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NRL Report 5162
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INTERCEPT THRESHOLDS FOR THE NRL MICROWAVE SIGNAL INTERCEPT SYSTEM

[UNCLASSIFIED TITLE]

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July 15, 1958

DECLASSIFIED by NRL Contract Declassification Team
Date: 11 APR 2017
Reviewer(s): [redacted]
Declassification authority: NAVY DECLASS GUIDE / NAVY DECLASS MANUAL, 11 DEC 2012
58 SERIES

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ABSTRACT
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The signal-to-noise thresholds for the headphones and the acquisition indicator of the NRL microwave signal intercept system have been determined with respect to pulse width and pulse repetition 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 10-Mc bandwidth, and (c) second i-f video.

The intercept capabilities of the NRL receiver system are best when the main i-f video section with the 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 greater 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.

PROBLEM STATUS

This is a final report on one phase of the problem; work on other phases is continuing.

AUTHORIZATION

NRL Problem R06-02
Project NE 071-200-2
BuShips No. S-1255

Manuscript submitted June 2, 1958

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INTERCEPT THRESHOLDS FOR THE NRL MICROWAVE SIGNAL INTERCEPT SYSTEM
[Unclassified Title]

INTRODUCTION

An evaluation has been made of the various indicator systems associated with the NRL microwave signal intercept system (1). This was accomplished by determining the signal-to-noise (S/N) threshold of this system as a function of pulse width (pw) and pulse repetition frequency (prf) of a pulse-type signal. This study is an extension of the intercept threshold work performed by Root, Beck, et al. (2,3,4). The receiver system consists of a modified AN/APR-9 which incorporates fast frequency-scan circuitry, a frequency-time raster with intensity modulation for signal acquisition, and a multigun indicator for time-base display and panoramic presentation. The period of the horizontal sweep for the acquisition indicator is two seconds, which is the time for one complete frequency scan of the receiver, and the vertical period is two minutes. A commercial version of this receiver system, which has the nomenclature AN/WLR-1, has recently been built by Collins Radio Company and is in its final evaluation stages. The threshold information given in this report applies also to the AN/WLR-1, because of the similarity of the circuit functions and requirements.

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 50 percent of the time. Since the acquisition indicator is used during signal search, this indicator was used in the threshold studies. The S/N threshold for the time-base display in the multigun indicator would be essentially as described by Root (2); therefore, it was not determined. Since Root's audio threshold work is also applicable to the receiver system under study, only a limited audio investigation was made.

Three different video sections were used with the acquisition indicator: (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. The 10-Mc video amplifier was also used for signal analysis in the multigun indicator. Since true signal reproduction is not important in the case of signal search, a compromise can be made in video bandwidth to obtain the maximum S/N ratio over the range of pulse widths expected. The 250-kc-bandwidth figure was arrived at by using the 10-Mc amplifier as a reference and setting the S/N ratios of the two video amplifiers equal at a pulse width of 0.1 μsec. For pulse widths greater than this figure, the sensitivity would be improved by utilizing the narrower band amplifier. Tests were made to determine what improvement in threshold was obtained by using this narrower bandwidth. The second i-f video section was investigated to determine whether there was any advantage in using this video unit on certain types of signals.

MEASUREMENT OF S/N THRESHOLD

A group of 80 observers, which included both civilian and Navy personnel at NRL, was used in this investigation. No observer was allowed to participate in the same experiment more than once. The S/N threshold is a function of observer variables such as fatigue, distraction, operator skill and physical condition, and also environmental conditions when observing signals. Since the main purpose of this investigation was to determine S/N

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thresholds and not the effect of physical and personal variables on these thresholds, the observers were kept as comfortable as possible, fatigue and distraction were kept at a minimum, and observers were chosen at random in an attempt to average out their skills.

The S/N thresholds were obtained by using a five-frequency position experiment. The face of the acquisition indicator was marked with numbers from one to five to represent the five positions at which test signals would be presented. The test frequencies were 2.6, 2.95, 3.3, 3.65, and 4.0 kMc. Preliminary to each daily run, the equivalent noise voltage was measured at the five frequencies, and a record was made of signal-generator corrections in order to obtain equal S/N ratios at the five frequency positions. The director and test receiver were situated in a dark room, with the observer in a darkened booth. Before commencing with the experiment, each observer was given a group of 20 signals of large enough amplitude to be detected easily on the raster. This permitted his sight to get adjusted to the darkness and also enabled him to become familiar with the test procedure.

