FACTORS DETERMINING THE PROBABILITY OF RADAR DETECTION

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INTRODUCTION

During World War II a large percentage of the effort of the Nation's physicists and engineers was expended on radar development. Soon after the war ended the results of this effort were incorporated into text books and many articles were published covering radar basic principles and techniques (11, p. 528-578). For a civilian application the value of search radar as a transportation safety device has been firmly established. Both civilian and military increased requirements have caused the development of higher power transmitting tubes and better quality associated components. These better components along with advanced circuitry techniques have greatly contributed to reduced radar weight and increased performance potential.

Search radar is designed to determine the existence and location of an object by the observation of reflected radio energy. An area of interest is scanned by the search antenna in such a manner that the complete area is repeatedly illuminated by radio frequency pulses. The reflected energy is converted in the radar receiving equipment to a visual presentation. The existence and space position of an object of interest is usually identified and utilized by an operator viewing the presented information. The target angular position is established by the antenna position at the instant the target reflected energy is received and presented to the operator. This requires that the visual presentation be harmonized with the center line of the antenna pattern. The range to the target is displayed to the operator as a distance proportional to the transit time of the pulse energy to and from the target. The space position of the target is usually presented on one or more two dimensional cathode-ray-tube presentations. Several presentation combinations of target azimuth, elevation, and range are possible, and the type selected usually depends upon the presentation most suited to the subsequent use of the detection information.

As is true with all equipment, it is necessary to have a performance criterion which will permit both the designers and the users to direct their efforts toward optimum equipment. For search radar the maximum range capability of a given design has been for some time the criterion for measuring and specifying performance. Thus, considerable effort has been expended on the development of precise values for the factors influencing the maximum radar range and both electronic circuitry and hardware are optimized with the primary objective of obtaining this maximum radar range. (5, p. 857-861). As recently as 1956 an article was published which included further refinements to the radar range equation parameters and is a good review of the achievements on radar detection theory up to the present time. (6, p. 224-231). In applying this maximum range criterion to the design of a new search radar, the range equation variables derived from test values on existing equipment are modified by the contemplated new search conditions and hardware. From these computations the maximum range specification of the new equipment is established. When a prototype radar system has been built, the absolute maximum range is measured for comparison with the equipment specification. Generally, this prototype search radar meets the specified maximum range value. But, unfortunately, when the same radar is subjected to realistic use some targets are not detected until it is too late and a few targets are not detected at all. Experience indicates that designing for maximum range is not the criterion for optimizing search radar.

It is the intent of this paper to develop a more suitable criterion for designing and evaluating search radar. The text is presented in the following general outline:

Part 1. A Summary and Interpretation of the Conventional Criterion for Rating Search Radar. The standard radar range equation is presented and calculations are made to predict the maximum range of a sample radar. The maximum range of this same sample radar was measured and an interpretation is drawn on the resulting correlation of the calculated and measured values.

Part 2. Equipment Operational Effectiveness, the True Measure of Equipment Value. The effectiveness concept of analyzing search radar is introduced in this section. The necessity for giving equal consideration to both effectiveness factors, reliability and performance, in the design and evaluation of a search radar is pointed out. Search radar performance is defined in this section as the percentage of targets detected at a specified range.

Part 3. The Development of a Comprehensive Criterion for Rating Search Radar Performance. The factors determining the probability of radar detection are discussed. A cumulative probability of detection equation is developed which includes both radar maximum range parameters and operator visual factors.

It is believed that, if the proposed criterion is applied, a contribution to the development of higher effectiveness search radar will have been made.

PART 1

CONVENTIONAL CRITERION FOR RATING SEARCH RADAR

The Maximum Radar Range has for some time been the accepted criterion for specifying, designing, and measuring the performance of search radars. Considerable emphasis has been placed on the refinements in establishing precise values for the variables of the "radar range equation." (10, p. 1-7) Some question exists as to the exact meaning of the "maximum radar range"; therefore, the radar range equation will be presented and available search radar test data will be applied to the variables of the equation to clarify the equation meaning.

Radar Range Equation. The maximum range of a radar set is established when the target is at such a range that the pulse energy after propagation to and from the target is of sufficient amplitude to produce a luminescent spot which is barely detectable on a cathode-ray-tube screen. To compute a value for the maximum range, it is necessary to determine, 1) the pulse energy leaving the radar transmitting antenna, 2) the attenuation of the energy traveling to the target, 3) the fractional part of the energy reflecting from the target in the direction of the radar receiving antenna, 4) the attenuation of the energy on the return trip, 5) the amount of this energy picked up by the radar receiving antenna, and finally, 6) for comparison with the pulse energy available at the receiver terminals, the external and internal noise energy at the receiver terminals.[1]

The radar range equation is: (10, p.4)

$$R_{MAX}^4 = \frac{P_T G_o^2 \lambda^2 \sigma}{(4\pi)^3 P_{R_{MIN}}} \text{ meters}^4 \qquad (1)$$

where: R_{MAX} = the maximum radar range in meters.

P_T = the transmitter peak power in watts.

G_o = the receiving or transmitting antenna gain over an isotropic radiator.

λ = the radiation wavelength in meters.

