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REVIEW OF NRL ACTIVITY IN THE COMPUTATION OF COUNTERMEASURES PROBABILITY OF INTERCEPT

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ABSTRACT
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NRL has long recognized the desirability of being able to assess a quantitative measure of the effectiveness of a microwave intercept system. Such a measure is the probability of intercept.

Of the many approaches possible in this assessment, NRL has chosen to develop a system simulator which reproduces in scaled time in the video domain the significant parameters affecting probability of intercept, and which produces as its output the simulated record of intercept success. NRL has also developed an analyzer which calculates from the simulator output the probability of intercept as a function of waiting time for intercept. These two devices constitute the NRL Intercept Probability Computing System.

The system has been operating about three years and has been used to make comparisons of intercept receiver performances, evaluate operating doctrine, and predict advantages to be gained by receiver improvements. Current plans include continuation of doctrine studies and possible improvements in the computing hardware. This work has been proceeding on a continuous but low-priority basis. Guidance is desired from potential users of the information to be produced as to the direction of future studies.

A bibliography is included citing twelve basic references on the subject and reproducing the abstracts of nine of these.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem R06-07
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REVIEW OF NRL ACTIVITY IN THE COMPUTATION OF COUNTERMEASURES PROBABILITY OF INTERCEPT

INTRODUCTION

It is clearly desirable to be able to express quantitatively the performance capability of a microwave intercept system. Such a measure is denoted by the term "probability of intercept." There are two general methods of determining the probability of intercept (hereafter symbolized by "P(t)"): simulation and field evaluation. Whereas field testing is an expensive and time-consuming process, and whereas P(t) is a statistical parameter requiring observations of many experiments for its estimation, simulation is the more desirable method of determing P(t), subject to certain limitations to be discussed later.

The Countermeasures Branch of the Radio Division, NRL, has produced in this area a considerable literature which may not be readily accessible. It is hoped that this brief report on NRL's philosophy of attack on the probability-of-intercept problem will prove useful. This brief review does not present detailed information, hence a number of references providing specific information are included (1-12), and the abstracts of the more important references are reproduced.

PROBABILITY OF INTERCEPT

Definition of P(t) (Stationary Case)

Hypothesizing an emitter, intercept system, and propagation path, and further assuming that the parameters of these components remain constant, P(t) may be defined as the probability that the intercept system first detects the emitter in time t or less after the creation of the conditions. The conditions might be created, for example, by a radar operator turning on his transmitter or by an intercept receiver operator changing bands so that his receiver covers the emitter frequency.

As a trivial example, consider a broad-band, untuned intercept receiver equipped with an omnidirectional antenna working against a radar transmitter equipped with a search antenna that makes one rotation in 20 seconds. Assume further that the transmitter power, receiver sensitivity, and propagation path are such that intercept is possible for one second out of every twenty. At the instant of creation of these conditions the orientation of the radar antenna relative to the intercept site is unknown, but there is a probability of one in twenty that the orientation is fortunate and that intercepts occur immediately. If intercepts do not occur immediately, the rate of growth of probability over the next nineteen seconds is linear, reaching unity at the end of nineteen seconds. Thus, for this case

$$P(t) = 1/20 + t/20 \qquad t \le 19$$

$$= 1 \qquad t > 19.$$

Additional examples are contained in Refs. 2 and 4.

[redacted]

Factors Affecting P(t)

It is now necessary to consider the factors affecting P(t) and which must be included in the simulation. These have already been divided into three general groups but will now be enumerated.

Emitter – Two general considerations determine the nature of the emitted signal: the modulation pattern and the field strength pattern.

In the case of a simple radar the modulation pattern is determined by a specification of pulse width and pulse repetition frequency and possibly of pulse shape. It is conceivable, however, that a more complex modulation pattern might be necessary to accurately simulate other signals such as those used in telemetry and guidance.

If the emitter is equipped with a stationary omnidirectional antenna, the field strength pattern is a constant, depending only on radiated power. In the more usual radar case, however, it is necessary to know the precise antenna pattern and the antenna rotation rate in addition to the radiated power.

Under certain types of simulation it may be necessary to simulate the emitter frequency. This point will be discussed later in the section on types of simulation.

Propagation Path – The modulated local emitter field having been determined, the field in the vicinity of the intercept receiver can be determined by simulating the effect of the propagation path. The factors to be considered here are the heights of the antennas of the emitter and receiver, the range between them, and possibly the state of the atmosphere and the nature of the intervening terrain.