The experiment was started with a signal amplitude which would result in about a 90-percent score for the majority of the observers. The signal amplitude was diminished in 1/2-db steps until the observer received the score he would theoretically achieve by guessing. A group of 15 signals picked randomly over the five frequency positions constituted the test at each signal amplitude, with a normal test run usually consisting of six to eight 15-signal groups. The observer was given 15 seconds to identify the position of the signal. Since the time required to scan the 2.3 to 4.45 kMc range of the rf tuner was approximately two seconds, the observer had about 7.5 traces to detect the signal. The start of the 15-second period was indicated in the observer booth by a soft green light, and termination was indicated by a soft red light. The signal was automatically started and terminated synchronously with these lights. The observer was told to use as much of the test time as necessary to identify the signal positively, since the time required for signal detection was not taken into account in the scoring. When the observer identified the signal by orally stating the position number, the signal was turned off and the next signal presented. If he could not determine the position at the end of the 15-second period, he was required to guess. Since the 50-percent S/N threshold was of interest, requiring a guess made the observers much more willing to interpret small signal indications. In many cases when an observer thought he was guessing, he actually received a much higher score than pure guessing would indicate. Guessing, however, was taken into account in the scoring. The time required for each experiment was usually about 45 minutes. Since the observer had to identify 90 to 120 signals in this period, he was given a 5-minute break after observing 60 signals, to minimize eye fatigue.

SCORING AND GRAPHING

In order to take guessing into account, the S/N threshold was determined through correlation scores. The correlation score defined here is similar to that used in the study of minimum visible radar signals (5). The proportion of lucky guesses in the five-position experiment with no discernible signal present can be estimated on the basis that in the long run an observer required to name the "correct" position will make only four misses in five observations. That is, for every four recorded misses he will make one correct guess. The correlation score is then

$$C = \left(1 - \frac{5m}{4n}\right),$$

where m is the number of misses and n the total number of observations. In this experiment, n is 15. The correlation score thus defined for five positions is an estimate of the probability of seeing a signal for an experiment based on an unlimited number of positions.

Correlation scores of a group of seven observers taking the identical test were plotted against S/N ratios on a single graph; these scores formed a cluster of points about each S/N ratio. A smooth curve, similar to the "betting curve" shown by Ashby, et al. (5), was drawn through the approximate center of these clusters. Since the center portion of these curves was straight and easily reproducible, the 50-percent correlation point, which is defined as the S/N threshold, is reasonably accurate for the conditions of this test. To show the effect of pw and prf variations on the S/N threshold of the equipment, a series of "betting curves" was plotted as the signal characteristics were varied. All points on the threshold curves in Figs. 1 and 2, except for curve IV of Fig. 1, were determined from a "betting curve."

