Proceedings of the IEEE 1984

National Radar Conference

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National Radar Conference

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FOREWORD

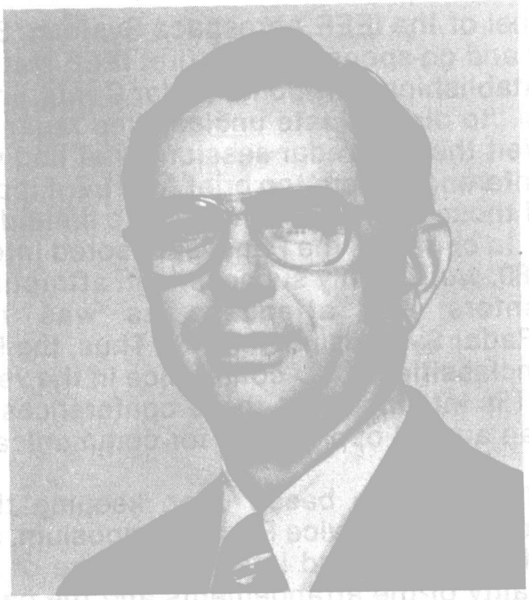
The Radar Systems Panel of the IEEE Aerospace Systems Society (AESS) is pleased to be the originator and co-sponsor of the first IEEE National Radar Conference. The rationale for establishing a National Radar Conference is based on a major objective of the panel "to disseminate unclassified radar information in a timely manner." The Panel felt that the radar sessions that had recently been attached to Regional IEEE Conferences were too brief to attract more than local audiences. The proceedings of those conferences were also limited in their distribution to the radar community. In contrast, the Panel-sponsored International Radar Conferences in 1975 and 1980, were highly successful in attracting a broad international group of presenters and attendees as was the specialized Mechanical Engineering in Radar Symposium (MERS). Thus, the Panel concluded that there is a need for an unclassified radar conference in the years between the International Conferences. It is intended that these conferences will provide the U.S. radar community with an annual opportunity for communication.

The time for this conference was based upon keeping the date several months from the classified annual Tri-Service Radar Symposium, and the location was based on knowledge of a capable and interested cadre of radar engineers here in Atlanta. The high quality of the arrangements and the papers in this Proceedings verifies that the Panel made the right choice. We would like to express our appreciation to General Chairman Dr. James C. Wiltse and Program Chairman Dr. Edward K. Reedy for a job well done. I would also like to thank Mr. Frederick B. Dyer of the Panel for acting as our liaison.

I wish to take this opportunity to invite you to submit papers and plan to attend the IEEE International Radar Conference in Washington, May 6–9, 1985. The panel welcomes ideas for another "IEEE National Radar Conference" in late 1986 or early 1987.

Fred E. Nathanson

Fred E. Nathanson
Chairman, Radar Systems Panel
IEEE AESS



GENERAL CHAIRMAN'S MESSAGE

This first IEEE National Radar Conference is jointly sponsored by the Aerospace and Electronic Systems Society and by the Atlanta Section. Under the previous scheme of things, the U.S. would see an IEEE Radar Conference only every five years (1975, 1980, 1985 in Washington). In the intervening periods international conferences were held in London. As Fred Nathanson has indicated in the Foreword, the plan now is to hold IEEE National Radar Conferences in the time intervals between the Washington and London conferences. Those of us in the Atlanta area are pleased to have been asked to organize the present conference.

The response to our call for papers was very strong, with a large number of abstracts submitted. Given the ground rule that there would be no parallel sessions, the number of papers of reasonable length that can be fitted into a two-day conference is about thirty (or a few more if presentations are very short). Since the Papers Selection Committee received more than 2½ times that many, the process of choosing was difficult, and several very good topics had to be omitted.

I would like to express my thanks to the members of the Operating Committee and the Papers Selection Committee who devoted so much time and energy to making the necessary arrangements and decisions for the conference. The assistance of the Atlanta Section in co-sponsoring this meeting is also gratefully acknowledged.

James C. Wiltse

James C. Wiltse
General Chairman
IEEE 1984 National Radar Conference

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In recognition of the importance of young engineers to the future of radar development, the IEEE AESS Radar Systems Panel announces the establishment of an annual Radar Panel Award. This award will be presented each year for outstanding contributions to the radar art. The awardee must be an IEEE member and less than 40 years of age on January first of the year of the award. The first award will be for 1985 and will be presented at the International Radar Conference in Washington, D.C., May 5–8, 1985.