Intercept System – There are numerous parameters associated with the intercept system that will affect P(t). These may be further subdivided into the antenna system, the tuning arrangement, and the detection system.

For the antenna, significant parameters are antenna pattern and antenna rotation rate. The term rotation rate applied to both the emitting and intercepting antennas is assumed to include the possibility of scan modes more complicated than simple rotation.

For the untuned intercept receiver, such as the crystal video system, the significant question is whether the signal is within the band of the receiver, although variations of sensitivity with frequency across this band might also be significant. For the scanning type of intercept receiver, significant factors are the frequency band scanned, the velocity and pattern of scanning, the scanning passband, and the location of the signal frequency relative to the scan band. For both types of receivers, continuity of tuning may be a factor. If, for example, a crystal video system has two frequency bands selected by a switch, and if the operator operates this switch every thirty seconds, a tuning factor is introduced.

The final factor is the detector. A single specification of sensitivity or threshold may be adequate here, but the threshold is more likely to be a function of the duration and distribution of the received signals and may even be probabilistically distributed, especially when a human operator is the decision element.

Computation of P(t)

There are two possible means of computing P(t) from the results of simulations. To distinguish them recall that P(t) is a probability function, because the phases at t = 0 are unknown and presumably randomly distributed. By "phases" are meant such quantities as the angles between the line from emitter to receiver and the direction of orientation of antennas and the position of a scanning passband relative to the signal frequency.

In the first method the initial phases are randomized, the simulation allowed to run, and the time of the first intercept noted. The whole process of randomization, running, and intercept recording is repeated many times. P(t) is then equal to the fraction of the runs in which the intercept occurred in time t or less.

In the second method no particular effort is made to randomize the initial phases, but the simulation is allowed to run through many intercepts. In this method P(t) is equal to the fraction of the experiment length occupied by time lengths t preceding the intercepts. Further discussion of this method may be found in Refs. 1 and 4.

Comparison of the two techniques favors the second for two reasons. First, it would be difficult to ensure adequate randomization in the first method. Second, the first method appears to require more data to give equally precise results.

Thus in the period 1951 to 1953 NRL conceived of a computer utilizing the second method for the computation of P(t). The analyzer section of the NRL Intercept Probability Computing System, constructed in 1954, is described in Ref. 4 and is pictured in Fig. 1.

Dynamic Case

Thus far the assumption has been made that the conditions that determine P(t) remain constant. This is a valid assumption for a stationary emitter and intercept system, but has to be re-examined where either or both are mobile. For these cases a dynamic P(t) must be determined, the calculation of which takes into account the relative motion of the two components. In this situation t = 0 represents some particular point on the relative orbit and any particular t can be translated into some relative position.

Because the NRL Probability Computing System employs a computational scheme depending on stationary statistics, it is necessary to analytically combine computer output information to obtain the dynamic P(t). Although the other computational philosophy would eliminate this necessity, its employment would require a simulation of a given orbit of closure. Our method is to compute the stationary P(t) as a function of range, and to combine these probabilities according to the orbit. Thus if a dynamic P(t) for a different orbit is required, it is not necessary to compute a new simulation.

When the closure rates are relatively low, this combination of the stationary probabilities is rather simple. In this quasistatic case, at any range it is only necessary to combine the integrated rate of accretion of P(t) with the probability that no intercepts have occurred at greater ranges, and add this combination to the total P(t) at greater ranges. For this method to be justifiable the closure rate must be such that the relative change in range is small during the time of the longest period of the cyclic simulation parameters such as antenna rotation period and frequency scan period. This requirement is almost always satisfied.