σ = the effective back scattering area of the target in square meters. (assuming an isotropic radiator)

$P_{R_{MIN}}$ = the minimum signal power discernible in noise (available power in receiver input for an antenna matched to the receiver) in watts.

The minimum available power required for detection of received pulses may be written as:

$$P_{R_{MIN}} = \overline{NF}KTBV \qquad (2)$$

(1) Not all internal noise is introduced at the receiver input terminals, however, it may be considered to be.

where: $\overline{NF}$ = the noise figure of the receiver, numeric.

K = Boltzmann's constant (1.36×10^{-23} joules/degree Kelvin).

T = the ambient temperature in degrees Kelvin.

B = the effective bandwidth of the receiver in cycles per second.

V = the pulse visibility factor (the ratio by which available signal power must exceed average noise power for a detectable signal).

Combining equations 1 and 2 gives this expression for R_{MAX}:

$$R_{MAX}^4 = \frac{P_T G_o^2 \lambda^2 \sigma}{(4\pi)^3 \overline{NF} KTBV} \text{ meters}^4 \qquad (3)$$

Using equation 3, it is possible to compute a number for the "maximum range" of a given radar if a value is known for each variable of the equation. It should be pointed out here that for a given radar each variable is time dependent. The target size is always in question due to scintillation. (1) The equipment peak power, frequency, and receiver gain change with time. Because of these effects the computed range of equation 3 is defined as the average maximum range or that range which represents a 50 per cent probability of detection.

(1) Chance "mirror" reflection of target.

To demonstrate the use of equation 3, a search radar was selected for which considerable test data are available. The specification values for this radar are:

TEST RADAR VALUES

Transmitting Peak Power (P_T)	= 85 KW
Antenna Gain (G_o) measured	= 850
Wavelength (λ)	= 3.245 cm
Pulse Length (τ)	= 0.5 microsecond
Receiver Noise Figure ($\overline{NF}$)	= 12.6
IF Bandwidth (B)	= 3.5 mc
Pulse Repetition Freq. (PRF)	= 2,000 PPS
Target Size (σ)	= 1 meter^2
Pulse Visibility Factor (V)	= 18.2 (1)
Ambient Temperature (T)	= 292 degrees Kelvin

Solving the radar equation:

$$R_{MAX}^4 = \frac{P_T G_o^2 \lambda^2 \sigma}{(4\pi)^3 \overline{NF}KTBV} \text{ meters}^4$$

(1) This value for the pulse visibility factor was derived from the curves shown in reference (5, p. 226-227). The received signal power must be 12.6 decibels above the root mean square noise for a 50 per cent probability of detection.

$$R_{MAX}^4 = \frac{(8.5 \times 10^4)(8.5 \times 10^2)^2(3.245 \times 10^{-2})^2(1.0)}{(2.0 \times 10^3)(12.6)\ (1.37 \times 10^{-23})(292)(3.5 \times 10^6)(18.2)} \text{ meters}^4$$

$$R_{MAX} = 10.03 \times 10^3 \text{ meters or } 11.0 \times 10^3 \text{ yards}$$

For this sample radar the "maximum range" or the range at which 50 per cent of the targets will be detected is 11,000 yards.

To check this computed value, the "maximum range" of this same sample radar was measured in the following manner:

1. A target (approximate size, 1 meter^2) was positioned well within the range capability of the radar.
2. After the operator identified the target, using a "B" presentation, (1) the target range increased.
3. The operator concentrated on the target pip and reported the range of the target and instant the target was lost in the background noise.

These tests were repeated many times to establish a satisfactory degree of confidence in the test data. A histogram of the frequency of target loss for each range interval is shown in Figure 1. Normally, the target originates at a long range and closes toward the search radar, therefore, it is desirable to recompute and plot

(1) A "B" type presentation is a two dimensional intensity modulated presentation, with target azimuth as the ordinate and target range as the abscissa.