Nominations for the 1985 award should be submitted to the Radar Systems Panel Awards Chairman, Major A. Johnson, General Electric Company, P.O. Box 4840, Court Street Plant, Building 4-Room 58, Syracuse, New York 13221, prior to September 1, 1984. Each nomination should include a description of the nominee's significant radar contributions and supporting evidence of their importance as well as a listing of related papers published or presented. Also, support letters should be submitted by five individuals familiar with the nominee's work, three of whom work outside of the nominee's company or government organization.

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CLUTTER MAPS: DESIGN AND PERFORMANCE

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ABSTRACT

With the advent of radar automatic detection and tracking (ADT) systems, false alarm control has become of primary importance. The conventional cell averaging CFAR works well only in a strictly spatially stationary environment such as thermal noise or barrage ECM. In nonhomogeneous, spikey clutter environments, this scheme will not provide CFAR processing. Recently, renewed interest has developed in the area of clutter map processing. The amplitude clutter map is a CFAR device which averages radar returns temporally over several radar scans to form estimates of the mean background level. For effective operation, this device requires temporal rather than spatial stationarity and thus is ideally suited for CFAR processing in environments such as land. However, clutter maps may cause the deletion of real target returns as well as clutter. Therefore, this paper gives an overview of amplitude clutter map processing and presents an analysis and design procedure which may be used to determine concept feasibility for a broad class of radars.

INTRODUTION

This paper discusses a procedure for the design and evaluation of an amplitude clutter map. First, the problem is formulated and the effectiveness of some of the more conventional solutions in spikey clutter backgrounds is discussed. Next, a review of amplitude clutter map processing is presented. Here, some of the basic spatial parameters are defined and a specific processing algorithm is reviewed. Following this, a procedure for analyzing clutter map performance is outlined and appropriate design criteria are presented. These criteria are then applied to a hypothetical radar in order to illustrate a procedure which may be used to obtain a preliminary design.

BACKGROUND

In [1], Hansen indicated the sensitivity of a constant threshold radar processing system to changes in receiver noise level. For square law detection and 16 pulses noncoherently integrated, his curves indicate that even a 2dB change in receiver noise level would raise the average P_{fa} from a nominal level of 10^{-6} by four orders of magnitude. A 2dB change in received noise level could easily occur simply from radar component drift due to aging as well as clutter or barrage ECM. This problem is especially critical for those radars which must interface with automatic tracking and weapons control systems.

Initial attempts at solving the problem were made by employing what were typically called Constant False Alarm Rate (CFAR) devices. The earliest of these devices simply estimated the mean background level by using several range cells surrounding the target cell of interest. This average background level was then used to set the final threshold. For a one parameter density such as Exponential or Rayleigh, it may be shown that the false alarm rate is independent of the received average power level. However, this is not true in spikey nonhomogeneous clutter such as within heavy storm cells or in backgrounds of sea or land.

For many years after this, attempts were made to improve on the limitations of the basic cell averaging CFAR. These included the split gate CFAR which attempted to compensate for nonstationarity due to clutter edges and the nonparametric CFAR which attempted to relieve the requirements for a-priori knowledge concerning the noise density function. However, the split gate CFAR did not solve the isolated spike problem and the nonparametric CFAR was very lossy.

During the same period of time, another type of CFAR device, the clutter map, was in development. The clutter map was a CFAR device which divided the radar space into cells (not necessarily equal to radar resolution cells) and averaged the radar returns temporally over several radar scans. Such a device is not affected by spatially nonhomogeneous or nonstationary clutter such as land.

Because of the typically large number of cells to be processed, the required processing speeds and the relatively high cost of digital memory, early clutter maps were typically of the blanking type. A blanking clutter map is implemented after final thresholding. This map simply employs a counter to determine how often clutter appeared in a specific cell. When the counter reached a prespecified level, this information was stored in a one bit map and used to blank all incoming returns within that region. However, as illustrated in Figure 1, blanking clutter maps were not CFAR devices. The curve in Figure 1 assumes square law detection with 4 pulses noncoherently integrated and indicates

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that P_{fa} will vary dramatically with changes in receiver noise level. Although this curve applies for a specific blanking logic, these results are typical for all blanking maps.