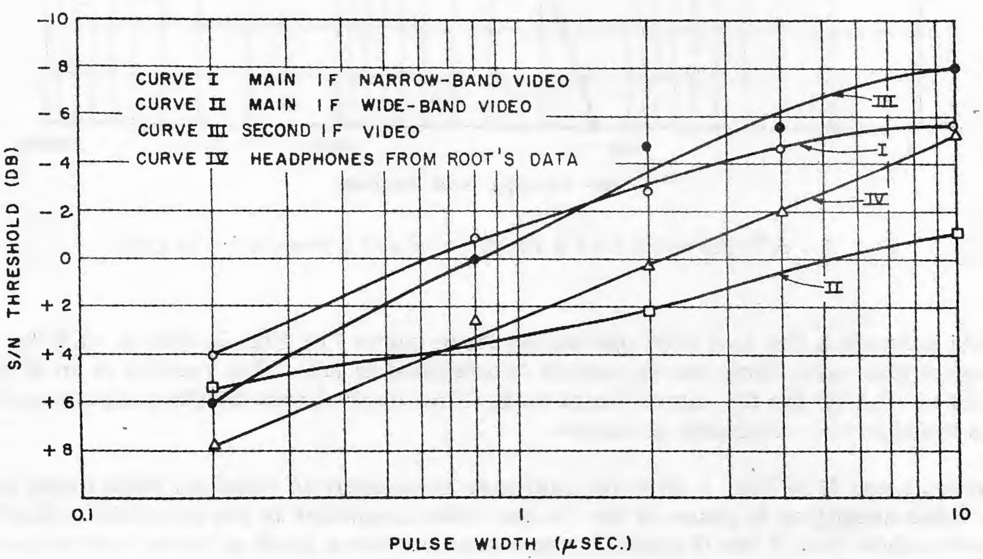


Fig. 1 - S/N threshold as a function of pw when prf is 1000 pps

ULTS

...es 1 and 2 show the S/N threshold for the NRL microwave signal intercept sys... the acquisition indicator utilizes the main i-f narrow-band and wide-band video ...-f video. The effect on the threshold when the audio headphones are used ... acquisition indicator is also shown on these figures. In Fig. 1, the S/N ... function of pulse width of the signal with the prf held constant ... the pulse width was held constant at 10 μsec and the prf was vari... or signal characteristics aside from those that can be read directly fro... ...rves can be determined by utilizing a combination of the curves shown in Figs. 1 and 2. For example, the S/N threshold for a signal which has a pw of 1 μsec and prf of 300 pps, when the main i-f narrow-band video is used in the acquisition indicator, can be determined as follows: (a) read the threshold from curve I of Fig. 1, with pw = 1 μsec and prf = 1000 pps; this is -1.4 db; (b) determine the difference in

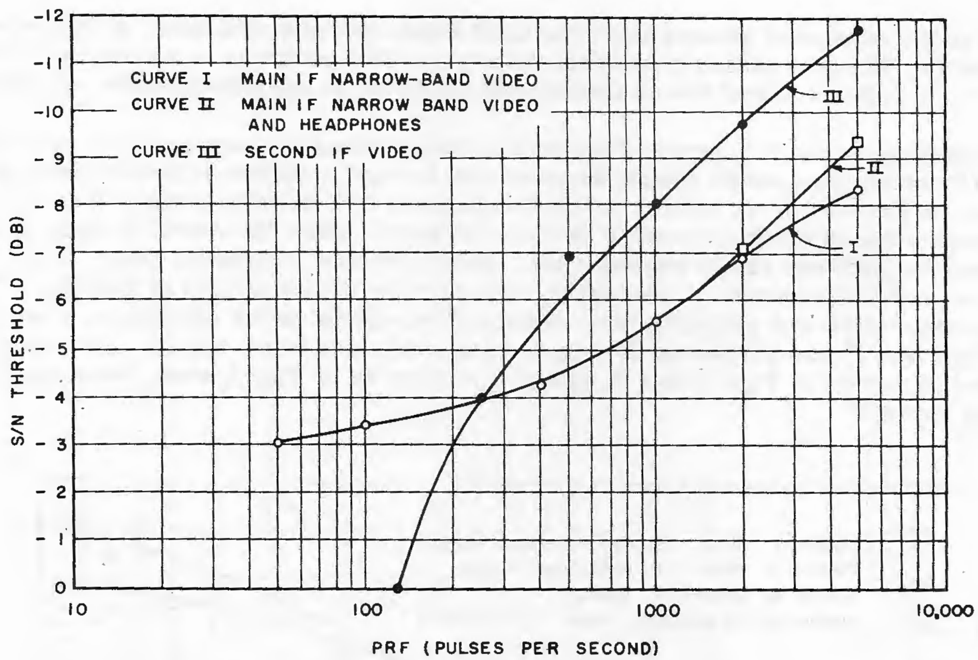


Fig. 2 - S/N threshold as a function of prf when pw is 10 μsec

threshold between a 300 and 1000 pps signal from curve I of Fig. 2; this is -1.6 db; (c) subtract this value from the threshold determined in (a). This results in an S/N threshold of +0.2 db for the signal described. This method was checked experimentally and was found to be reasonably accurate.

Curves I and II of Fig. 1 show the increase in sensitivity obtained when using the 250-kc video amplifier in place of the 10-Mc video amplifier in the acquisition display. The curves show that if the threshold measurements were made at pulse widths narrower than 0.2 μsec, the two curves would have intersected in the vicinity of 0.1 μsec, which the point at which the S/N ratios of the two video sections were set equal. Since the ad tages of using different main i-f video bandwidths are reflected mostly by pw variations and not by prf variations, it was not considered necessary to make a threshold study o wide-band video as a function of prf.