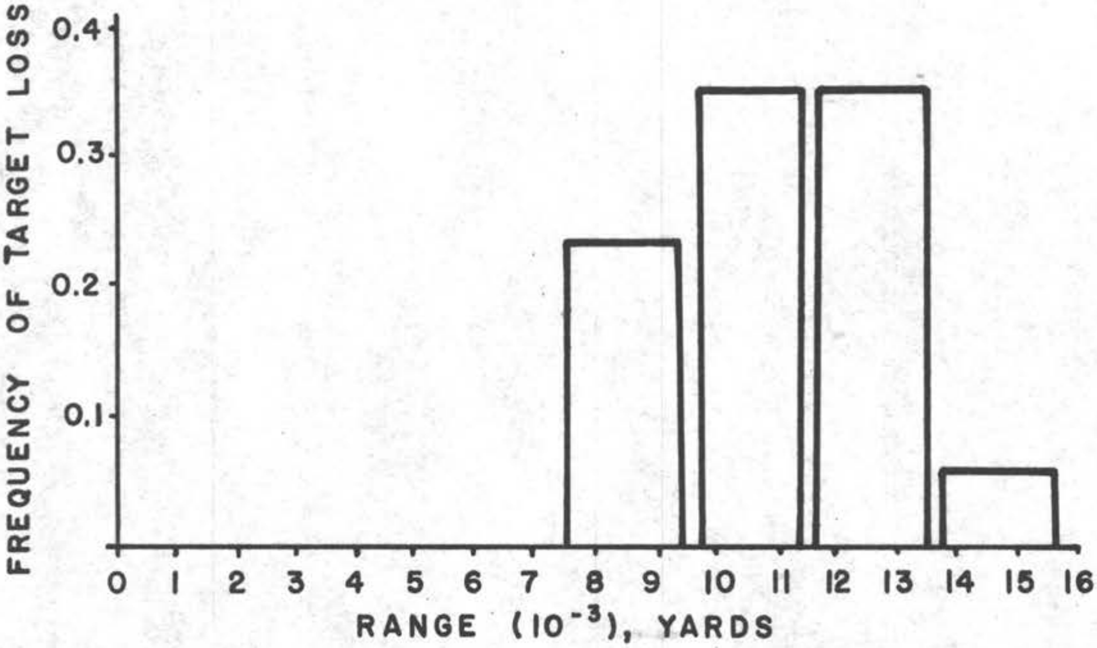

FIGURE 1 HISTOGRAM OF TARGET LOSS FREQUENCY WITH RESPECT TO RANGE.

the data as the percentage of targets detected at a given range. This was done by integrating the distribution of Figure 1 from 15,000 yards to zero yards. The results are shown in Figure 2, and indicate that the "maximum radar range" or the range at which 50 per cent of the targets could be detected is 11,700 yards. This compares closely with the range of 11,000 yards computed from the range equation. It is, therefore, assumed that by using the radar range equation and applying published values for the pulse visibility factor a "maximum range" value which represents the 50 per cent probability of detecting a target will result <u>if the operator at all times knows and is concentrating on the precise position of the target signal on an intensity modulated presentation</u>.

Realistically, the purpose of a search radar is to detect a target's approach with the operator being unaware of not only the azimuth or elevation position of the target but also unaware of the very existence of the target. Thus the operator must continuously scan the cathode-ray-tube screen and make decisions as to which presented spots are noise and which spots are possible targets. It is, therefore, reasonable to expect that a realistic probability of detection versus range curve will be lower than that of Figure 2 due to significant factors, such as, screen size, target closing rate, antenna beam width, screen viewing distance, ambient light conditions, search frame time, and others.

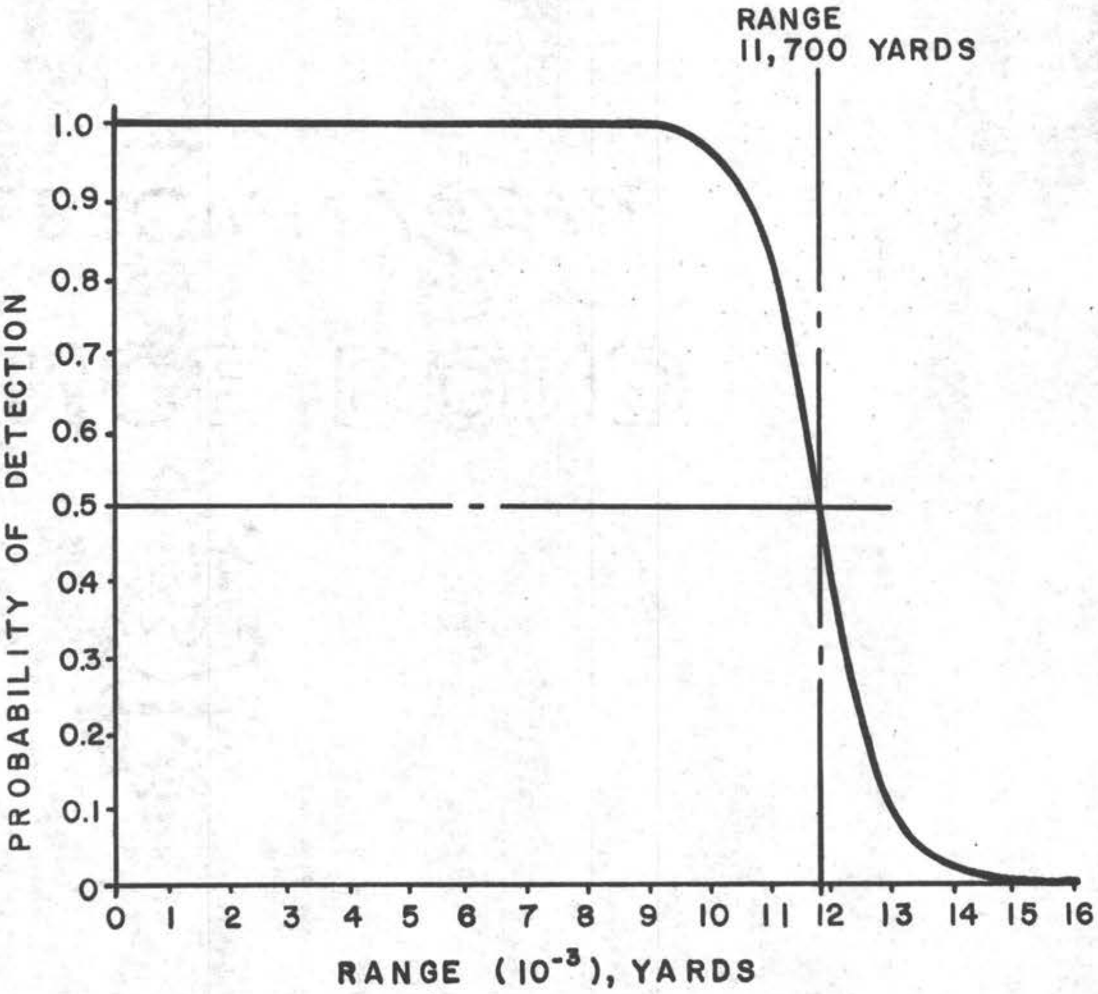

FIGURE 2 PROBABILITY OF DETECTION WITH RESPECT TO RANGE.