Most recently, due to advances in high speed integrated circuitry and decreases in cost of digital memory, there has been, within the Navy community, a renewed interest in high resolution, amplitude clutter map processing. However, the design of a high resolution clutter map is not necessarily feasible for any combination of radar parameters. Consider, for example, a radar which operates with a one second update rate and uses a 2 μs pulse. In this case, any radially inbound target whose velocity is less than Mach 1.8 would be suppressed to some extent by the clutter map. Clearly, this is an unacceptable solution for defense applications. Therefore, the purpose of this paper is to give a general overview of clutter map processing as well as an understanding of some of the basic parameters which enter into the design tradeoff study.

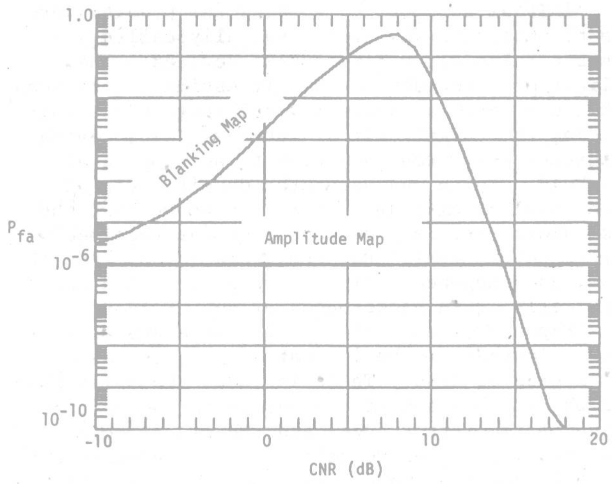

Figure 1: Clutter Map CFAR Performance

PROCESSING OVERVIEW

Clutter map processing is a CFAR technique that is used to set independent thresholds in each map cell to yield a constant false alarm rate. As shown in Figure 2, this technique works by dividing the radar space into clutter map cells. In this figure, each small cell represents, in range-bearing space, one resolution cell. In this example, the five small highlighted cells represent one clutter map cell and the map cell size in range is equal to five resolution cells. The additional cells labelled as spreading cells denote the region considered during the map update process. The reasons for using spreading cells will become apparent in the following discussion. In this example, although only five resolution cells comprise a clutter map cell, due to map spreading, a total of twenty-seven cells are considered during map update.

Functionally, clutter map processing consists of the steps indicated in Figure 3. For the amplitude map, the processing consists of map spreading followed by map update. For each clutter map cell, the map spreading logic selects for map update the greatest amplitude of all resolution cells within the map cell as well as the additional spreading set that borders that map cell. This amplitude is then stored in the appropriate location of the measurement map. The measurement map which has cells equal in size to the clutter map cell is used for map update.

Map processing consists of averaging the contents of the measurement map with the current stored values in the clutter map. The average amplitude in each map cell is estimated by low pass, digital filtering of the input data. Assuming a constant update time (nominal radar scan period), the mean return in each cell is estimated as

$$Y(n) = \alpha X(n) + (1 - \alpha) Y(n - 1) \quad (1)$$

where Y(n) is the mean estimate after update 'n', X(n) is the radar measurement, and α is the clutter map filter gain coefficient. The current estimate of the mean clutter power, Y(n), is then used during the next update to set the threshold for all resolution cells within the clutter map cell. At steady state the filter operation described by (1) is equivalent to a simple cell averaging CFAR which uses

$$N' = (2 - \alpha)/\alpha \quad (2)$$

cells. However, in this case, the cells correspond to the returns from a particular point in space received over N′ successive radar scans.

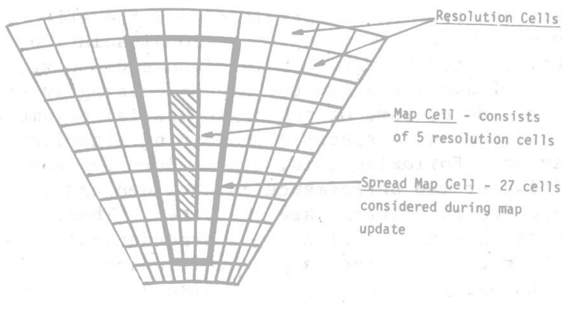

Figure 2: Clutter Map Cell Definitions

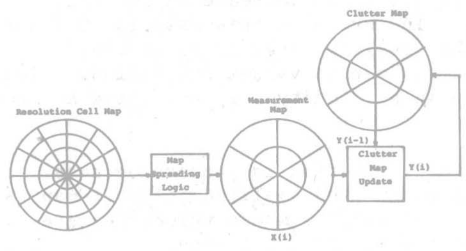

Figure 3: Amplitude Map Processing Details

PERFORMANCE ANALYSIS AND CRITERIA

Several criteria must be considered in the design and evaluation of an amplitude clutter map. These include settling time, velocity response and processing loss. These criteria depend not only on clutter map parameters but also on the specific radar parameters and signal processing employed. Therefore, to assess the performance requires an analysis or simulation program.

