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PANORAMIC RECEIVER THRESHOLDS

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H. M. Beck
W. R. Faust
H. K. Weidemann

August 17, 1948

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Hqts., 311th Air Div., Andrews Field
Attn: Capt. R. R. Perry (1)

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CONTENTS

ABSTRACT

The results of a preliminary investigation into minimum visible signal levels for a panoramic receiving system in the presence of receiver noise are presented. Several parameters of a panoramic system were varied in collecting statistical data from experiments designed to determine the minimum detectable signal in the presence of receiver noise. The parameters investigated that were considered of greatest importance were sweep rate, i-f bandwidth, video bandwidth, and bandwidth swept.

The minimum visible signal power was determined by means of a statistical study based on signals presented at six specified positions on a panoramic receiver indicator. This minimum signal power is given in terms of the "mean" noise power for the six positions involved. The signal level corresponding to $(S/N)_{50}$ in each case is the signal power necessary for an observer to name the correct position, in the six-position experiment, 50 percent of the time. This signal level is defined as corresponding to visual signal-to-noise ratio of unity.

An expression is given for relative pip display length for a CW signal, in terms of the parameters of the system. It is tentatively suggested that the minimum visible signal may be related to pip relative display length.

PROBLEM STATUS

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

AUTHORIZATION

NRL Problem No. R06-17R (BuShips Problem S-1255.3).

PANORAMIC RECEIVER THRESHOLDS

INTRODUCTION

An effort has been made to determine the minimum visible signal power for a panoramic receiver. This signal level is a function of the various parameters of the system which is composed of receiver, indicator, and observer.[1] The several parameters were each varied in as independent a manner as possible while all other parameters were held essentially constant. For convenience a "standard" set of these parameters was chosen for the purposes of this test. A set of 30 observers, after adequate preliminary preparation, was considered as representative of an infinite population of experienced observers. A subset of five or six observers was used as a sample of this population for each parameter setting. The actual determination of the minimum visible signal was made from data collected on the basis of a six-position experiment.

DEFINITIONS

Definition of Signal Threshold Power

Several discrete positions are marked on the indicator, each one of which has equal "random" probability of being the signal position. A signal of a definite signal-to-noise level for that position is presented for a definite time T. The observer is instructed to designate the position where he believes the signal to be, determined by any means at his command. The correlation above chance between the actual signal positions and those named by the observer is plotted as a function of signal-to-noise power ratio, S/N. The signal-to-noise ratio for which the correlation is 50 percent is here defined as a "visual" signal-to-noise ratio equal to unity, and has been taken as the signal-to-noise threshold, written $(S/N)_{50}$. A signal-to-noise ratio having any other percentage correlation is designated by the corresponding subscript $(S/N)_{10}$ for 10 percent, $(S/N)_{90}$ for 90 percent, etc.

Parameters to be Changed

Only those parameters considered unique to a panoramic system intercepting steady-state signals were varied. These are defined as follows:

1. Sweep Rate (n)
2. Frequency Band Swept (F)
3. I.F. Bandwidth (B)
4. Video Bandwidth (b)

---

[1] A. V. Haeff, "Minimum Detectable Radar Signal and its Dependence upon Parameters of Radar Systems;" IRE Proceedings, 34, 857-861, Nov. 1946

Randomness of Position

It is, of course, necessary that data collected from a six-position experiment be representative of the complete system. In the panoramic case a completely random sequence was found to be inadequate for this purpose. In contrast to the radar case, the actual noise present varies with signal position, and in the relatively small samples involved in a practical experiment it is possible that one, or several positions might be favored or neglected over considerable periods of time. To circumvent this, a "restricted" randomness was used in the following manner:

Each of the 720 permutations of six numbers were typewritten on small cards, and these cards were placed in a container. Four cards, with replacement and mixing, were drawn and the sequence recorded on the score sheet form. This score sheet form then contained 24 prospective observations in such a sequence that each position was represented as often as every other position. In justification of this method, it should be noted that 720 numbers (or things) may be drawn from a container four at a time, in approximately 10^{10} different ways. It should be apparent that the observer's ability to "outwit" the system becomes negligible as soon as one signal is missed. It was noticed furthermore, that an observer without means of recording previous observations received entirely negligible aid from the divergence of the system from true randomness. Additional scrambling of the numbers within a "run" was considered and found to be unnecessary.

It may be mentioned here that design of experiment sometimes calls for a restriction on randomness; for example, in the use of the Latin square and rectangle in biological and industrial experimentation.

PROCEDURES

Measurement of Signal Threshold

A signal is presented for a time T at any one of the six positions, labeled 1, 2, . . .,6, each position representing a different definite frequency. The signal position is chosen at "random" (as defined above), but the exact instant of presentation is indicated to the observer by a buzzer; the observer is again alerted at the end of each observation. After each presentation the observer is required to name one of the six positions as the most likely signal position. A set of 24 observations is considered a standard sample for a given signal-to-noise ratio, and these are to compute the correlation above chance for the individual observer. The mean correlation score for a group correlation score for a group consisting of five or six observers is considered a standard observer sample.