The present criterion of designing and rating search radar by maximizing the equipment range capability cannot produce an optimum radar, because other factors which have serious effects on the radar detection capability are ignored. A better criterion is therefore necessary.

PART 2

EQUIPMENT OPERATIONAL EFFECTIVENESS, THE TRUE MEASURE OF EQUIPMENT VALUE

All equipment should be designed and evaluated in terms of operational effectiveness. Operational effectiveness is an expression of the ultimate value of the equipment to the user and includes all factors which contribute to or detract from the accomplishment of the intended equipment purpose (7, p. 75-83) Equipment operational effectiveness is defined and measured in terms of the probability that the equipment will perform its intended purpose.

A value for equipment operational effectiveness is determined by combining two quantities. These are:

1. Equipment Reliability (P_R) or the probability that equipment will be operable when required, and,
2. Equipment Performance (P_P) or the probability that equipment will perform its intended purpose, assuming it has not failed.

From probability theory the general equation for the equipment operational effectiveness is:

$$P_E = (P_R)\,(P_P) \qquad (4)$$

This equation shows that both effectiveness factors, reliability and performance, are of equal importance and in the design and evaluation of equipment, both factors should be allocated equal consideration. Both factors are controlled by the inherent nature of the equipment design.

The reliability of equipment is dependent upon the failure rate of each individual part, the number of parts, the failure rate distribution of each part, and the amount of designed-in redundancy. The field of reliability engineering and the procedures for obtaining equipment with high reliability are presently receiving considerable emphasis, industry wide. (4, p. 23-29) (2, p. 1-46) (8, p. 1-40)

The performance of a system is directly dependent upon the purpose of the equipment. The parameters contributing to equipment performance can be established if the equipment purpose is defined properly.

Airborne Search Radar Purpose. Search radar was initially developed for military use in searching for enemy targets, and is becoming increasingly important in civilian use as an anti-collision device for transport airplanes. In all cases, the purpose of search radar is to detect an object at a sufficient range to permit the initiation of either defensive action, offensive action, or maneuver to avoid a collision. From the foregoing effectiveness discussion and the definition of search radar purpose, it is evident that a search radar with high operational effectiveness would have simultaneous high reliability and a high performance (detection capability at a given required range).

Although it is not intended that reliability be slighted, since a nonoperable high performance radar is useless, this paper will be limited to a discussion of radar performance.

<u>Search Radar Performance</u>. To make detection possible, certain physical requirements must be met. For example, the "target" (1) must be within the maximum range limits before a signal will be presented to the operator. Even when the physical requirements make detection possible, immediate detection on every try will not occur. The process of detection is statistical in nature and not absolute. Therefore, search radar performance should be expressed in terms of "probability of detection". (2) To illustrate this effect when a target is very faint, the probability of detection

(1) The meaning of "target" as used in this paper is any object, pattern, or marking which human beings are expected to detect or identify visually. Other terms which are frequently used by radar operators and radar engineers to refer to signals, are radar echo, image blip, and pip.

(2) "Probability of detection" should be qualified whenever used because the absolute value will vary considerably with conditions of equipment use. It is intended here that the operator be unaware of the position or time the target will appear on the screen. This could be called surprise probability of detection.

approaches zero. As the target range is decreased the presented signal increases the time allotted for observation increases and the probability of detection increases, but may not reach unity. Experience in everyday life shows that we may be looking for an object in plain sight and yet sometimes fail to find it. The human span of perception is limited. (12, p. 901-905)

To summarize, search radar usage is probabilistic and the best criterion for design and evaluation of a search radar is that criterion which will permit maximization of the probability of detection at the required range, the operator being unaware of the initial position and existence of the target.

PART 3

RECOMMENDED CRITERION FOR RATING SEARCH RADAR

Regardless of the specific application of a particular search radar, it should be designed to provide a maximum probability of detecting a target before it reaches the required detection range. For example, the forward surveillance radar on a transport airplane is of no value to the pilot unless he is warned of an approaching airplane in time to maneuver the airplane in such a manner as to avoid a collision. The minimum safe detection range is established by the closing rate of the two airplanes and the combined pilot reaction time and airplane aerodynamic maneuver capabilities. It goes without saying that a high percentage of detections at this range is mandatory.