A Clutter Map Analysis Program (CMAP) was developed primarily to simulate the response of an amplitude clutter map to a constant velocity radially inbound target. This program is valid for the processing illustrated in Figure 4 and assumes a Swerling II target in a Rayleigh noise background. CMAP simulates the motion of target or point Rayleigh clutter through 400 range resolution cells computing at each iteration the average P_d or P_{fa}.

The response in any one particular cell will depend on the number of times that cell was updated. For example, a stationary target will continously update the same resolution cell, and the resulting P_d versus time (or settling time) will be as shown in Figure 5. This curve was computed assuming an SNR of 20 dB, four pulses noncoherently integrated and a map gain, α, of .125. The threshold was selected to provide a steady state P_{fa} of 10^{-6}. Since the map operates with an inherent one scan delay, the point target is detected with probability one at its initial appearance (scan #1). Every scan thereafter, the target P_d is reduced as a result of the increase in clutter map cell contents.

To consider more clearly the effects of range spreading, consider the response curve indicated in Figure 6. This curve represents the clutter map response to a constant 40 knot target and assumes five range cells per map cell, no map spreading, and a gain, α, of .125. As this curve vividly illustrates, the response will be cyclic with a transition to one each time the point target (or clutter) enters a new map cell. Since the cycle time is about seven scans, the average P_d (P_{fa} for Rayliegh point clutter) cannot drop below 1/7 or 10^{-1}. Such a design would represent no design margin for ship's motion errors due to sea motion or inaccurate compensation.

The results obtained for the same case but employing one cell range spreading are illustrated in Figure 7. Ignoring the first few scans during the target's initial appearance, it is noted that the effect of spreading is to prepare cells prior

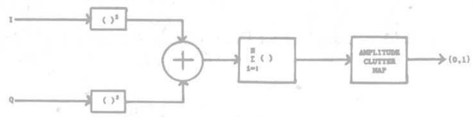

Figure 4: CMAP Assumed Signal Processing

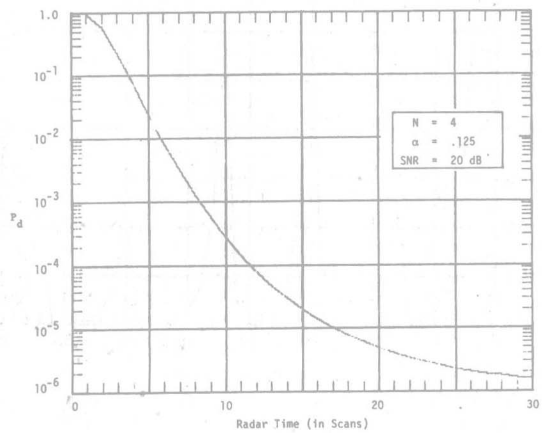

Figure 5: Response for a Stationary Swerling II Point Target

As the target velocity is increased, cyclic curves are also obtained as shown in Figure 8. The primary difference here is that at the higher velocities (320 knots in this case) the width of the clutter map free regions (regions where the P_d equals one) increases while the width of the suppressed areas, as well as their depth, decreases. This results in an increase in detection probability. The cycle in this case is 10 radar scans and the resulting average P_d is .96. Computing these average values for various velocities results in a velocity response curve as shown in Figure 9.

The final criterion is processing loss. Processing loss for the amplitude clutter map is defined only for targets whose velocities are greater than the Map Free velocity.

The Map Free Velocity in range may be readily computed considering the minimum number of range cells the target must move so as not to fall in a cell which was previously updated. In general, this number is equal to the number of range cells per map cell plus the number of range cells spread (one side). In this example, since there are five range cells per map cell and ± 1 cell used for range spreading, a point target must move six resolution cells (300 feet) in 2 seconds to be map free. This results in a map free velocity of 150 ft/sec or approximately 90 knots.

