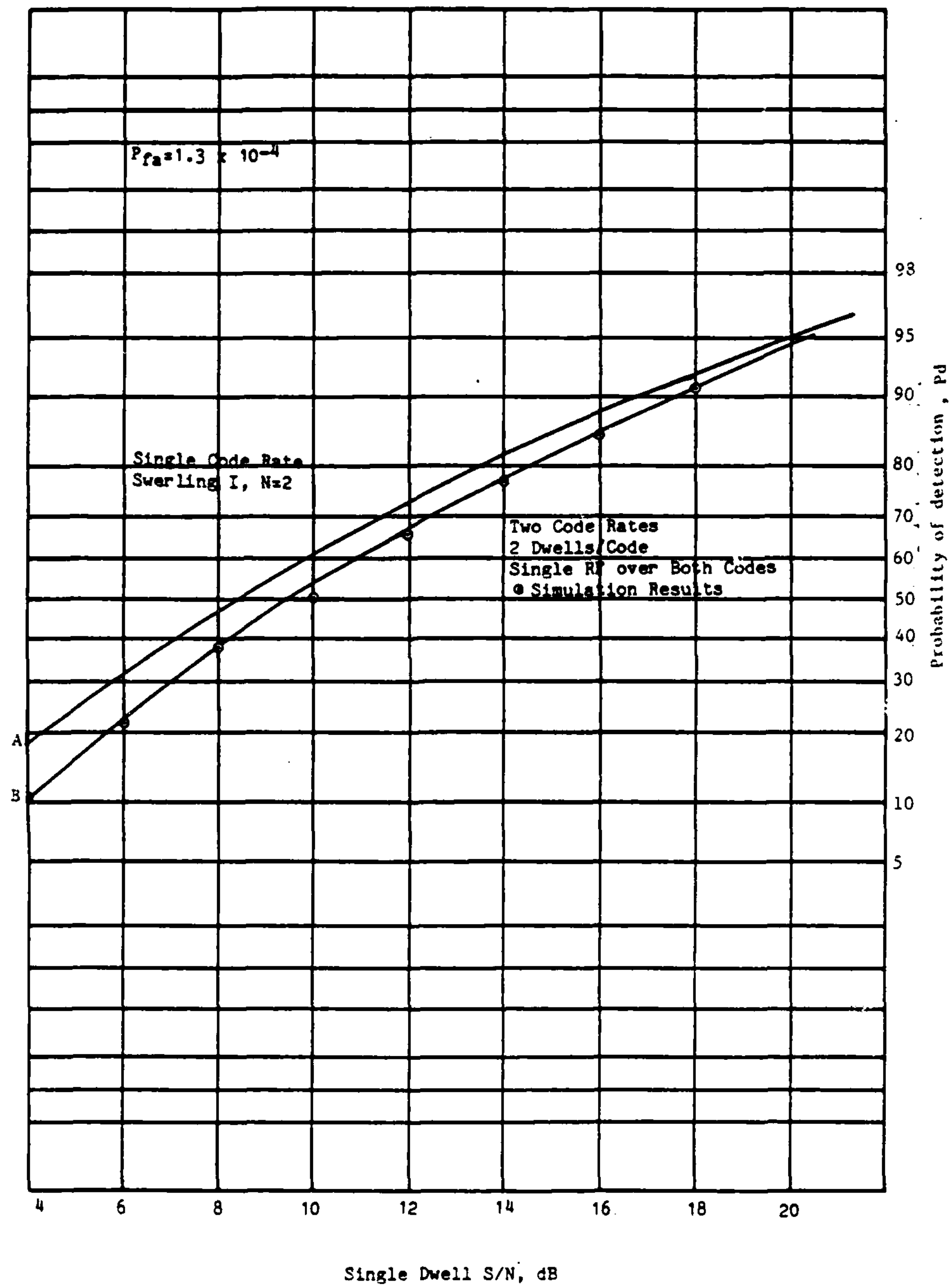

Figure 4. Probability of detection vs single dwell S/N for case I fluctuating target

beam dwell time. The radar cross section was uncorrelated between successive beams. The results of the simulation are presented as curve B in Figure 4. For a detection probability of 50 percent and false alarm probability of 1.3×10^{-4}, the detectability factor (S/N required per dwell) is 9.57 dB. Detectability factors for other probability of detections are available from curve B of Figure 4.

IV. Coincidence Detection Loss

The increase in S/N required per dwell for the two code rate detection is simply the difference bewteen 9.57 dB from the simulation and the 8.47 dB from Equation (10), or 1.1 dB at 50 percent. The increase required for the two code rate detection varies with the detection probability and is the difference between curves A and B of Figure 4. This increase in S/N may be treated as an additional loss factor and is termed coincident detection loss. Table 1 gives the coincident detection loss as a function of detection probability.

Table I. Coincident Detection Loss vs Pd

Pd (%)	Loss
10	1.61
20	1.37
30	1.22
40	1.15
50	1.10
60	1.05
70	.99
80	.92
90	.81
95	.34

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