Measurement of Noise

The block diagram, Figure 1, shows a manual control (battery, potentiometer and associated switching arrangement) on the reactance tube modulator. This control makes it possible, with the sweep voltage off, to tune the signals of frequencies corresponding to the six positions successively into the pass band of the receiver for the purpose of measuring the individual noise (measured at the second detector) at these positions. In this manner the sequence of six noise measurements was repeated about five times whenever a parameter was changed.

The mean of the five measurements was used as the reference noise at each position. Chauvenet's criterion was used as a check, to decide if any relatively large or small measurement was to be accepted or rejected.[2]

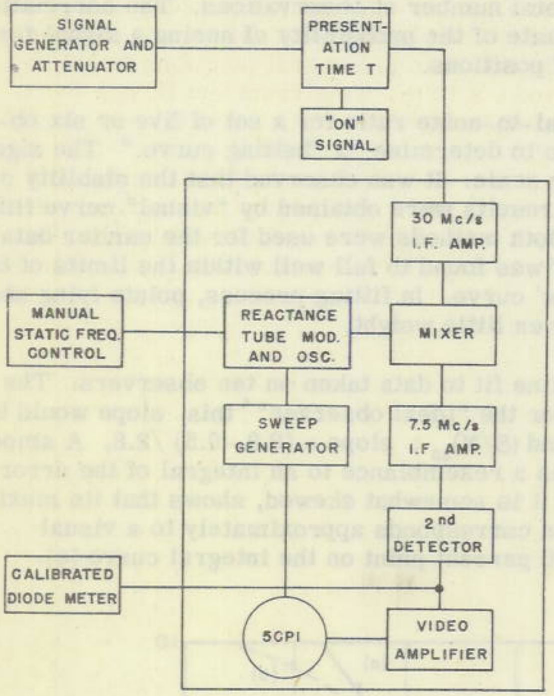

Fig. 1 - Block Diagram of Equipment

Errors in Measurement

The following errors in the data were treated as random effects for the purposes of this experiment:

1. Statistical fluctuation in noise
2. Statistical fluctuation due to lucky guesses
3. Operator skill and condition
4. State of "training" of operator (improvement through practice)
5. Distraction
6. Fatigue
7. R. F. leakage
8. Apparatus instability
9. Errors in measurement of noise

In regard to No. 4, the data from a new observer on his first series of runs was not given equal weight to that from "seasoned" observers. The difference between a "seasoned" and "new" observer after this initial period seldom seemed of any great significance.

The Correlation Score

The correlation score is used here in a manner analogous to that used in the study of minimum visible radar signals.[3] It is employed as a device to evaluate the relationship between observational data and signal levels in the presence of noise. The proportion of lucky guesses in the six-position experiment with no signal present can be estimated on the basis that an observer required to name the "correct" position will make only five misses in six observations, in the long run. That is, for every five recorded misses he

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[2] M. Merriman, "A Textbook on the Method of Least Squares;" John Wiley & Sons Publishing Co., 166

[3] R. M. Ashby, V. Josephson, S. Sydoriak, "Signal Threshold Studies;" NRL Report No. R-3007 (Unclassified)

will make one correct guess. The correlation score is then

$$C = \left(1 - \frac{6}{5}\frac{m}{n}\right)$$

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

The mean correlation score for each signal-to-noise ratio for a set of five or six observers is plotted against signal-to-noise ratio to determine a "betting curve." The signal-to-noise ratio is plotted in decibels on a linear scale. It was observed that the stability of the data was ordinarily such that equally good results were obtained by "visual" curve fitting to these data as by the use of least squares. Both methods were used for the earlier data, and the curve determined by the visual method was found to fall well within the limits of the standard error of estimate of the least squares' curve. In fitting process, points lying above about 90 percent and below 10 percent were given little weight.

Figure 2 shows an example of a straight-line fit to data taken on ten observers. The slope of this line (a) is approximately 0.13. For the "ideal observer"[4] this slope would be 0.14 - i.e., 2.8 db difference between $(S/N)_{90}$ and $(S/N)_{50}$; slope = (0.9 - 0.5) /2.8. A smooth curve (b) through the system of points indicates a resemblance to an integral of the error function. The differential of this curve, while it is somewhat skewed, shows that its maximum is quite near to the mean. The mean then corresponds approximately to a visual signal equal to the noise as defined from the 50 percent point on the integral curve (c).