Given this requirement, the processing loss may be defined as the additional SNR required to obtain .5 detection probability (with P_{fa} constrained) above that of an ideal system. The ideal system is equivalent to clutter map processing with gain, α, equal to zero ($N \to \infty$). This definition of processing loss is illustrated in Figure 10.

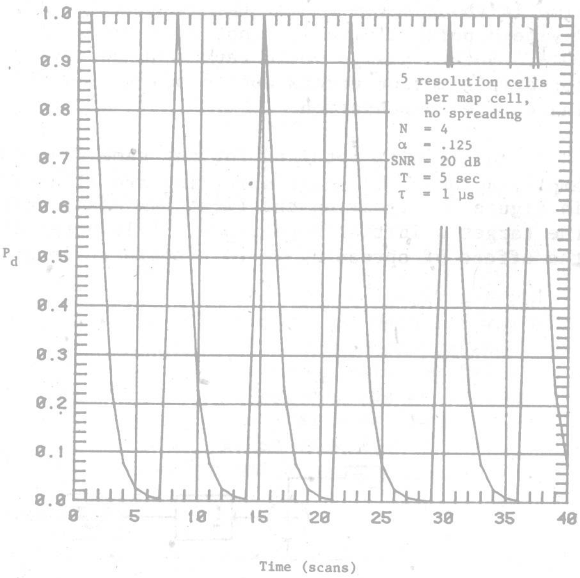

Figure 6: The Effects of Range Spreading on the Detectability of a 40 Knot Target: No Range Spreading

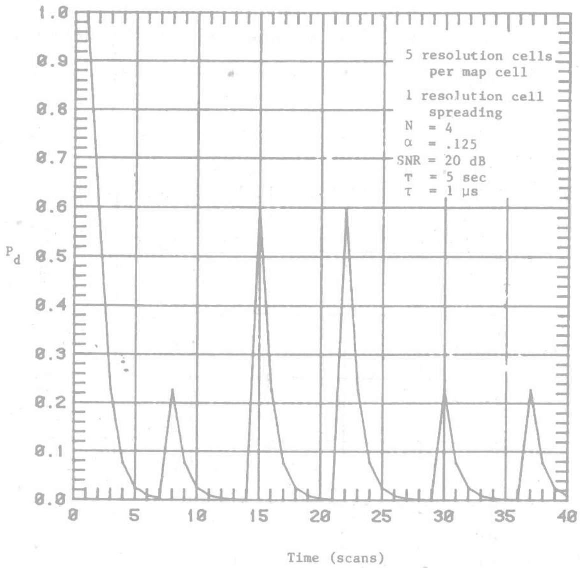

Figure 7: The Effects of Range Spreading on the Detectability of a 40 Knot Target: One Range Cell Spreading

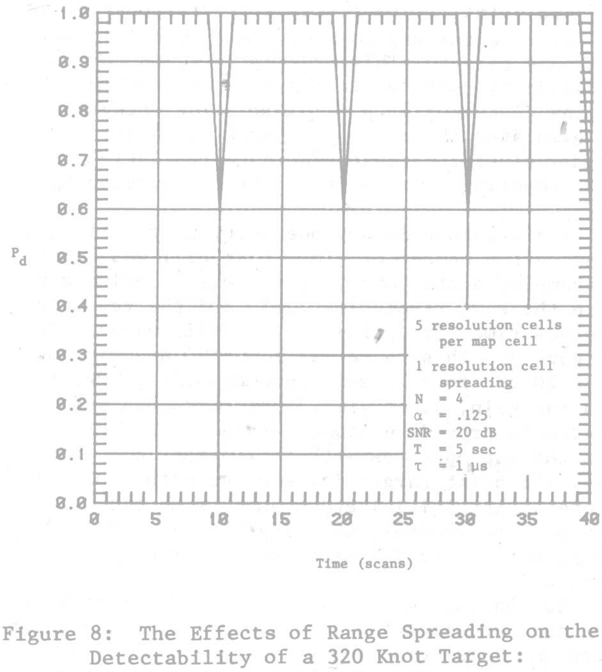

Figure 8: The Effects of Range Spreading on the Detectability of a 320 Knot Target: One Range Cell Spreading

to target transitions. This results in a similar curve but with the peak detection probabilities experienced during map cell crossover significantly reduced.