To design a radar which will provide a high percentage of detections, when required, it is necessary that an equation be developed which gives the dependancy of all important parameters on the percentage of detection versus range. This equation should include all controllable and uncontrollable parameters. The controllable parameters are those characteristics of a radar system which are subject to modification by the equipment designer. Such as:

1. Search frame time.

2. Apparent [1] target rate.

3. Apparent [1] target size.

4. Apparent clutter and noise [2].

5. Cathode-ray-tube ambient lighting.

6. Presented target brilliance.

7. Maximum radar range.

Those parameters which are not controllable by the designer are:

1. Target size and reflection characteristics.

2. Target closing rate.

3. Weather.

4. Altitude.

5. Terrain conditions.

Before developing an equation which includes the above parameters, several terms must be defined which are indicative of the searching operation.

(1) Apparent is used to distinguish between true target rate and the cathode-ray-tube target rate, as modified by the selection of cathode-ray-tube size and associated sweep circuitry.

(2) Clutter and noise can be modified to a certain extent by selection of circuitry.

<u>Probability of Detection Per Frame</u> (P_{Di}) Looking at the detection problem from the operator's point-of-view, the target plus clutter and noise are presented repeatedly. The operator's success of detecting the target involves chance. Thus, for each presented frame there is a finite probability that the operator will detect a target, if a target is within the scanned area. The "probability of detection per frame" is defined as "the probability that the operator will detect a target in one search frame" (the operator being unaware of the time and position of the target).

<u>Cumulative Probability of Detection</u> ($P_{\overline{D}}$) The operator continuously observes the cathode-ray-tube screen and, hence, integrates the presented information over many successive frames. This integration process increases the probability that the operator will detect a target over that of the single frame case. The term "cumulative probability of detection" has been assigned to this integration process and is defined as "the probability that a target will be detected in a given number of frames". <u>When a value is established for the cumulative probability of detection, a true measure of search radar performance is then available.</u>

From probability theory, the general equation for the cumulative probability of detection is:

$$P_{\overline{XD}} = \prod_{i=1}^{n} (P_{XD_i}) \qquad (5)$$

A more usable form of equation 5 may be obtained by taking the log of both sides:

$$\text{Log } P_{\overline{XD}} = \sum_{i=1}^{n} \text{Log } P_{XD_i} \qquad (6)$$

where:

$P_{\overline{XD}}$ = the cumulative probability of not detecting the target in "n" frames (controllable by design).

P_{XD_i} = the probability of not detecting the target in the i^{th} frame (controllable by design).

n = the number of presented frames (controllable by design).

however;

$$P_{XD_i} = 1 - P_{D_i} \qquad (7)$$

and

$$P_{\overline{XD}} = 1 - P_{\overline{D}} \qquad (8)$$

Therefore:

$$\text{Log } (1 - P_{\overline{D}}) = \sum_{i=1}^{n} \text{Log } (1 - P_{D_i}) \qquad (9)$$

The cumulative probability of detection can be determined if the <u>probability of detection per frame</u> (P_{D_i}) and the <u>number of presented frames</u> (n) are known.

Number of Presented Frames. The procedure for establishing the number of presented frames is indicated by a review of the process of detection. The search antenna continuously scans at a constant frame rate. The target originated beyond the maximum range capability of the radar. For this condition, the reflected signal is lost in the presented clutter and noise and the probability of detection for a single frame is zero. When the target arrives at the maximum range of the radar, the probability of detection becomes finite. The number of frames presented to the operator over a given range interval for which the probability of detection is finite, is:

$$n = \frac{R_D - R_{MAX}}{\dot{R}\ F} \qquad (10)$$

where: R_{MAX} = the maximum range of a discernible target if the operator fixation is on the target, in yards. The standard range equation and procedures shown in Part I are applicable for determining this value (controllable by design).

R_D = the range for which the target is to be detected, yards.

$\dot{R}$ = the target range rate, in yards per second. (Noncontrollable by design.)

F = the search frame time, in seconds per frame. This value is established by the required search azimuth and elevation area, the antenna beam width and the antenna mechanical speed limitations. Considerable flexibility is possible in choosing a search frame time for a given required search area since continuous rotation multi-antenna configurations are possible.

A general equation which is independent of any specific radar can be obtained by normalizing the range factor of equation 9.

Let $$x = \frac{R_D}{R_{MAX}} \qquad (11)$$

and combining equations 9 and 11 gives:

$$n = \frac{\dot{x} - 1}{\dot{x}\, F} \qquad (12)$$

Combining equations 8 and 12:

$$\log\,(1 - P_{\overline{D}}) = \sum_{i=1}^{\frac{x-1}{\dot{x}\,F}} \log\,(1 - P_{D_i}) \qquad (13)$$

Equation 13 indicates that the number of presented frames by a given range can be increased either by increasing the maximum range capability of the radar, or by reducing the search frame time. It would appear at first that optimizing a radar design to maximize the number of presented frames would improve a given design considerably. This approach, however, would require the assumption that the probability of detection per frame is constant and independent of target range, target closing rate, and frame time. Both theory and experimental evidence indicates that this assumption is not valid. The probability of detection per frame varies considerably, and before optimum design trade-offs can be made, the interdependance of several display variables, affecting the probability of detection per frame, must be established.

Probability of Detection Per Frame. By again considering the problem from the operator's point-of-view, an insight to those visual factors which affect target detection can be obtained. If a single bright target were presented on a "clean" screen to a reasonably diligent operator the probability of detection per frame would approach unity. This "clean" screen condition is unfortunately not typical of the condition in present radar equipment. Considerable "radar noise" is presented simultaneously with the target signal. This has the effect of increasing operator confusion and reduces the probability of detection per scan over that of a clean screen.