Curve II of Fig. 2 indicates that when the headphones are used together with the acquisition indicator, the S/N threshold is improved when the signal has a prf above about 1500 pps. It was not necessary to take threshold data below this figure, since obviously when this curve intersected the main i-f narrow-band video threshold curve, the latter curve would then define the best threshold. The audio section investigated followed the main i-f narrow-band video. Since the S/N threshold obtained when using the headphones agreed quite well with Root's work (2a), it was not necessary to run a separate curve utilizing only the headphones. The audio section of the NRL multigun analyzer which was evaluated in Root's report was almost the same as that used in the receiver investigated. Curve IV of Fig. 1 was plotted from this source, and it can be seen that the S/N threshold decreases at a faster rate for the headphones than for the acquisition indicator. It can be concluded that the headphones have the threshold advantage only when the signal has a prf and pw greater than 1500 pps and 10 μsec, respectively. At times, it is also advantageous to use the headphones when the signal prf and pw are below these values, even though the threshold of the headphones is below that of the acquisition indicator. When signals are of great enough amplitude to be detected in the headphones, this indication can be very helpful in discriminating signal intercepts from noise burst and also in identifying signals which are closely grouped.

Curves I and III of Fig. 1 show the comparison in S/N threshold of the receiver when the main i-f narrow-band video and the second i-f video are used. Above 1.4 μsec, the latter has a better threshold, and below this figure the former has the better threshold. Curves I and III of Fig. 2 indicate the advantage of using the second i-f video when the input signal has a prf higher than 250 pps. As would be expected, the largest improvement in sensitivity, when utilizing the second i-f video, was obtained at the highest prf and pw setting. This was 3.4 db at a prf of 5000 pps and a pw of 10 μsec. By using the curves of Figs. 1 and 2 as previously described, three-dimensional curves were drawn, with the main i-f narrow-band video (Fig. 3) and the second i-f video (Fig. 4) incorporated in the acquisition indicator. Figure 5 is a composite of Figs. 3 and 4 and indicates the regions in which the two video sections are favorable.

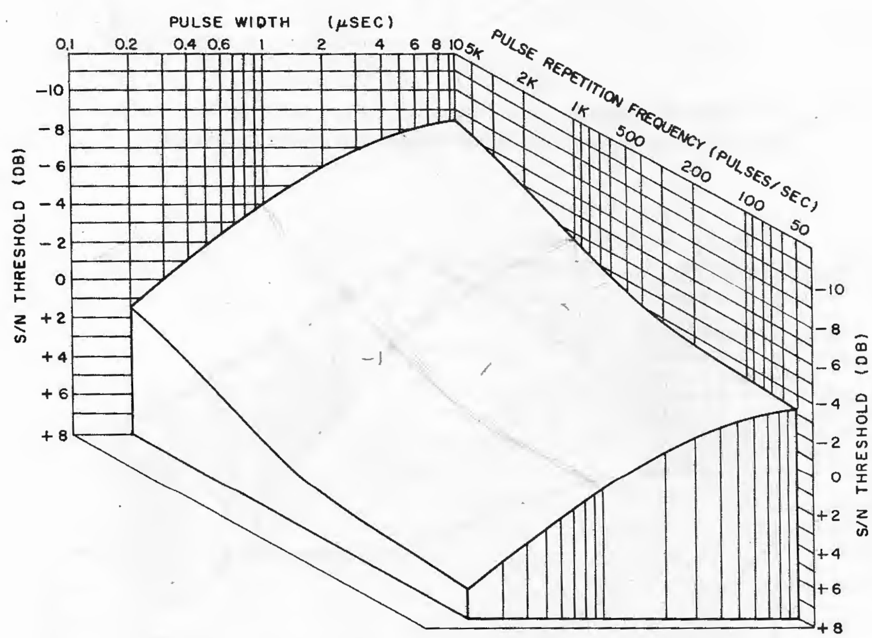


Fig. 3 - S/N threshold as a function of pw and prf when the main i-f video with a 250-kc bandwidth is used in the acquisition indicator

In interpreting the advantage of using the second i-f video in the acquisition indicator against certain types of signals, it must be remembered that this S/N threshold investigation does not in itself determine the probability-of-intercept capabilities of a receiver. In other words, for the purposes of the investigation, the signal was always present at the rf input terminals, and the receiver did not have to search for the signal. In searching for