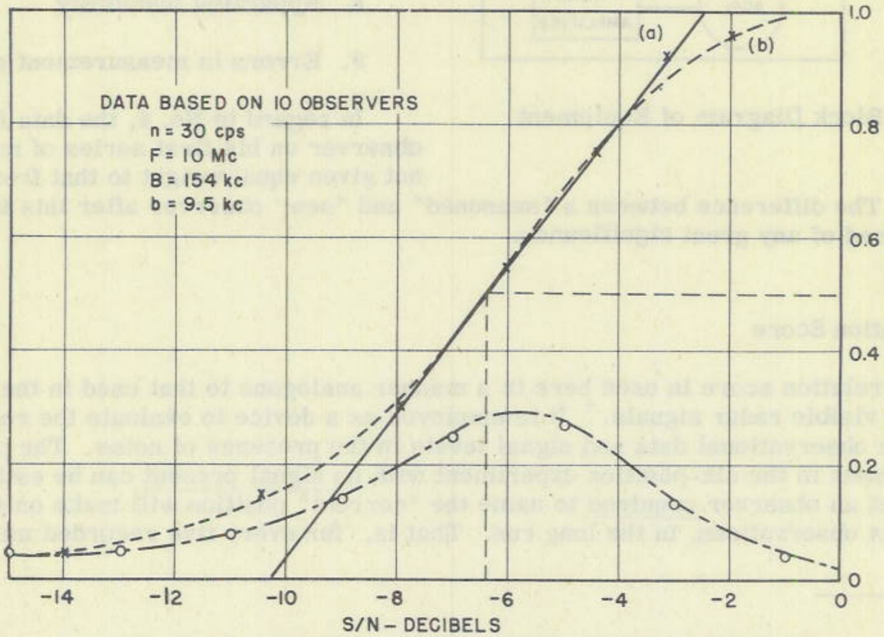

Fig. 2 - Correlation Data Based on 10 Observers for a Given Set of Parameters

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[4] R. M. Ashby, V. Josephson, S. Sydoriak, op.cit.

Problems Involved in Collection of Data

Before starting his sequence of "runs" for any particular parameter setting, the observer aided in setting the signals of various frequencies on the six positions to take up any frequency drift in the system, and to give preliminary observation practice and familiarity with base line irregularities. The frequencies were set manually. Short and longer period nonlinear frequency drift was the major reason for the avoidance of a more desirable automatic system.

Although the spread in long- and short-period variation in a single observer, and variation between observers was assumed to be due to statistical fluctuation, the averaging of results of the several observers resulted in reasonably stable data. The variation between observers normally appeared to be of nearly the same order of magnitude as long-period variation in one observer.

Ample periods of rest were given to remove fatigue considerations. In a complete set of "runs" (by one observer), lasting from one to one and one-half hours, ten to twenty per-cent of the time was used in rest periods taken at approximately fifteen minute intervals, spread throughout the total time.

Each point on the "betting" curves represents the combined influence of five or more observers, with about 24 observations per observer on the significant part of the curve. On the average, then, each point on these curves represents about 120 observations. The total number of runs made was 788, amounting to about 15,000 individual observations.

Equipment

The block diagram shown in Figure 1 indicates the physical arrangement of the apparatus.

"Standard Set" of Parameters

The parameter settings used most frequently while varying any one of them were as follows: (An RDP Panoramic Adaptor was used in making these tests.)

$n = 30$ cps

$F = 10$ Mc

$B = 154$ kc

$b = 9.5$ kc

v = Sweep velocity = 285 cm/sec

T = Signal presentation time = 15 sec

L = Line size = 9.5 cm

Type of Screen -- P1

Ambient Light -- duplicated as closely as possible; hood used, lights off, blinds closed

E_L = A.C. line voltage = 117 v

Range of Parameter Variation

Table 1 below lists the range of parameter variation, together with the ratio of maximum to minimum parameter values:

TABLE 1

Parameter	Range of Variation	Ratio of Maximum to Minimum Parameter Setting
n	3 - 300 cps	100
F	1.1 - 10 Mc	9.1
B	10 - 300 kc	30
b	1 - 45 kc	45

EXPERIMENTAL RESULTS AND INTERPRETATIONS

Variation of Parameter F, Bandwidth Swept

The bandwidth swept out during one cycle of sweep was varied from a maximum determined by the limitations of the system (in this case the reactance tube modulator was the limiting factor) to a minimum determined by the "resolution" of the system. The minimum "resolution" was taken arbitrarily as the sweep width which made large amplitude signals cover on the average, no more than half the distance in both directions from a desired position to the adjacent positions. It may be a consideration for future study to determine a definition for "resolution" in a panoramic system when only one signal is present.

Figure 3 shows the betting curves taken on this parameter for three different bandwidths: 10 Mc, 5.5 Mc, and 1.1 Mc. This earlier data was taken in two different ways: (1) the same constant signal level, measured with respect to a one-microvolt reference level, was maintained for the duration of a complete "run" of say 24 observations. (2) the same constant signal-to-noise ratio (not necessarily the same for any two positions) was maintained during a complete run. Most of the data was taken by this second method; it was only during preliminary work that method (1) was used. The two sets of curves are displaced by an amount determined by their respective reference levels: one microvolt, and mean noise of the six positions.