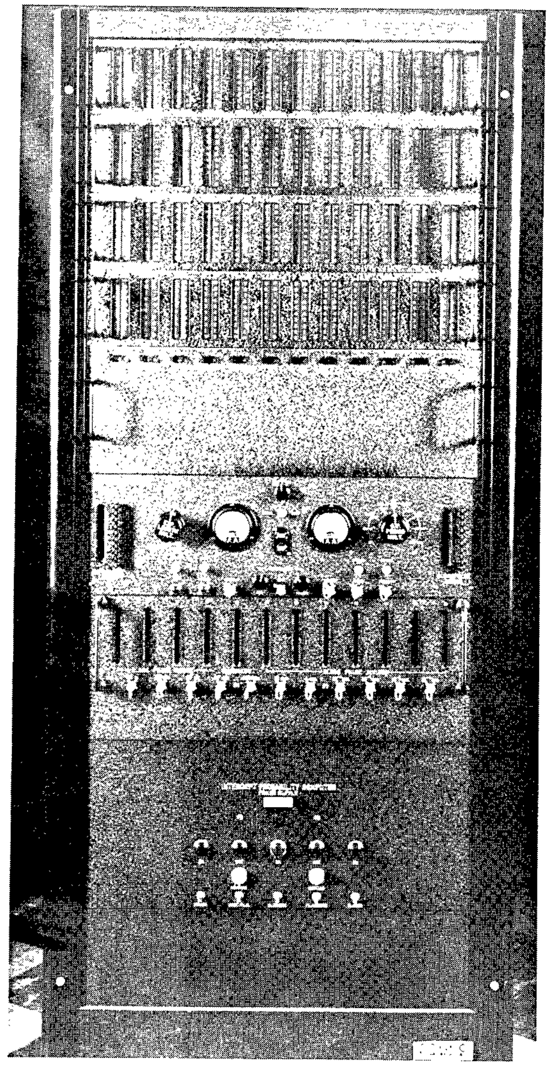

Fig. 1 - Intercept probability analyzer

Where the closure rates are very high, more complex analysis is necessary. Usually simplifying assumptions are available, but a general solution has not yet been obtained. Further work on this question is anticipated.

Utilization of P(t)

Three general types of questions that require P(t) information for their resolution are apparent. Undoubtedly others exist, and it is hoped that the readers of this report can find applications to their own work.

The first involves the choice of equipment for a given intercept mission or function. A typical question might be, "What combination of available intercept receivers and antennas will maximize the probability that a snorkeling submarine will detect the signal from

[redacted]

an airborne search radar before that radar detects the submarine?" Another question of the first type might be, "If the sensitivity of a given receiver could be increased a certain amount, how much more likelihood would there be of its detecting a bombing radar n seconds before the aircraft reached its bomb release point?"

The second involves doctrine, i.e., such questions as, "What is the best speed for a CVS to rotate its AN/SLR-2 antenna to maximize the probability of detection of hostile submarines assumed to be emitting signals of given characteristics?"

The third involves evaluation of mission results; for example, "A given ferret mission detected no signals of a given type from a given location. How likely would detection have been had the signals been present?"

SIMULATION

Types of Simulation

There are two general types of simulation which must be carefully distinguished. In the first type, the electromagnetic field is actually simulated and connected to the intercept system. This requires generation of the microwave signals representing the environment in which the intercept system is to function. In the second type, both the environment and the characteristics of the intercept system are simulated in the video domain.

The major advantage of direct microwave simulation is that it is not necessary to make separate measurements of individual parameters of the intercept system under evaluation; the system is connected to the simulator and its performance is noted. The major disadvantages of this scheme include the great expense of the microwave hardware necessary in the simulator and the limitation of the applicability of the technique to intercept systems that exist in hardware form.

Video simulation, on the other hand, is relatively inexpensive, and can be applied to hypothetical intercept systems whose parameters are defined as well as to existing systems whose parameters can be measured. This flexibility is particularly valuable in determining desirable changes in the parameters of existing systems. For example, determining the answer to "What would be the effect of doubling the frequency search speed of the AN/WLR-1 receiver at S-band?" would require building a new receiver if microwave simulation were employed but would only require turning one knob on the simulator if video simulation were employed. Similarly, the direct simulation tests one sample from the population of intercept receivers, while video simulation allows the investigation of the effect of normal variations in the parameters of a population of receivers.

Perhaps the most significant advantage of video over direct simulation, however, is the ability to conduct video simulation in scaled time while direct simulation is tied to the real-time characteristics of the intercept system. Thus direct simulation can take nearly as long as field evaluation, while video simulation can produce the same amount of information in about 1/100 the time.

For these reasons, NRL designed and constructed a video simulator. This device is described in Ref. 5 and pictured in Fig. 2. It has been operating since 1957.

Limitations of Simulation

There are a number of limitations that must be noted with respect to simulation in general, to video simulation, and to the NRL simulator.