Radar Noise. The term radar noise is defined as "any extraneous luminescent spots tending to interfere with proper and easy perception of those targets which it is desired to detect", (1, p. 541). It is convenient to classify radar noise as to its origin and characteristics as presented on the cathode-ray-tube screen.

If the radar transmitter is turned off the following internally and externally generated noise will appear on the cathode-ray-tube screen:

1. Antenna Noise. External noise picked up by the antenna and thermo noise generated within the antenna are referred to as "antenna noise". For microwave frequencies this type of noise is largely thermal in origin. (9, p. 103)

2. Converter Noise. Internal noise is generated in the converter. In the microwave region a crystal diode mixer is most always universally used. Crystal noise results from two sources: 1) thermal noise of the semiconductor resistance, and 2) "fluctuation" noise caused by motion of charges on the contact surface. (9, p. 108-111)

3. Local-Oscillator Noise . In the conventional oscillator, noise is generated principally because of shot and partition noise in the anode circuit. (9, p. 112)

4. Intermediate-Frequency Noise. Internal noise also originates in the intermediate-frequency amplifier particularly in the first stage. The fundamental sources of this noise are: 1) thermal noise in circuit elements (such as transformer losses, tube glass losses, etc.), 2) shot noise in the anode, and 3) induced grid noise. (9, p. 116)

5. Environmental Noise . One other source of noise is generated in other equipments in close proximity to the radar set. For example, in an airplane installation, transients are coupled through the common power supply system or intercabling, and result in a noise presentation on the cathode-ray-tube screen.

All of the above type noise sources have an apparent random nature when observed on the cathode-ray-tube screen, since they will appear either with or without transmitter operation. The effects of the above noise energy can be reduced by circuit ingenuity if the source of noise does not cause it to appear initially on the same two terminals as the input signal. It is important that the design of circuitry and intercabling be consistent with communication design standards for noise reduction. (1, p. 540-577) If the signal and noise are introduced at the same two terminals, better construction, or lower component temperature, will produce some improvement.

If the transmitter is turned on the following externally generated noise will appear on the cathode-ray-tube screen: Clutter. The term clutter is used to signify reflected energy from nonoperationally significant objects and includes:

1. Primary ground return,
2. Second trip around ground return,
3. Cloud return, and
4. Side lobe return.

Clutter signals are generated by stationary and moving objects in much the same manner as an aircraft type target. The reflected pulse energy presented on the screen will be time correlated, thus, specific clutter configurations are uniform for a number of search frames. Since clutter signals are similar to aircraft signals and since the return power from clutter is large with respect to the target signal power, the probability of detection per frame is seriously affected by this type of noise. Moving-target-indication, or MTI, systems have been developed to discriminate between clutter and target signals. However, these circuits add weight, cost and complexity to the radar and are difficult to apply to nonstationary search radar equipment. The application of discriminating circuitry which has the effect of clutter reduction based upon the characteristic difference between the desired target signal and clutter signal can significantly improve search radar effectiveness. However, until usable circuitry of this type becomes available, the operator must continue to perform this discriminating function.

If the presented target signal contained no distinguishing characteristics, operator detection would be obtained by chance only. The probability of detection per frame for a single target would then be:

$$P_D = \frac{1}{N + 1} \tag{14}$$

where N = the total number of presented noise spots in one search frame.

On a typical search radar with a two second frame time, the number of noise spots (N) may be as high as 2,000. Thus, the probability of detection per frame is approximately 0.0005. By applying this constant value to equation 13 a cumulative probability of detection of 0.90 would require an average of 3,800 frames or 2.1 hours of observation.

Fortunately, the targets of interest will have characteristics which improve detectability over that of chance. To take advantage of these distinguishing characteristics an equation is required for the probability of detection per frame, which includes operator visual factors. (3, p. 31)

Design Factors that Affect Visibility. The following visual factors are believed to be the primary controlling parameters influencing the probability of detection per frame:

1. Target Motion. A search radar converts target real movement into target apparent movement, the radar set movement being a reference.

   Real movement is defined as "a stimulus that moves through a distance S at a rate $\frac{ds}{dt}$. (12, p. 895)

   Apparent movement is established under the following conditions. "A given stimulus (a dot, a line, an illuminated area, etc.) is presented to the subject for a duration extending from a few milliseconds up to about 400 milliseconds. Then a second stimulus, similar to or different from the first, follows after a pause and in a new location". Apparent movement is created. (12, p. 898) The designer has control over the apparent target motion, by selection of the cathode-ray-tube screen size, the associated circuit sweep rates, the search frame time and the recommended operator viewing distance. Sufficient test data are not available to show the absolute relation between apparent target motion and probability of detection per scan. However, sufficient data are available which indicate that the relationship is approximately that which is shown in Figure 3.

2. Target Size. The target radar cross sectional area is usually much smaller than the antenna beam width. However, the target apparent area presented on the cathode-ray-tube screen varies considerably with the antenna gain pattern, the cathode-ray-tube size, the antenna scan rate, the cathode-ray-tube bias setting, the range of the target and the operator viewing distance.