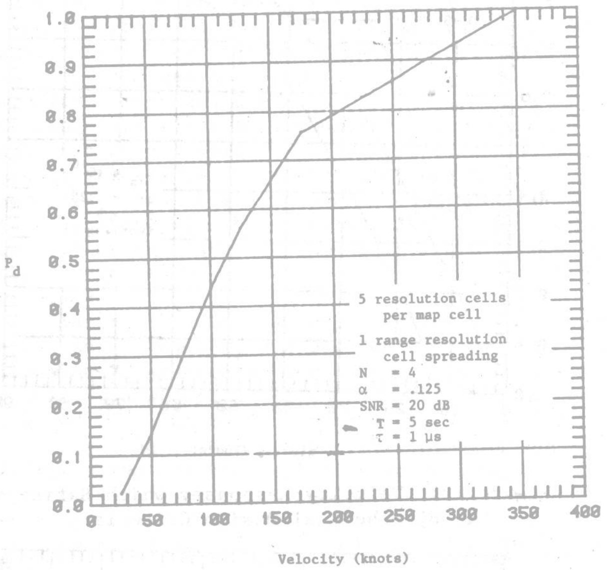

Figure 9: Illustration of Clutter Map Velocity Response

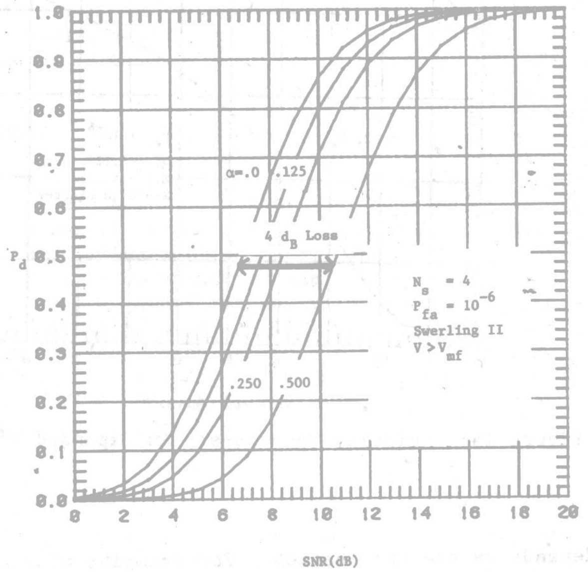

Figure 10: Definition of Clutter Map Processing Loss

DESIGN PROCEDURE

The determination of an initial clutter map design depends on four key radar parameters: 1) compressed resolution cell size, 2) radar update period, 3) number of pulses noncoherently integrated, and 4) detector law employed. To illustrate the design procedure, consider designing an amplitude map for a radar with the parameters indicated in Table 1.

TABLE 1 Assumed Radar Parameters

Compressed Pulse Length, τ	.5μs
Update Period, T	5 seconds
# Of Pulse Integrated, N	4

Assume this is a 2-D long range radar which includes pulse compression, followed by square law detection, noncoherent integration of 4 pulses and a cell averaging CFAR. With respect to the clutter, the CFAR is one which simply normalizes the incoming video to the local background level. If we assume that the number of CFAR cells is large then the CFAR may be thought of as a perfect normalizing circuit and essentially reduces the clutter map dynamic range requirements.

The clutter cell may not have dimensions smaller than a radar resolution cell and therefore the minimum Map Free velocity in the range dimension is given by

$$V_{mf} = (C\tau/2)/T \tag{3}$$

where $C\tau/2$ is simply the pulselength converted to range units. For this example, $C\tau/2$ is equal to 250 ft and V_{mf} minimum is equal to 50 ft/sec or 30 knots. In general, if the clutter map is to employ range spreading, the following relationship holds

$$V_{mf} = (N_r + N_{rs})(C\tau/2)/T \tag{4}$$

where N_r is the number of range resolution cells collapsed into one map cell and N_{rs} is one-half the additional number of cells used for map spreading. For the cell size defined in Figure 2, $N_r = 5$ and $N_{rs} = 2$.

The first parameter which may be fixed is clutter map gain, α. The clutter map gain primarily affects clutter map loss and settling time. The loss as a function of gain, α, is illustrated in Figure 11. The loss decreases with decreasing α (increasing N′) and increasing number of pulses integrated, N. From this curve, it is noted that the loss may be kept under 1.5 dB by selection of the gain, α, to be less than. 2.