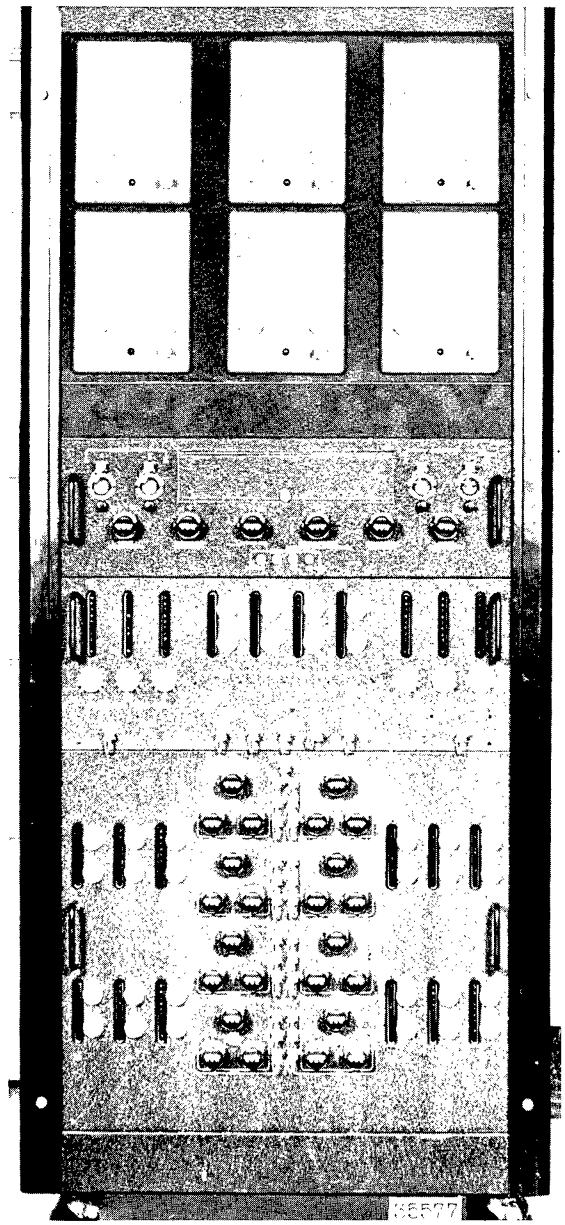

Fig. 2 - System simulator

All forms of simulation are somewhat idealized. They seldom take into account the usual deteriorations in intercept system performance that occurs between the laboratory model and the production unit under fleet maintenance. They usually select arbitrary values of environmental factors such as the transmitter antenna rotation rate. Equally probable values of such parameters, differing only slightly from the ones selected, may yield profoundly different results. Futhermore most simulations do not adequately take into account the variations between operators and evaluate the statistics of the performance of a few typical operators under somewhat unrealistic conditions.

Video simulation has additional limitations. Among the major limitations that may be mentioned are the necessity of developing statistics on operator performance, the use of timing waveforms to generate antenna patterns and frequency scanning patterns where the frequencies selected are somewhat arbitrary and may be unrealistically stable, and the difficulty in measuring not only the average values but more important the range of variations of the simulated parameters of the intercept system.

The NRL simulator as originally constructed possessed still more limitations. Chief among these were the ability to simulate only one transmitter at a time, the inability to introduce frequency instability in the timing waveforms, limitation to the static case, and limitations in the type of operator statistics that can be simulated. Some of these limitations are now being removed, as discussed in the following section.

Despite all these limitations, however, it is felt that the NRL Intercept Probability Computing System can provide useful information at a very modest cost, provided that organizations having a use for this information assist in the tasking of the system with awareness of its limitations.

PROJECTS UNDER WAY

Since mid-1957, the NRL Intercept Probability Computing System has been operated on a continuous but low-priority basis. Reference 10 describes a study which formed part of the system checkout procedure. The system was also used to provide some of the data in Ref. 11.

The two major problems that have been undertaken are a study designed to determine optimum operating doctrine for the AN/WLR-1 for various missions, and a comparison of the AN/WLR-1 and AN/SLR-2 with various indicators and antennas as to their effectiveness against an airborne X-band radar.