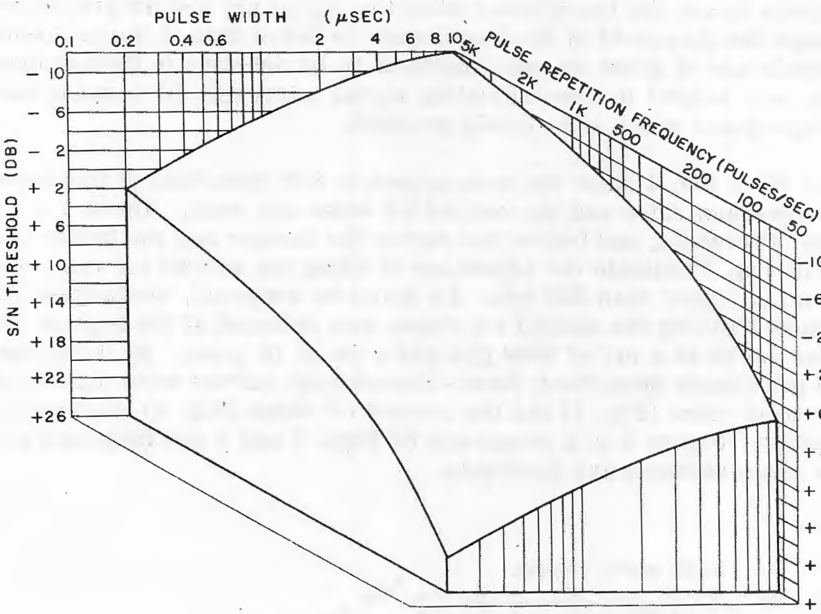


Fig. 4 - S/N threshold as a function of pw and prf when the second i-f video is used in the acquisition indicator

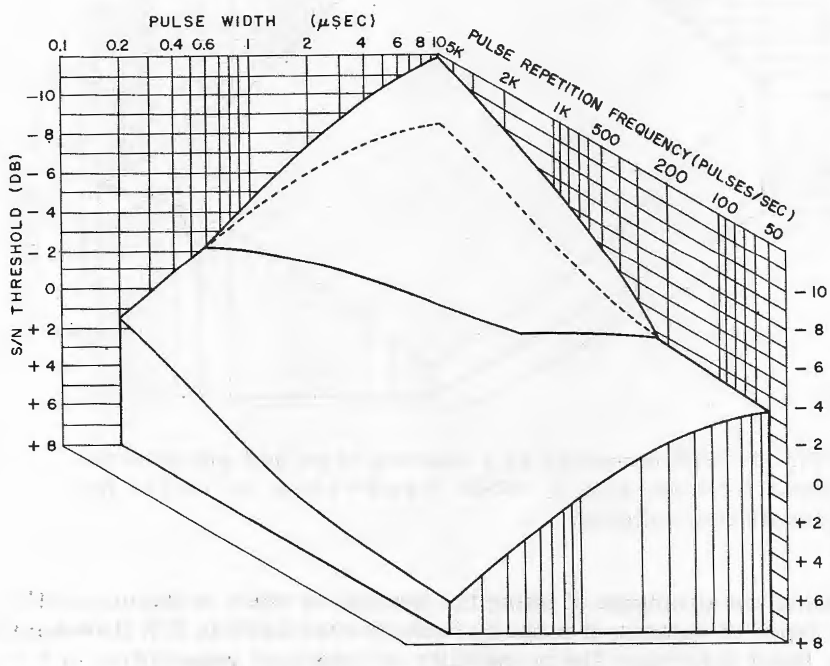


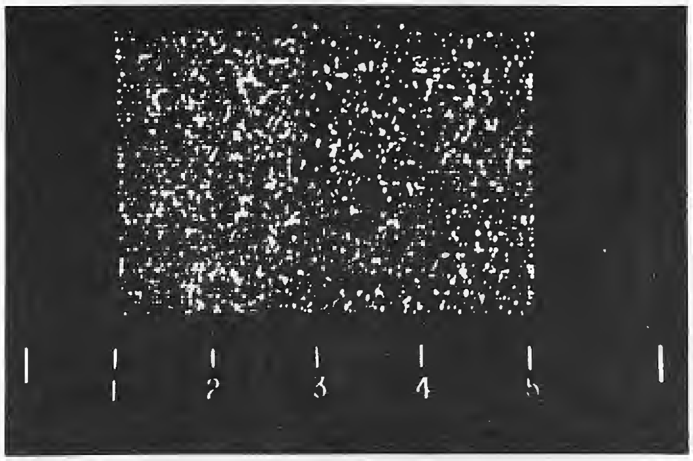
Fig. 5 - Comparison of S/N threshold when main i-f and second i-f video is used in the acquisition indicator