   To illustrate this effect, Figure 4 shows the variation of target apparent size as a function of relative range. The following radar characteristics were assumed:

   1) a 15 inch paraboloid antenna,
   2) 3,750 degree per second antenna sweep rate,
   3) 11,000 yard maximum range,
   4) a 3 inch cathode-ray-tube "B" presentation with an azimuth gradient of 62.6 degrees per inch,
   5) a 15 inch operator viewing distance, and
   6) a pulse repetition rate of 2,000 PPS.

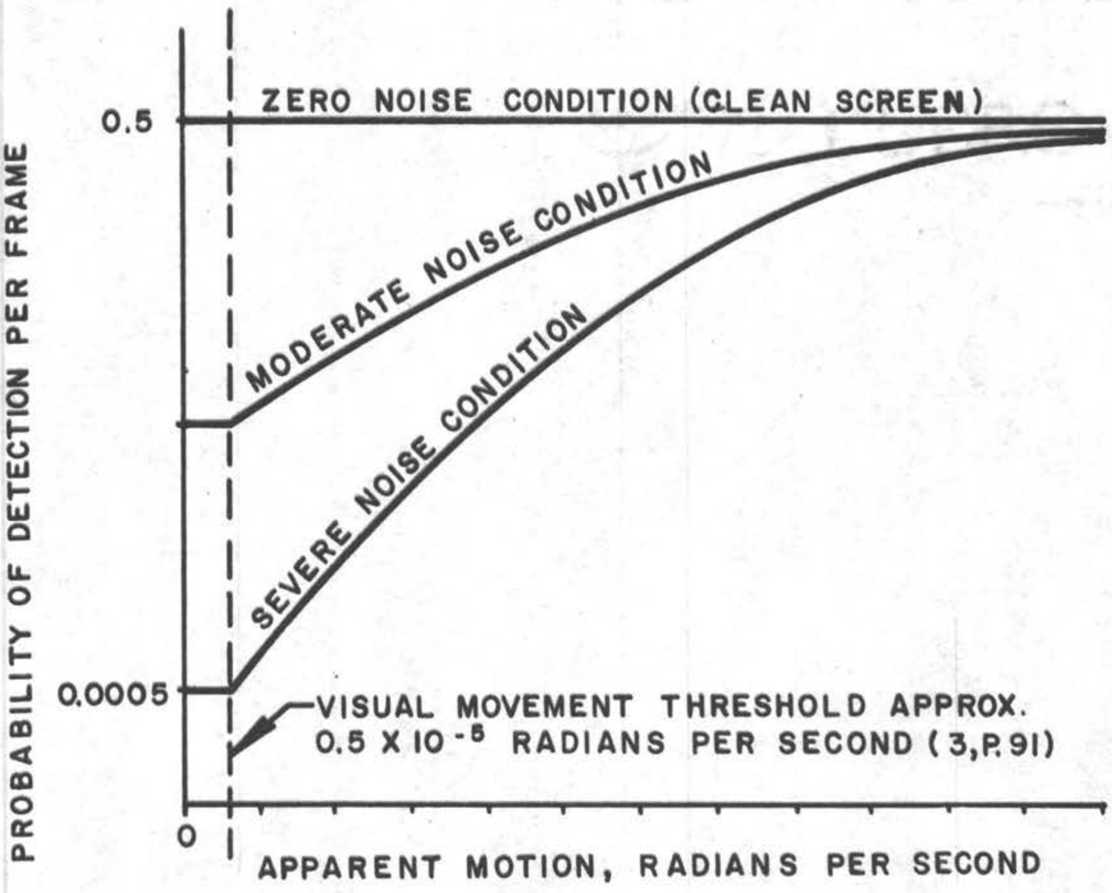

FIGURE 3 APPARENT MOTION EFFECT ON THE PROBABILITY OF DETECTION PER FRAME.

The apparent target width on the cathode-ray-tube screen is made up of a series of discrete pulses. To show this, the target width of Figure 4 is plotted as pulses.

The radar designer has control of the apparent target width. Therefore, the effects of apparent target width on the probability of detection per frame should be included in equation 13.

3. Target Intensity. As the antenna sweeps across the target, the signal intensity varies with the antenna gain pattern. If the return signal were not modified by automatic gain control circuitry, the presented spot brightness would increase with decreased target range. This effect can also be shown in Figure 4. As the target decreases in range and the increased signal voltage produced screen luminescence above the visual brightness threshold, more spots are presented producing an apparent increase in target width. The brightness of the center of the target will be limited by the saturation of the receiver. If automatic gain control or noise limiting circuits are included in the receiver, that design choice should be made which will produce the highest probability of detection.