As part of the first problem numerous simulations of the AN/WLR-1 against an S-band search radar have been conducted at various receiver antenna rotation rates because of the suspicion that the maximum rotation speed provided in the equipment should not be ordinarily used but would be employed by the operators in the absence of specific operating doctrine. Work on the problem has been suspended, however, in favor of the second problem (Ref. 12) which was undertaken in response to a request by OpDevFor (now OpTEvFor – Operational Test and Evaluation Force). Conclusions in regard to optimum antenna rotation rate derived from results of this second problem, however, are of sufficient generality to be applied to this aspect of the first problem.

Studies are also underway as to possible improvements in the NRL Intercept Probability Computing System. Among the areas being investigated are punched paper tape readout of the analyzer for subsequent reduction by a general purpose digital computer, improved methods of antenna pattern simulation including the introduction of rotation rate instability, inclusion of an additional scanning gate to better simulate panoramascopes, provision for more sophisticated operator statistics in the simulation, generalizations in the intercept pulse requirement circuitry, and further hardware and analytical work to better accommodate dynamic cases.

FUTURE PLANS

Present plans call for the resumption of work on the formulation of AN/WLR-1 operating doctrine and design and implementation of some of the hardware improvements mentioned above. It is anticipated that these plans will be prosecuted on a continuous low-priority basis with the expenditure of slightly less than one man-year per calendar year.

These plans can readily be modified to meet the requirements of the ECM community. Guidance as to the desires of potential users as to information required and the rate of expenditure of effort justified is earnestly solicited.

REFERENCES

The following references will provide the interested reader with specific information on the theory, hardware, and utilization of the NRL Intercept Probability Computing System. The abstracts of the more important references are included.

Concept of Intercept Probability*

1. Beck, H.M., "Time-Dependent Probabilities," NRL Report 3915 ([redacted]), Dec. 1951

ABSTRACT: The problem of intercept probability breaks down into a number of subtle subproblems. An effort is made to establish consistent terminology by using the word "probability" properly in the statistical sense and the word "intercept" properly in the tactical sense. The need then arises for new terms to describe processes of well-known electronic countermeasures. Several probabilities are formulated so that quantitative measurement becomes both meaningful and possible. A procedure is given to measure time-dependent probabilities by an electronic digital analyzer. ([redacted])

2. Bullock, G.M., "Probability of Intercept for Countermeasures Receivers," NRL Report 4626 ([redacted], Sept. 1955

ABSTRACT: The probability of intercepting an electromagnetic transmission, particularly that of a radar system, by a countermeasures receiver has been a major concern of designers and operational groups. In spite of the effort expended by many investigators, the concept of probability of intercept has remained somewhat nebulous and often misunderstood. This condition resulted, in part, from the lack of a suitable definition of probability of intercept and from an insufficient examination of the factors that influence the problem.

As a result of the work described in this report, the concept of probability of intercept has been clarified. It may be defined as a function of time that represents the chance of an intercept occurring for a specific set of over-all parameters. Perhaps the greatest effort in the past to improve the probability has been in minimizing the effect of coincidence of intermittent events. There are, however, at least three other important factors that influence the probability of intercept. These are (1) frequency spectral characteristics, (2) modulation characteristics, and (3) receiver sensitivity. The first two of these factors are important in determining whether or not a receiver is capable of intercepting various signal types either as entities or in the presence of other signals. The factor of receiver sensitivity is important in establishing the detection ranges not only of the major lobe but of the complete 360-degree coverage.

The consideration of these factors provides a more sharply defined and constrained concept of intercept probability, so that quantitative, comparative information can be obtained for different receiver techniques. Although some gross comparisons have been

*Parts of Refs. 4 and 5 also pertain to this heading.

made for a few signal types and receiver techniques, functions of sufficient accuracy to be of use in evaluation of systems will not be available until the completion of a new computer and simulator by the Countermeasures Branch of the Naval Research Laboratory. [redacted])

Simulation and Computation*

3. Tool, A.Q., "An Intermittent Signal Simulator for Intercept Receiver Testing," NRL Report 3663 ([redacted]), May 1950

4. Wald, B., "Computation of the Probability of Countermeasures Interception," NRL Report 4612 ([redacted]), Oct. 1955

ABSTRACT: The evaluation of countermeasures intercept equipment and the formulation of optimal strategies for its employment require a knowledge of the probability of intercept for a given receiver operating against a given transmitter, i.e., the probability that an intercept will occur within a given time after the start of an intercept effort. Mathematically, the problem reduces to that of finding the probability of occurrence of one of a number of events distributed in a stationary time series, a given time after a random entry into this series.