Figure 4 shows the almost straight line variation of $(S/N)_{50}$ with bandwidth swept, F. (Note the expanded scale in this figure.) A slight increase in "visibility" is noted for small frequency sweeps. (The smallest frequency sweep results in the maximum signal break in the base line.)

Variation of Parameter n, Panoramic Sweep Rate

As indicated in Table 1, the sweep rate was varied from 3 cps to 300 cps. The minimum was determined by the combined limitations of the external sweep generator in use at the time, and the panoramic adaptor. The maximum was that reasonably realizable through modifications of the internal sweep generator and associated circuits. It might be added that there exists close "interlocking" between circuits, and a modification of a given section immediately leads to complementary adjustments in a number of other circuits. This became particularly apparent at the parameter limits. Figure 5 shows the variation of $(S/N)_{50}$ against the parameter n, and shows a decided minimum in the region from 16 to 24 cps. This is at the edge of the flicker region for the type of screen used.

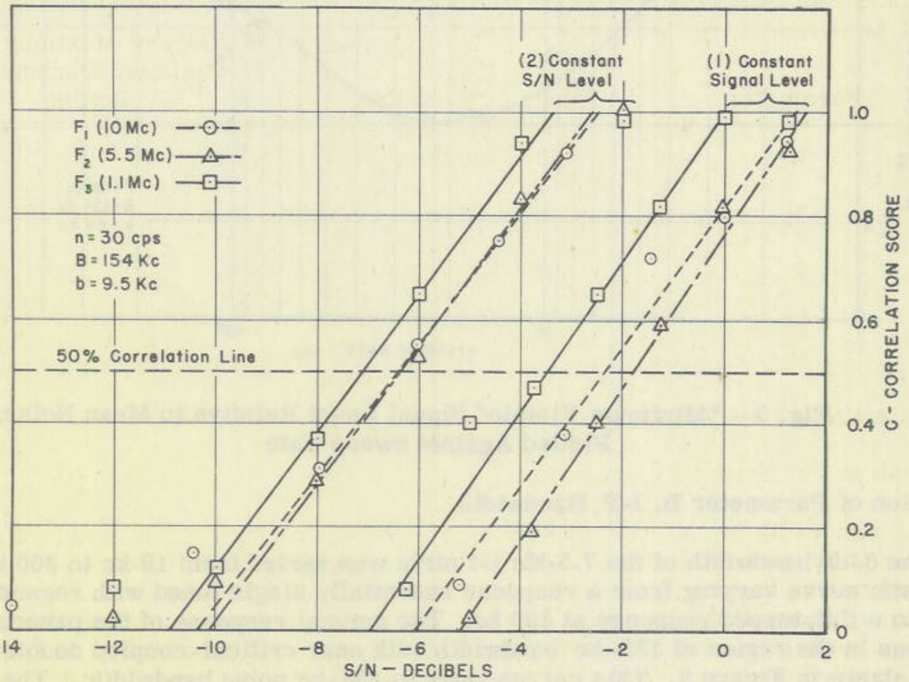

Fig. 3 - Correlation Data for Three Sweep Bandwidths, F, Taken by Two Different Methods

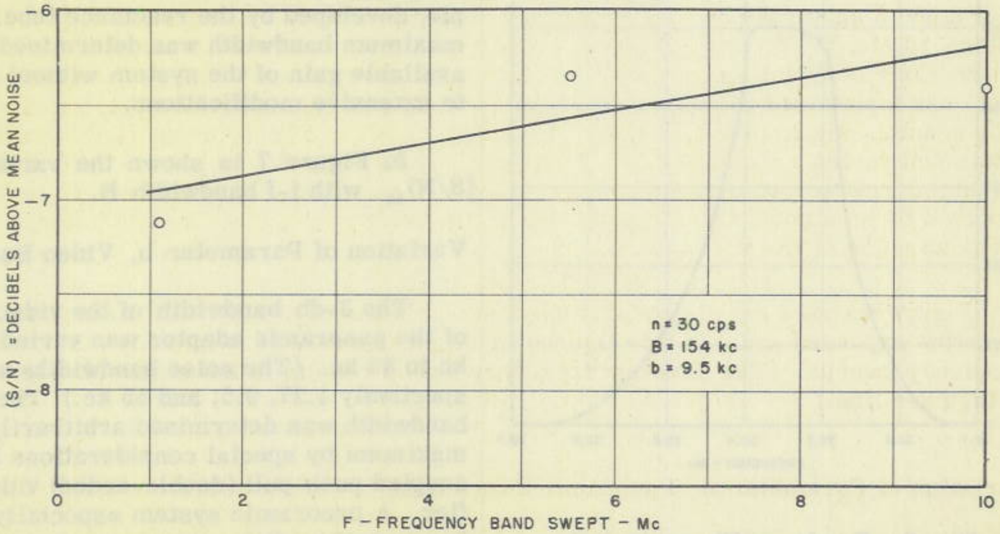

Fig. 4 - "Minimum Visible" Signal Level Relative to Mean Noise, as a Function of the Parameter F