Figure 12 illustrates the required time in radar scans for the map to settle (reach steady state) as a function of gain. Since the map must resettle each time the radar transmitter is interrupted (during Emission Control or at initial turn on), settling time should be minimized. A good choice in this case is to select a gain, α, of .125 since this meets our previous loss requirement of $\alpha < .2$ and minimizes settling time. For the gain selected, the settling time is approximately two minutes and the processing loss is .8 dB.

Now assuming a system velocity requirement of 100 knots, (3) may be used to fix the value of $(N_r + N_{rs})$. From (3), if $(N_{rs} + N'_{rs})$ is equal to 3, the Map Free velocity is 90 knots which is consistent with the 100 knots system requirement.

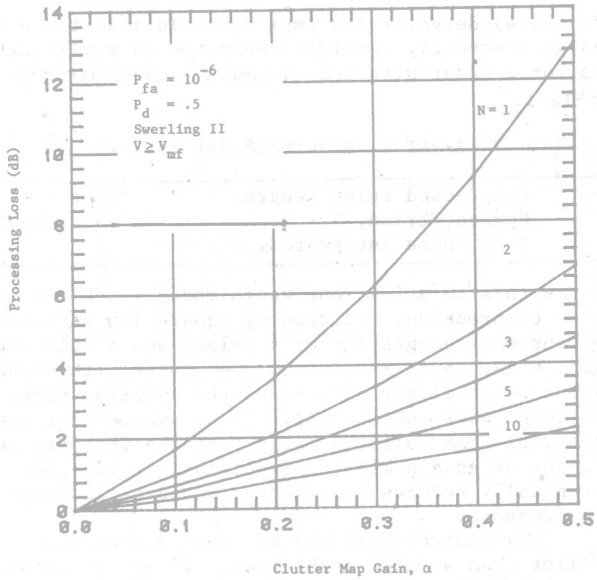

Figure 11: Clutter Map Processing Loss: P_d = .5

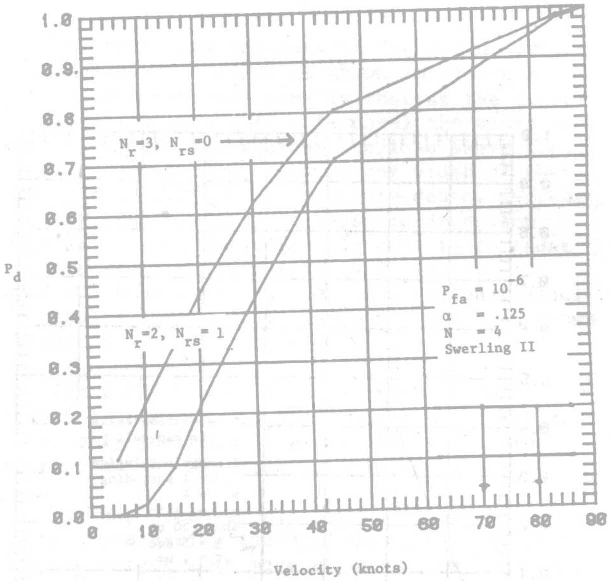

Figure 13: Velocity Responses which Satisfy the Hypothetical Design Criteria

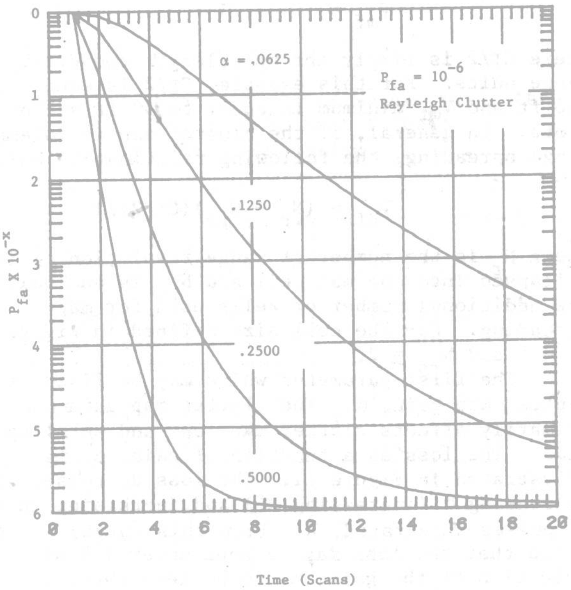

Figure 12: Map Settling Time as a Function of Clutter Map Gain, α.