Although several mathematical techniques are available for the solution of this problem, the selection of a suitable computational method allows the utilization of electronic computing techniques.

The computer developed for this purpose consists largely of registers which accumulate timing pulses fed to them by a set of simple computing elements. These elements are controlled by the time series to be analyzed in accordance with the mathematical rule selected. At the end of the analysis, the 24 registers, each of which have a capacity of four significant decimal figures, have accumulated 24 points on the probability of intercept vs. waiting time curve.

The computer is capable of analyzing at moderately high speed any distribution of events fed into its input terminals, although the solution of problems of interest to countermeasures must await the completion of a system simulator capable of generating the appropriate time series. A high-speed simulator is now being designed for this purpose. ([redacted])

5. Wald, B., "A Countercept System Simulator," NRL Report 4957 ([redacted]), June 1957

ABSTRACT: In order to best utilize a previously reported time-series analyzer in the computation of countercept probability (the time-dependent probability of asynchronous countermeasures interception) a system simulator has been developed. This device simulates in real or scaled time the output of any given intercept receiver working against any given transmitter. The simulator takes into account all significant parameters – antenna patterns and rotation rates, transmitter power, receiver sensitivity, receiver bandwidth, receiver scan band and scanning rate, the position of the signal frequency in the receiver scan band, the nature of the transmitted signal (e.g., pulse width and pulse repetition frequency), the nature of the indicator and its coupling to the operator or other decision element (e.g., the minimum number of pulses required for the recognition of a pulsed signal or the minimum duration of a signal recognized as a communication), the statistical variation of receiver threshold introduced by the presence of a human operator, and the attenuation introduced by the propagation path (i.e., the effect of range and elevation).

*Parts of Refs. 7 and 12 also pertain here.

The simulator has been completed and has been used in conjunction with the analyzer to solve one problem in receiver system design. It is hoped that the problem-solving program can be greatly expanded and that the computational facility can be made accessible to other activities. ([redacted])

Assessment of Data Required in Simulations

6. Beck, H.M., Faust, W.R., and Weidemann, H.K., "Panoramic Receiver Thresholds," NRL Report 3336 ([redacted]), Aug. 1948

7. Beck, H.M., "Second Report on Panoramic Receiver CW Thresholds," NRL Report 3496 ([redacted]), June 1949

8. Root, W.B., "Intercept Thresholds: Panoramic, Time Base, and Audio Indicators," NRL Report 4491 ([redacted]), Feb. 1955

ABSTRACT: As part of a continuing program in the quest for an intercept indicator of optimum effectiveness, this experiment was designed to determine the average observer's success in detecting threshold signals through the use of various indicators. The panoramic presentation (panscope) threshold characteristics of an AN/APR-9 intercept receiver were determined at the Naval Research Laboratory before and after modification of the i-f and panscope circuitry. In further threshold tests, the NRL multigun analyzer was substituted for the panscope. A comparison was also made of the audio thresholds of both the AN/APR-9 and the NRL multigun analyzer.

The following facts were established:

1. Narrow-band panoramic systems, such as those contained in the AN/APR-9, AN/BLR-1, AN/SLR-2, etc., have relatively good response to cw signals and wide-pulse radar signals, but relatively poor response to narrow-pulse radar signals.

2. The NRL multigun analyzer, which incorporates wide-band circuitry and time-base presentation, is superior to the panscope with regard to narrow-pulse response and response to extremely short bursts.

3. The audio response of the NRL multigun analyzer, which incorporates high-level pulse stretching and other audio refinements, is superior to the audio response of the AN/APR-9.

4. Audio and wide-band video threshold levels are practically identical

It was concluded that more effective intercept sensitivity than is now available could be obtained by employing a combined indicator with simultaneous panoramic, time base, and audio presentations. (Confidential Abstract)

9. Garofalo, N.R., "Intercept Thresholds for the NRL Microwave Intercept System," NRL Report 5162 (Confidential Report, Unclassified Title), July 1958

ABSTRACT: The signal-to-noise thresholds for the headphones and the acquisition indicator of the NRL microwave intercept system have been determined with respect to pulse width and pulse repetion frequency of a pulse-type signal. The S/N threshold was defined as the second-detector S/N power ratio in db at which an average observer would detect a signal with 50-percent success. Groups of observers were used in five-frequency position experiments to determine those values of threshold which were of interest. The acquisition indicator utilized a time-frequency raster with intensity modulation and was investigated while using three different video sections: (a) main i-f video with a 250-kc bandwidth, (b) main i-f video with a 10-Mc bandwidth, and (c) second i-f video.