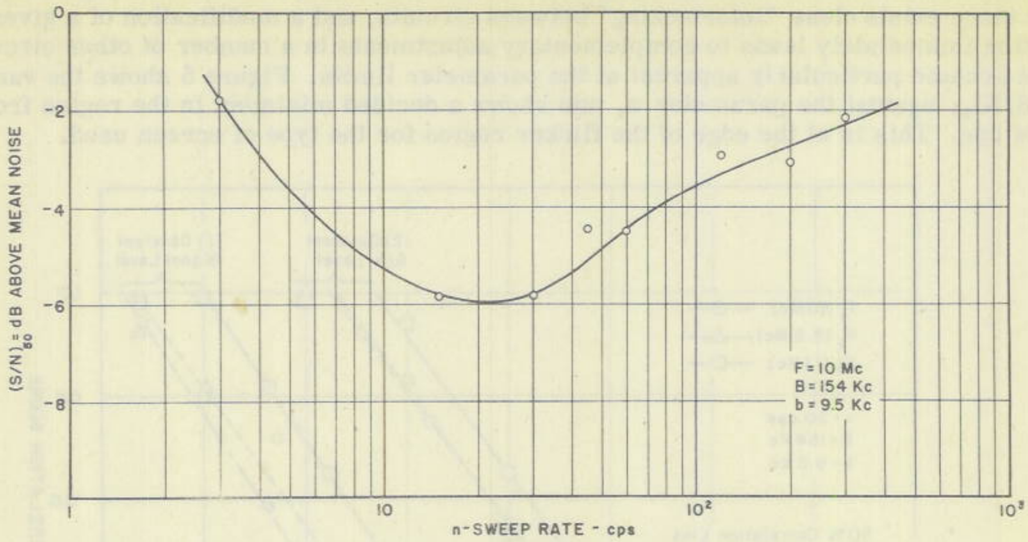

Fig. 5 - "Minimum Visible" Signal Level Relative to Mean Noise, Plotted Against Sweep Rate

Variation of Parameter B, I-F Bandwidth

The 3-db bandwidth of the 7.5-Mc i-f strip was varied from 10 kc to 300 kc, the characteristic curve varying from a response essentially single tuned with regeneration at 10 kc to a flat-topped response at 300 kc. The normal response of the panoramic adaptor used was in the region of 130-kc bandwidth with near critical-coupled double-tuned selectivity, shown in Figure 6. This corresponds to 154-kc noise bandwidth. The minimum bandwidth attainable was determined by the stability of the amplifier and by the residual frequency modulation due to power supply ripple, developed by the reactance tube. The maximum bandwidth was determined by the available gain of the system without resorting to extensive modifications.

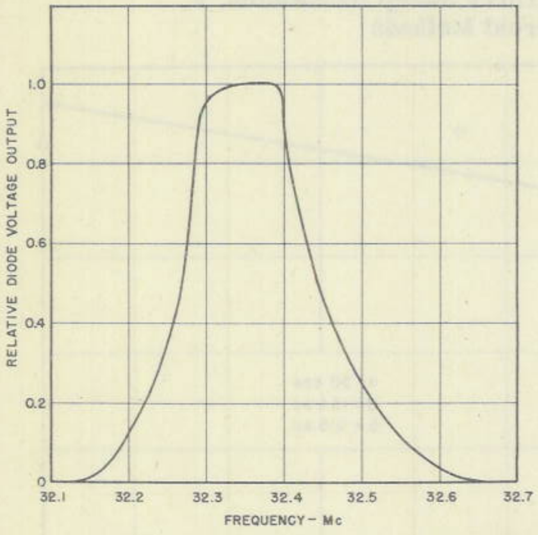

Fig. 6 - Bandpass Characteristic of the 7.5 Mc I-F Amplifier

In Figure 7 is shown the variation of $(S/N)_{50}$ with i-f bandwidth B.

Variation of Parameter b, Video Bandwidth

The 3-db bandwidth of the video amplifier of the panoramic adaptor was varied from one kc to 45 kc. (The noise bandwidths were respectively 1.27, 9.5, and 55 kc.) The minimum bandwidth was determined arbitrarily and the maximum by special considerations in a direct-coupled push-pull (double-ended) video amplifier. A panoramic system especially predesigned for variation of the various parameters seems desirable in future studies of this kind.