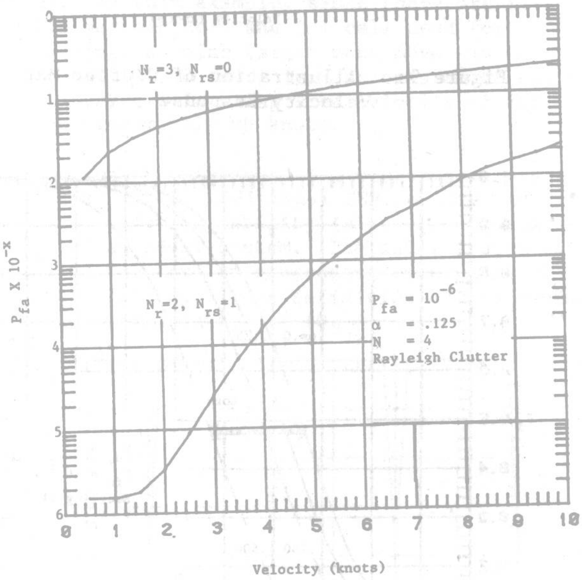

Figure 14: Velocity Responses: An Expanded View

Assuming $N_r > N_{rs}$, the velocity response for the combinations (N_r = 3, N_{rs} = 0 and N_r = 2, N_{rs} = 1) is indicated in Figure 13. Note that the two curves are very similar with a maximum 10 knot difference. As expected, both curves reach P_d = 1.0 at 90 knots and therefore the selection of either curve from this standpoint is not critical.

However, as illustrated in Figure 14, upon expanding the region between 0 and 10 knots, large differences become apparent for low velocity point clutter. At zero relative velocity, both curves converge to the design P_{fa} of 10^{-6}. However, at 2 knots, there is four orders of magnitude difference between the two cases. The choice now clearly depends on the application. For example, with a land based radar, the case N_r = 3, N_{rs} = 0 might be selected since on first considerations, there should be no apparent velocity between the land clutter and radar. However, due to system instabilities, multipath and changes in the atmospheric index of refraction, even land clutter spike's may have small but zero meaned positional shifts. Such shifts will cause the land clutter spikes close to the edge of a clutter map cell to oscillate between map cells causing an increase in false alarm rate. Therefore, even for land based radars, a minimum spread of ± one cell is always recommended

This problem is even more critical in a shipboard radar environment. The received signals must now be compensated for ship's motion since even a 10 knot relative velocity will raise the steady state P_{fa} to about 10^{-1}. In this case, it is clear that the solution, $N_r = 2$, $N_{rs} = 1$, provides better protection against ship's velocity compensation errors. In addition, there is one source of error that cannot be compensated for using the ship's gyro. This is the velocity component of the sea relative to fixed land clutter. Therefore, even if ship's motion compensation is perfect, there will be a residual 2-3 knot apparent velocity which cannot be removed. Again these issues require the selection of $N_r = 2$, $N_{rs} = 1$ in this case.

The final issue is the selection of cell size in bearing. However, because the cross-range dimension is generally much larger than the range dimension, a selection of one bearing cell per map cell, $N_b = 1$, and minimum spreading, $N_{bs} = 1$, is typically a good choice since this combination minimizes the Map Free velocity in bearing and provides some protection against velocity compensation errors. The resulting initial design for this hypothetical radar is summarized in Table 2.

TABLE 2 A Hypothetical Design

Clutter Map Gain, α	$.125 = 2^{-3}$
# Of Range Cells Per Map Cell, N_r	2
# Of Range Cells Spread, N_{rs}	±1
# Of Bearing Cells Per Map Cell, N_b	1
# Of Bearing Cells Spread, N_{bs}	±1

SUMMARY

In the paper, it was noted that the amplitude clutter map was an ideal CFAR processing technique for temporally stationary but spatially nonhomogeneous clutter such as land. The basic concepts used in amplitude clutter map processing were discussed and a method for analyzing the performance when interfaced with specific radars was presented. A hypothetical radar was then postulated in order to illustrate a design procedure which may be used to determine concept feasibility and an initial clutter map design.

REFERENCE

1. V. Gregers Hansen, "Constant False Alarm Rate Processing in Search Radars," IEE Radar Proceedings, London, October 1973.