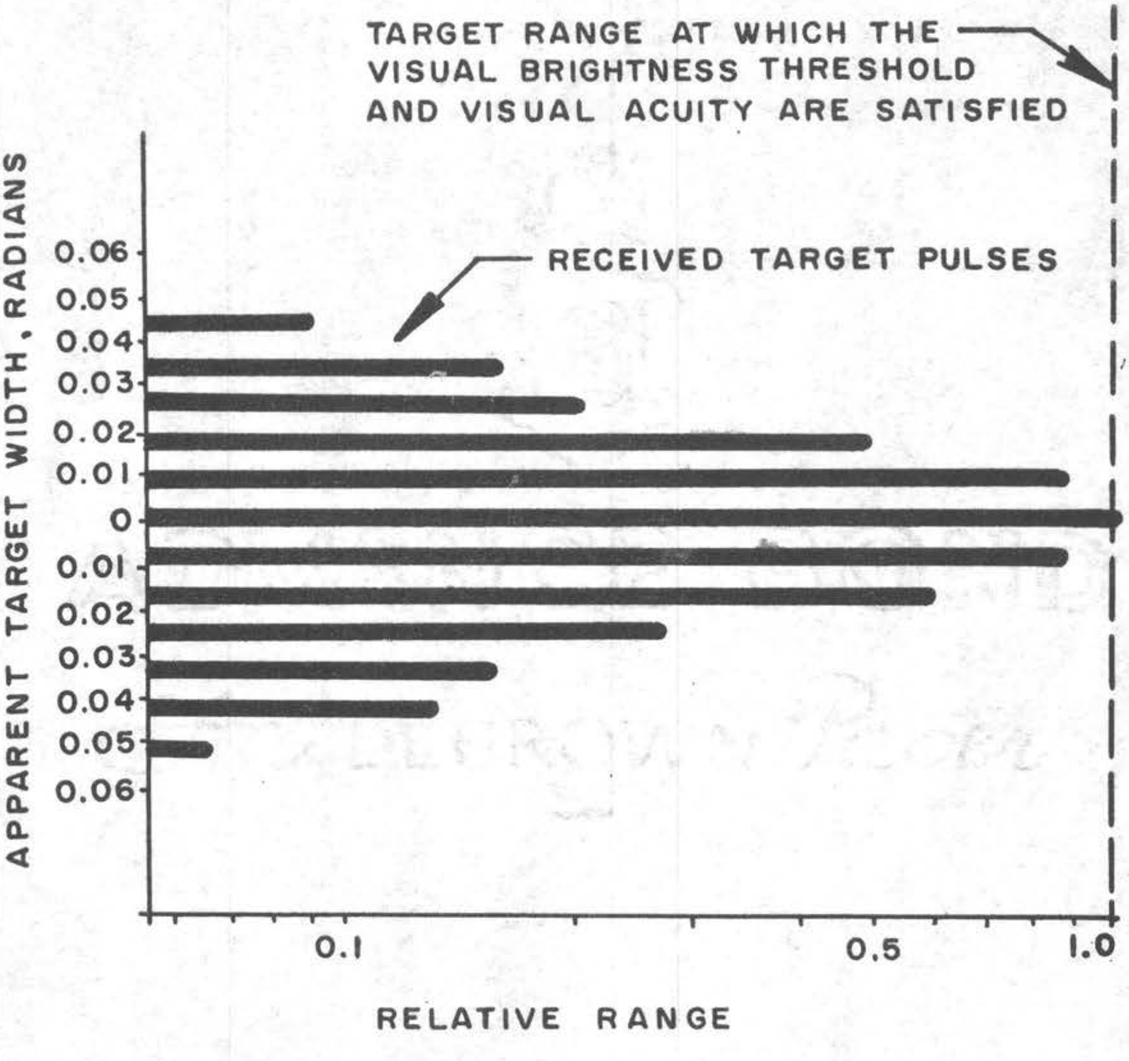

FIGURE 4 APPARENT TARGET WIDTH WITH RESPECT TO RELATIVE RANGE.

Circuitry can discriminate between random noise and a target signal. However, the operator may be able to discriminate between clutter noise and the target and obtain a higher probability of detection per frame than possible by circuitry.

4. Cathode-Ray-Tube Screen Ambient Lighting. The effects of ambient lighting levels on the cathode-ray-tube screen on the probability of detecting per frame should be investigated and included in equation 13.

Recommended Test to Establish Target Detectability. The process of detection is a stochastic process, that is, any process running along in time and controlled by probabilistic laws. A numerical observation, made as the detection process is performed, would indicate its evolution.

A test is being conducted under the direction of the author to determine the probability of detection per frame as affected by the operator visual factors outlined herein. The test equipment has been designed to simulate as nearly as possible the true conditions of noise and target signals. The testing procedure will be conducted as follows:

1. The simulated target will originate beyond the maximum range capability of the radar.

2. The initial angular position of the target will be randomized.

3. The target will be caused to reduce its range at several specified rates.

4. The operator will report the range at which a detection is obtained. The test equipment will record the number of presented frames from the time the minimum discernible signal (range equivalent) is reached until the range detection is reported.

5. The test will be repeated for different conditions of clutter noise, ambient lighting, target apparent size and target apparent brilliance.

6. The human factor effects of operator fatigue and variation of operator visual sensitivity will be randomized for the initial testing.

7. All numerical values of the established visual factors will be converted to apparent values, thus making them independent of the specific test radar.

The data will be analyzed and an equation for the probability of detection per frame established. By applying the test values to equation 13 it will be possible to maximize the cumulative probability of detection for a specific radar by the selection of appropriate electronic hardwares.

It is contemplated that an existing airborne search radar will be modified and a realistic flight test performed to check the laboratory predicted improvement. Nonproprietary results can be made available upon request.

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