signals, a receiver which is frequency scanning with a 20-Mc main i-f bandwidth has a much higher probability of intercepting a signal from a rotating radar antenna than if this receiver had a 0.6-Mc second i-f bandwidth. To illustrate this point, two local radar signals were attenuated to the point at which just the main lobe of the radar antenna could be detected by the NRL receiver. The characteristics of the radars were:

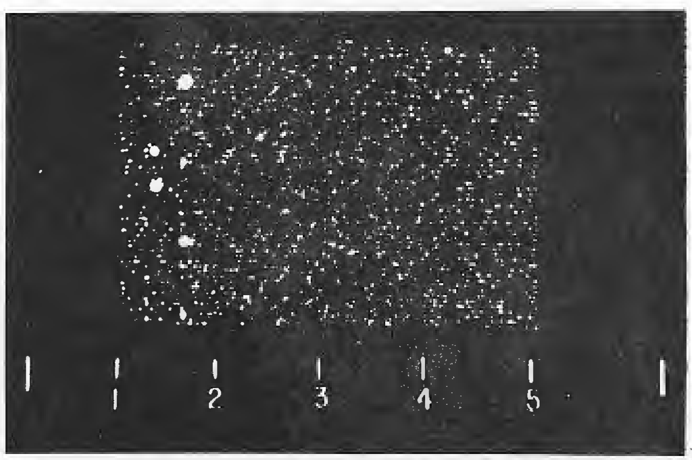
	Radar I	Radar II
Frequency	2700 Mc	2840 Mc
Antenna Rotation Rate	30 rpm	6 rpm
Antenna Beamwidth	4.5 deg	1.3 deg
PRF	1300 pps	1000 pps
PW	1 μsec	1 μsec

The receiver antenna main lobe (beamwidth of 12 deg) was put on the radar bearing, and with the receiver frequency-scanning, separate pictures were taken of the acquisition-indicator raster with the two video sections. The second i-f video was used for the raster display shown in Fig. 6a, while the main i-f video was used in Fig. 6b. Signal intercepts would be indicated between positions 1 and 2 on the raster display. When the main i-f video was used, radar II was intercepted 4 times and radar I was intercepted twice, while it is difficult to determine the presence of any signal when the second i-f video was used. The pw and prf of the radars are such that the S/N threshold when using the main i-f narrow-band video section is slightly better by about 0.5 db (Fig. 1). This fact has no influence on this investigation, because the radars' signal levels are well above the S/N threshold, as evidenced in Fig. 6b, so a 0.5-db variation in sensitivity is insignificant.

Utilizing the second i-f video has the further disadvantage of yielding a much brighter background-noise raster than does the main i-f video. This, of course, leads to additional eye fatigue. In the course of the S/N threshold experiments, the observers made numerous complaints about this phenomenon. In order to illustrate this point, a picture was taken of one complete raster at the same camera setting with each of the video sections incorporated in the acquisition indicator. The i-f gain was set in both cases so that just the peaks of the noise spikes could intensity-modulate the crt. This method of setting the i-f gain control seemed to be the best for detecting low-level signals. To show the effect of different S/N thresholds on the acquisition display, a signal with a pw of 10 μsec and prf of 1000 pps was inserted at the same level for the two video conditions. The pictures, which are shown in Figs. 7a and 7b, were taken with an exposure time of two minutes and an f/11 setting. The improvement in signal presentation when the second i-f video is used (Fig. 7b) represents an improvement in S/N threshold of 2.4 db (Fig. 1). The comparison of these pictures definitely shows the increase in brightness of the background-noise raster when the second i-f video is used. A possible explanation of this phenomenon is that the narrow bandwidth of the second i-f explores the humps in the rf and main i-f passband in 0.6-Mc segments, while the main i-f explores the rf passband in 20-Mc segments. The main i-f has a tendency to average out passband variations, but the second i-f must follow its variations rather closely. Since the variations in the rf and i-f passband can be 3 db or higher, the gain control must be set, when using the second i-f, so that the noise spikes at the low points in the passband can intensity-modulate the crt. This results in a high-intensity spot at the high points in the passband, which leads to the bright background-noise raster.