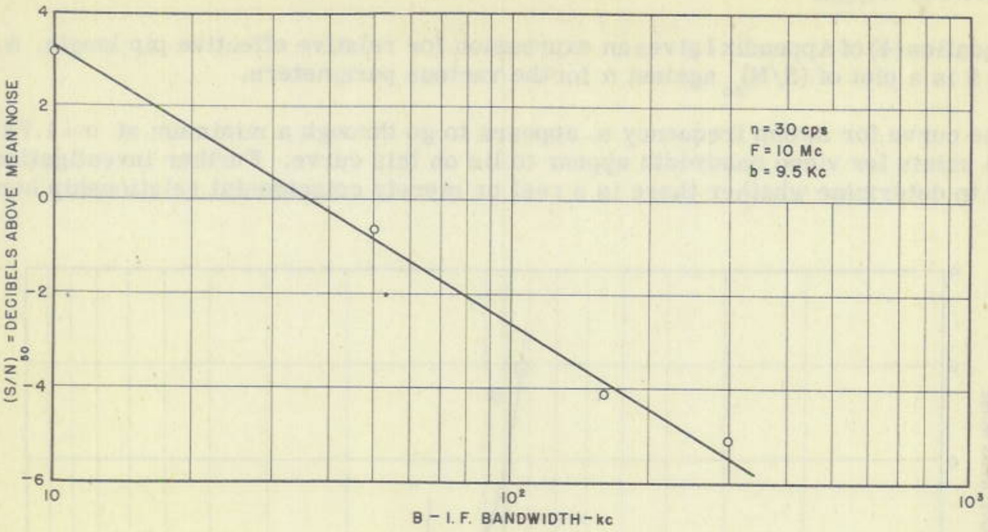

Fig. 7 - "Minimum Visible" Signal Level Relative to Mean Noise, for Parameter B,I-F Bandwidth

Figure 8 shows the small amount of data obtained from variation of the video bandwidth.

Considerable emphasis on video bandwidth appears desirable in any future investigations of this type. Families of curves could be obtained experimentally to verify and extend or modify the tendencies indicated by the information contained here.

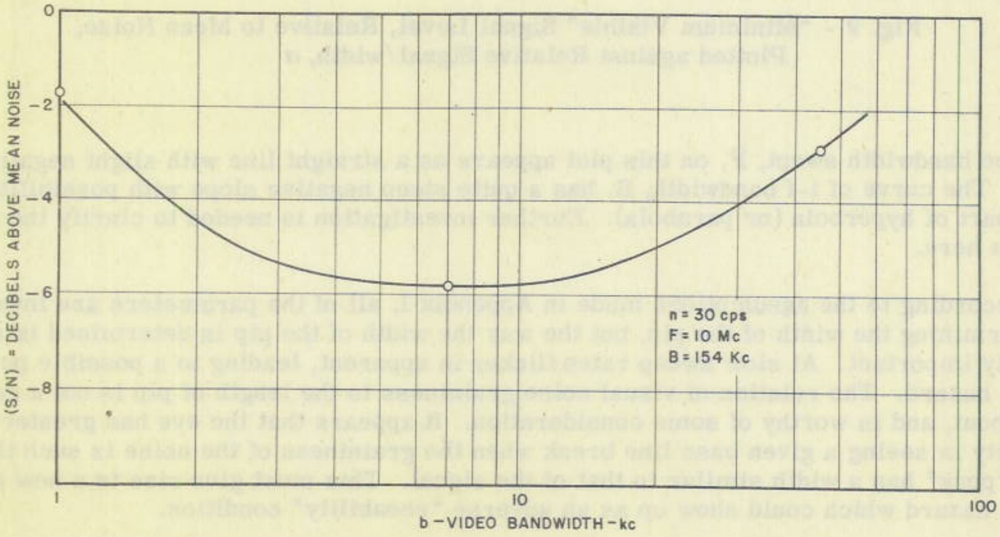

Fig. 8 - "Minimum Visible" Signal Level, Relative to Mean Noise, for Video Bandwidth, b

Effective Pip Length

Equation (4) of Appendix I gives an expression for relative effective pip length, α. Figure 9 is a plot of $(S/N)_{50}$ against α for the various parameters.

The curve for sweep frequency n, appears to go through a minimum at $\alpha = 1.7 \times 10^{-2}$, and the points for video bandwidth appear to lie on this curve. Further investigation is needed to determine whether there is a real or merely coincidental relationship here.