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The intercept capabilities of the NRL receiver system are best when the main i-f video section with a 250-kc bandwidth is incorporated in the acquisition indicator. The headphones have a better S/N threshold than this indicator when the signal has a prf and pw better than 1500 pps and 10 μsec, respectively. The S/N threshold of the receiver is improved over a limited range of signal characteristics when the second i-f video amplifier replaces the main i-f video amplifier in the acquisition indicator, but the decrease in probability of intercept capability of the receiver with the former video section more than offsets the advantage in threshold, unless a considerable amount of a priori information is available. ([redacted])

Applications

10. Wald, B., and Christman, D.B., "A Comparison of Omnidirectional and Rotating Directional Antennas for Intercept," NRL Report 4905 ([redacted]), Feb. 1957

ABSTRACT: With the completion of an intercept probability computer it has become possible to determine the probability of intercept for a given receiver working against a given transmitter. Considering an AN/WLR-1 intercepting the lower beam of an AN/CPS-6B radar, it has been found that a high performance omnidirectional antenna would be a better intercept antenna than the AN/SLR-2 direction-finding antenna rotated at high speed. While this conclusion applies quantitatively only to this one case, the computed data suggests that development of omnidirectional microwave intercept antennas should be pursued, and that provisions should be made for the installation of these antennas with the AN/WLR-1 system. ([redacted])

11. Garofalo, N.R., "Probability of Intercept for Various Countermeasures Receiver Systems under Average Tropospheric Scatter Conditions," NRL Report 4988 ([redacted]), Sept. 1957

ABSTRACT: The probabilities of intercept of three receiver systems were compared when operating against an airborne early warning radar of the AN/APS-20 type. The receiver systems considered were a fast-scan superheterodyne receiver, AN/WLR-1, incorporating first an omnidirectional antenna with a gain of 5 db, and then a fast-scanning directional antenna of the AN/SLA-3 type, and a wide-open DF crystal video receiver. This report is concerned only with tropospheric propagation conditions for an over-water path with the threshold of the normal scatter zone defined to be 50 db below free space in the diffraction zone, and with the scatter attenuation rate assumed to be 0.2 db per nautical mile. By utilizing intercept range curves which incorporate average scatter information for a ship-to-ship (h_T = 130 ft) and a ship-to-aircraft intercept path (h_T = 20,000 ft) together with probability of intercept data derived from a probability computer, time for 90% probability of intercept versus range curves were computed for the three receiver systems under various intercept operating conditions. Assuming the receiver directional antenna and the radar antenna scan to be 360°, and that the radar is continuously operating, the AN/WLR-1 has a higher probability of intercept when incorporating the omnidirectional antenna than when using the directional antenna for ship-to-ship and ship-to-aircraft intercept paths. The improvement for the former intercept link is much more pronounced than that for the latter, and the major increase in probability of intercept is achieved only after long waiting periods. If the radar and receiver operating conditions are varied so that the radar is transmitting periodically, or if the receiver antenna is sector scanning, the advantage of the omnidirectional antenna can be marginal. The only advantage of the DF crystal video receiver without rf amplification over the AN/WLR-1 is simplicity since it has been shown that the AN/WLR-1 with an omnidirectional antenna has a higher probability of intercept under all conditions.

When the radar is operating intermittently, it becomes necessary to greatly increase the sensitivities of existing receiver systems if high probability of intercept is desired in the scatter region. A crystal video receiver which utilizes low-noise traveling-wave tubes as rf amplifiers has an order of sensitivity that will permit interception of signals in the normal scatter region after one rotation of the radar antenna. A study should be made to determine the feasibility of designing a practical DF crystal video receiver with existing TWT techniques. A radar countermeasures intercept system which incorporates both a highly sensitive DF crystal video receiver and an AN/WLR-1 seems to be the mose efficient. This investigation also indicated that an analysis to determine the optimum rate for receiver antenna rotation for highest probability of intercept as a function of receiver, radar, and signal characteristics, could be well warranted. ([redacted])