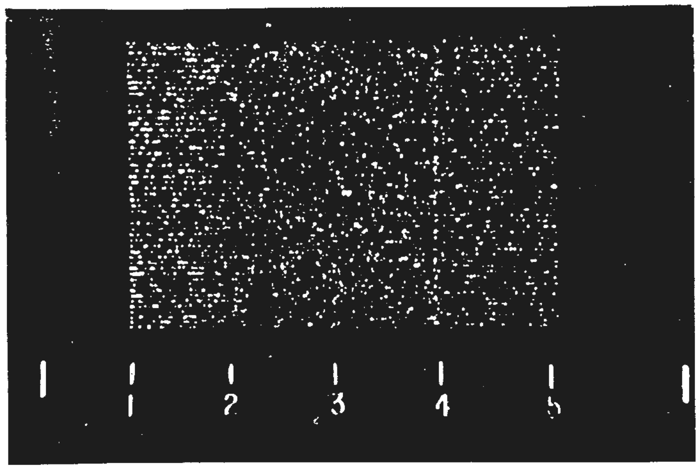


(a) Acquisition indicator with second i-f video section (2-minute exposure with about f/19 setting)

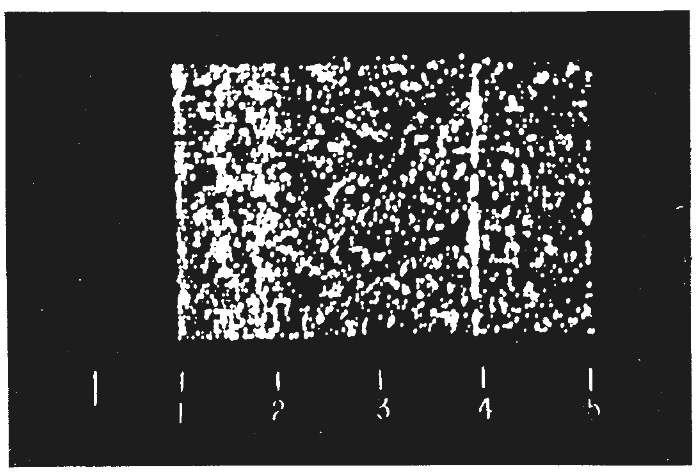


(b) Acquisition indicator with main i-f narrow-band video section (2-minute exposure with f/11 setting)

Fig. 6 - One raster of acquisition indicator when the NRL microwave signal intercept system operates against radars I and II (see tabulation, p. 7)



(a) Main i-f video used in acquisition indicator



(b) Second i-f video used in acquisition indicator

Fig. 7 - Comparison of background-noise raster. Exposure time for camera was 2 minutes at an f/11 setting. Constant signal level at position 4.

The disadvantages of low probability of intercept, and to a lesser extent that of background raster brightness, when the second i-f video is used for the acquisition indicator, outweigh the S/N threshold advantage that this video section has over the main i-f narrow-band video section in the region shown in Fig. 5. The second i-f video can be used with advantage in this region if a priori information exists such that the radar antenna bearing is known, and if the antenna main beam remains stationary at this bearing. Intercepting a signal under these conditions would be similar to identifying a signal in the S/N threshold tests.

CONCLUSIONS

The intercept capabilities of the NRL microwave signal intercept system are best when the main i-f video section with a bandwidth of about 250 kc is used in the acquisition indicator. Figure 3 is a three-dimensional plot of the S/N threshold as a function of signal prf and pw when this video section is utilized. Figure 2 shows the increase in threshold achieved in the acquisition indicator when the main i-f video bandwidth is changed from 10 Mc to 250 kc. The S/N threshold of the NRL receiver is improved over a limited range of signal characteristics when the second i-f video amplifier is used in the acquisition indicator (Fig. 5), but the decrease in probability of intercept capability of the receiver with this video section more than offsets the advantage in threshold, unless a considerable amount of a priori signal information is available. If signals of high prf and wide pw (above 1500 pps and 10 μsec) are expected, it is advantageous to use the headphones together with the acquisition indicator, since the threshold of the headphones is higher in this region.

ACKNOWLEDGMENTS

The constructive suggestions of Mr. H. K. Weidemann and Mr. G. M. Bullock are gratefully acknowledged.

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