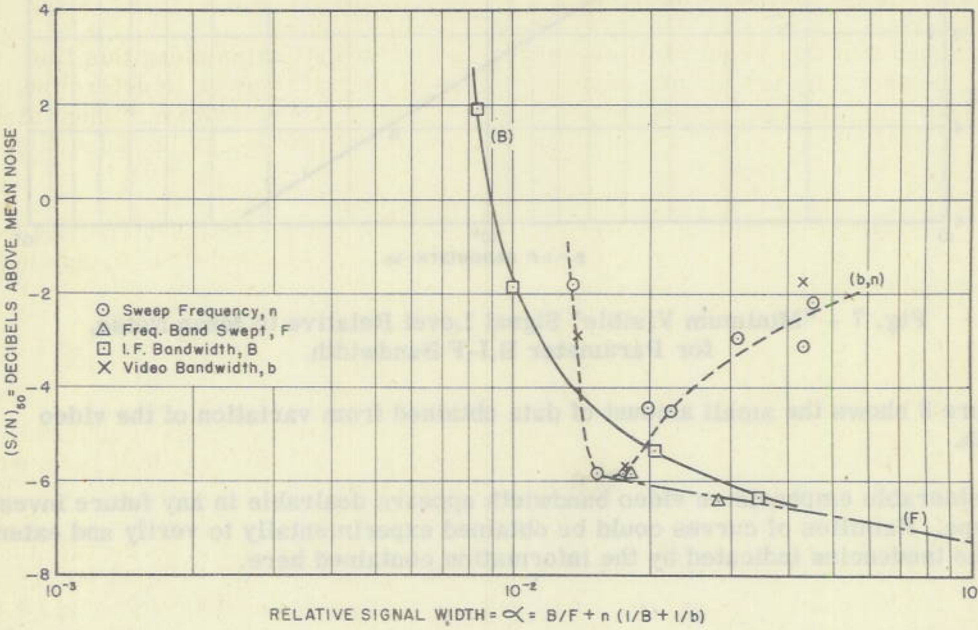

Fig. 9 - "Minimum Visible" Signal Level, Relative to Mean Noise, Plotted against Relative Signal/width, α

The bandwidth swept, F, on this plot appears as a straight line with slight negative slope. The curve of i-f bandwidth, B, has a quite steep negative slope with possibility of being part of hyperbola (or parabola). Further investigation is needed to clarify the tendencies here.

According to the assumptions made in Appendix I, all of the parameters are involved in determining the width of the pip, but the way the width of the pip is determined is apparently important. At slow sweep rates flicker is apparent, leading to a possible psychological hazard. The relation of visual noise graininess to the length of pip is not a constant throughout, and is worthy of some consideration. It appears that the eye has greater difficulty in seeing a given base line break when the graininess of the noise is such that a noise "peak" has a width similar to that of the signal. This must give rise to a new psychological hazard which could show up as an adverse "seeability" condition.

For any given α, it appears that variation of some or all of the parameters might give a favorable "visual noise graininess" to visual signal break condition, as well as favorable "rms" noise and signal amplitude relationship. In Appendix II an attempt is made to express the signal-to-noise visual width ratio.

CONCLUSIONS

Because of the number of pertinent parameters entering into any criterion for minimum visible signal in a panoramic system, it is felt that considerably more data will be necessary before reliable design information can be evolved. For example, in contrast to the radar case, the i-f bandwidth B determines not only the rise time of the signal and the character of the noise, but also the length of the internally generated pulse. The sweep rate not only determines the pulse rate, but enters also into the expression for pulse length. There is also some indication that the video bandwidth b, might be of more importance in this panoramic case.

It is hoped that this report will encourage further investigation along this line. It indicates the necessity for further studies of some of the parameters to determine, from a probability point of view, optimum operating conditions as related to minimum discernable signals. In addition an explicit expression for minimum visible signal as a function of the various parameters is desirable.

The extension of these studies to radar intercept by a panoramic system may lead to modification of any criteria evolved for “optimum” receiver conditions as applied to CW intercept.

PROPOSALS FOR FUTURE STUDIES

At present it is realized that a better use of time could be achieved by placing more emphasis on flexibility of equipment to permit rapid and accurate control of parameter values.

At least two pieces of equipment seem necessary to facilitate and accelerate the collection of data: (1) a generator with a frequency range of at least 25 to 35 Mc, capable of modulation with narrow pulses and (2) a unit consisting of an auxiliary second i-f amplifier, second detector, and video amplifier, with adequate gains and with provisions for variable bandwidths. The bandwidth variation capabilities should be beyond the limitations of the RDP panoramic adaptor.

* * *

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APPENDIX I

Time Width of Displayed Signal

The following is a possible definition of over-all effective pip display time for a panoramic receiver. Let

B = effective equivalent (7.5 Mc) i-f bandwidth

t_0 = time that a stationary CW signal is in the equivalent bandwidth B which is being swept across this signal

F = bandwidth swept out by (reactance tube) modulator, per cycle of sweep

n = panoramic sweep rate

$t_B = K_1^2/B$

$t_b = K_2^2/b$

Then from Figure 10 (b) it can be seen that

$$t_o = t_B + t_b + t_c = (B/F)(1/n). \qquad (1)$$

And the total effective pip time, assuming $t_B = t_D$, $t_b = t_d$, is

$$t_e = t_B + t_b + t_c + t_D + t_d;$$

$$t_e = 2(t_B + t_b) + t_c; \qquad (2)$$

or from (1) and the definitions:

$$t_e = t_o + t_B + t_b;$$

$$t_e = B/nF + K_1^2/B + K_2^2/b \qquad (3)$$

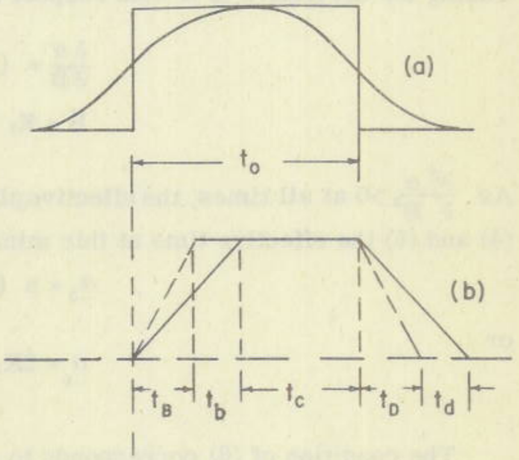

Fig. 10 - Effective Pip Presentation Time for $t_o \geqslant t_B + t_b$

Figure 11 shows the region where $t_B \leqslant t_o < t_B + t_b$. Here $t_0 = t_B + a_1 t_b$ where $0 \leqslant a_1 < 1$, and again the effective time is the same as given by (3):

$$t_e = B/nF + K_1^2/B + K_2^2/b.$$

The region still to be considered is shown in Figure 12 where $t_o < t_B$; it can be seen that the effective pip time is again given by Equation (3); $0 < a_2 < 1$:

$$t_e = B/nF + K_1^2/B + K_2^2/b.$$

By definition let α be the proportion of the total trace occupied by the effective pip length:

$$\alpha = t_e/(1/n) = nt_e;$$

$$\alpha = \frac{B}{F} + n\,(K_1^2/B + K_2^2/b). \qquad (4)$$

[redacted] [redacted]

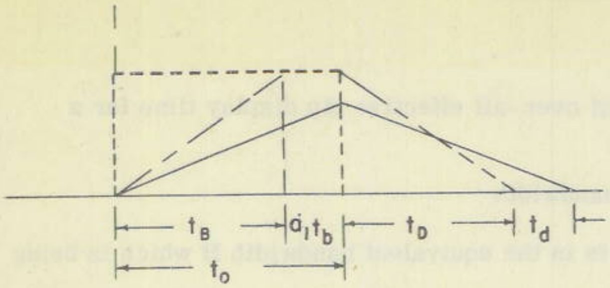

Fig. 11 - Effective Pip Time for $t_B < t_o < t_B + t_b$

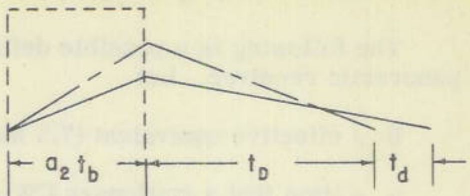

Fig. 12 - Effective Pip Time for $t_o < t_B$

Taking the derivative of α with respect to B and setting it to zero

$$\frac{\partial \alpha}{\partial B} = (1/F) - n K_1^2/B^2 = 0;$$

$$B = K_1 \sqrt{nF}. \tag{5}$$

As $\frac{\partial^2 \alpha}{\partial B^2} > 0$ at all times, the effective pip time is a minimum when (5) is satisfied. From (4) and (5) the effective time at this minimum is given by

$$\alpha_0 = n\ (2K_1^2/B + K_2^2/b),$$

or

$$\alpha_0 = 2K_1 \sqrt{n/F} + K_2^2 n/b. \tag{6}$$

The condition of (6) corresponds to some pip attenuation. The condition for no attenuation, $t_c = 0$, gives

$$\alpha_1 = 2n\ (K_1^2/B + K_2^2/b), \tag{7}$$

which corresponds to an "optimum" resolution.[5]

It should be noted that the information contained in (4) can be given dimensions of bandwidth, say β, by multiplying through by F:

$$\beta = \alpha F = B + nF\ (K_1^2/B + K_2^2/b). \tag{8}$$

* * *

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[5] W. R. Faust, "Resolution of Panoramic Receivers;" NRL Report No. R-2749 (Unclassified)

APPENDIX II

Signal-to-Noise Visual Width Ratio

Assuming that the noise pulse length is small with respect to the build-up times of the i-f and video amplifiers, the effective noise pip width, t_n , under the same assumptions as in Appendix I, is given by

$$t_n = t_B + t_b = K_1^2/B + K_2^2/b. \qquad (1)$$

This corresponds to Figure 12, with $a_2 \to 0$.

Let $\alpha = t_n / (1/n)$, then

$$\alpha = n(K_1^2/B + K_2^2/b). \qquad (2)$$

For the signal

$$t_e = B/nF + K_1^2/B + K_2^2/b. \qquad (3)$$

The ratio of signal display time to noise display time, ϵ, is then

$$\epsilon = \frac{t_e}{t_n} = \frac{B/nF + K_1^2/B + K_2^2/b}{K_1^2/B + K_2^2/b} ;$$

$$\epsilon = 1 + \frac{B}{nF\,(K_1^2/B + K_2^2/b)} \qquad (4)$$

If ϵ is called the signal-to-noise visual width ratio, it can be seen that ϵ can never be less than or equal to unity. It appears that for maximum visibility due to any contrast effects, ϵ should be sufficiently larger than unity.

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