12. Fortna, J.D.E., "Simulated Countercept Performance of the AN/WLR-1 and AN/SLR-2 Receivers," NRL Report 5537 ([redacted]), Oct. 1960

ABSTRACT: As a result of a request from OpTEvFor, a comparison of the relative effectiveness of AN/WLR-1 and AN/BLR-1 (AN/SLR-2) type intercept systems against the AN/APS-31 type airborne radar has been conducted utilizing the NRL Intercept Probability Computing System. Data was obtained for 300-rpm and 100-rpm operation of the AS-570-SLR antenna system, for 100-rpm operation of a hypothetical wider beamwidth receiving antenna system, and for different signal indicators employed by the AN/BLR-1. Calculations were performed to estimate the effectiveness of these systems against a rapidly approaching radar.

Results of simulated performance against the AN/APS-31 at constant or closing range indicate that under any method of antenna operation considered, the AN/WLR-1 performs much more effectively than the other systems. The modified AN/BLR-1 with 250-kc video bandwidth employing the AN/SLA-2 as signal indicator proved better at 100-rpm antenna operation than the operational AN/BLR-1 with panscope for the radar pulse width (5 μsec) simulated. This system also proved better than the operational AN/BLR-1 with the larger 10-Mc video bandwidth employing the AN/SLA-2 as indicator for any of the methods of antenna operation above and the pulse width mentioned. With the exception of the AN-BLR-1 with panscope, the simulated performance of all equipments was considerable better at 100-rpm methods of antenna operation for low (200 pps) prf. The data also indicated that for the commoner prf's in the 500 to 1000 pps range, the 300-rpm operation of this receiver antenna is preferable, and, in the case of the hypothetical antenna, twice this value would be desirable.

Results of the simulated performance against the AN/APS-31 approaching at an altitude of 1000 feet at 180 knots indicate that high intercept probabilities were unobtainable at ranges greater than 10 nautical miles except by the AN/WLR-1 system and the 100-rpm (at 200 pps) narrow-band video AN/BLR-1 with AN/SLA-2 as signal indicator. Against the AN/APS-31 approaching at the same altitude at 600 knots, high intercept probabilities were unobtainable at ranges greater than 10 nautical miles for all countercept systems except the AN/WLR-1 regardless of the method of antenna operation considered. Indications are that increasing receiver sensitivity by the use of traveling-wave tubes would result in extending the range of the AN/BLR-1 equipment against rapidly approaching radars of the AN/APS-31 type by about 10 nautical miles.

In the case of a stationary (or slowly moving) countermeasures receiver employed against a stationary (or slowly moving) radar, the optimum rotation rate of the receiver direction-finder antenna appears to lie between two limits: rotation at such a high rate that the receiver main lobe is directed at the transmitter for a time insufficient to make a significant contribution to intercept, and rotation at such a low rate that further reduction in rotation rate increases waiting times at shorter ranges without a significant decrease in waiting times at longer ranges. If the antenna rotation rate is increased from the lower limit, waiting times at greater ranges increase while waiting times at shorter ranges decrease.

The values of the upper and lower antenna rotation rate limits are determined by receiver main lobe beamwidth and radar prf. The optimum rate depends upon the relative desirability of greater range and shorter waiting times within the range of rotation rates determined by the upper and lower limits.

In the case of an approaching radar, the relative desirability of greater range and shorter waiting times would depend upon the closing rate of the radar as well as upon the waiting time for given probabilities of intercept versus range curves of the stationary receiver-stationary transmitter countercept situation. For the equipments as simulated and the velocities of approach illustrated, the 100-rpm methods of antenna operation yielded the best overall performance over the approach path.

Improvements in present systems suggested by the results are increased system sensitivity and antenna design alteration. Increased sensitivity may be obtained in the AN/BLR-1 with AN/SLA-2 as indicator for the frequently encountered pulse widths by narrowing the video bandwidth from 10 Mc to 250 kc, and in all systems by employing traveling-wave tubes. Improved performance of the short on-signal time systems, the AN/BLR-1 with panscope and the AN/WLR-1, may be obtained by employing a wider beamwidth antenna. If doubling the AS-570/SLR beamwidth at X-band with no more than a 3-db loss in sensitivity can be accomplished, significantly shorter waiting times may be obtained without significantly decreasing the range over which the main lobe contributes to intercept probability. ([redacted])

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