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TRACKING RADAR EXTERNAL RANGE NOISE MEASUREMENTS AND ANALYSIS

[redacted]

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ABSTRACT

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A preliminary investigation has been made of external noise resulting from the finite target size in tracking radar range information using the PB4Y and SNB aircraft as targets. The power spectrum and amplitude distribution function of recorded external range noise is given for each view of these aircraft. The total rms external range noise is shown to be a function of target shape and size. A formula was developed which related target configuration to the total rms external range noise, and which allows the prediction of the rms noise for a given target. Future plans include making a complete study of the external range noise problem using various range error detection techniques.

PROBLEM STATUS

This is an interim report on one phase of this problem; work on the problem is continuing.

AUTHORIZATION

NRL Problem R02-13
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TRACKING RADAR EXTERNAL RANGE NOISE MEASUREMENTS AND ANALYSIS
[[redacted] TITLE]

INTRODUCTION

Radar range information is determined by the time of reception of the target echo with respect to the transmitted pulse. The time of reception of the echo might be chosen as the echo midpoint, leading edge, or some other reference point depending upon the type of range error detector. If the target were composed of a single small flat plate perpendicular to the direction of radiation, the echo pulse would be identical to the transmitted pulse and any reference point on the echo pulse could be used to determine the true radar range of the plate.

A practical target, however, has finite size and presents a distribution of reflecting surfaces over the extent of the target. The resultant echo pulse will be different in shape and length from that transmitted, since it is the sum of the echoes from each of the individual reflecting surfaces. This echo pulse may also change in its time position over the range extent of the target. This change in shape, length, and position will cause a change in range reading depending upon the type of range error detector used. In addition, the target in flight will maneuver, roll, pitch, yaw, and vibrate causing a change in the relative phase of individual echoes with time, in effective area of the reflecting surfaces, and possibly in effective reflector distribution. The received echo pulse will, therefore, change its range information with time, with respect to some fixed point on the target, as these motions at the target take place.

Range noise is defined as the deviation of the range information from some reference point on the target. The choice of the reference point is arbitrary, since this choice has no effect upon the ac components of the noise. The reference point might be chosen as the point indicated by the long time average of the range information; its position indicates the point on the target seen at the radar as the target's true range.

The range noise is a function of the effective target configuration and is contained with the range information that may be extracted from the target echo. The noise, therefore, cannot be eliminated by circuit design, although the noise for some target conditions and configurations might be minimized by choice of the range error detection technique or modification of range circuits.

RANGE NOISE MEASUREMENT TECHNIQUE

The external radar range noise is measured at the error detector output of an electronic range unit[1] tracking the target under investigation. This range unit is modified to allow an operator to introduce manually a "velocity aiding" voltage into the tracking loop to maintain zero average range error or tracking on the effective center of the target. The remaining error voltage is a fluctuation of the range information about this effective center of the target and is the external range noise to be measured. A low-pass filter is

[1]The electronic range unit will be explained in detail in a future report by C. M. Morrow, Tracking Branch, Radar Division.

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placed in the tracking loop to prevent the fluctuations of range error detector output from being tracked out so that open loop range noise data can be obtained.

The range noise measuring circuitry is shown in a block diagram in Fig. 1. The input to the electronic range unit is video information taken from a monopulse tracking radar which tracks the target. The output of the unit's range error detector[2] is recorded on magnetic tape as a measure of the external range noise. In practice the output does contain some true target position information that is not completely tracked out and some of the low-frequency components of range noise will be distorted by entering the tracking loop through the low-pass filter. This undesired true target information and the noise components distorted by the tracking loop fall in the 0- to 0.5-cps range for the courses flown by the aircraft and are removed by low-pass filtering. Since noise data in the 0- to 0.5-cps range would not be reliable without increasing the data runs beyond reasonable length to obtain a sufficient sampling of these components, no effort is made to extend measurement to the lower frequencies.

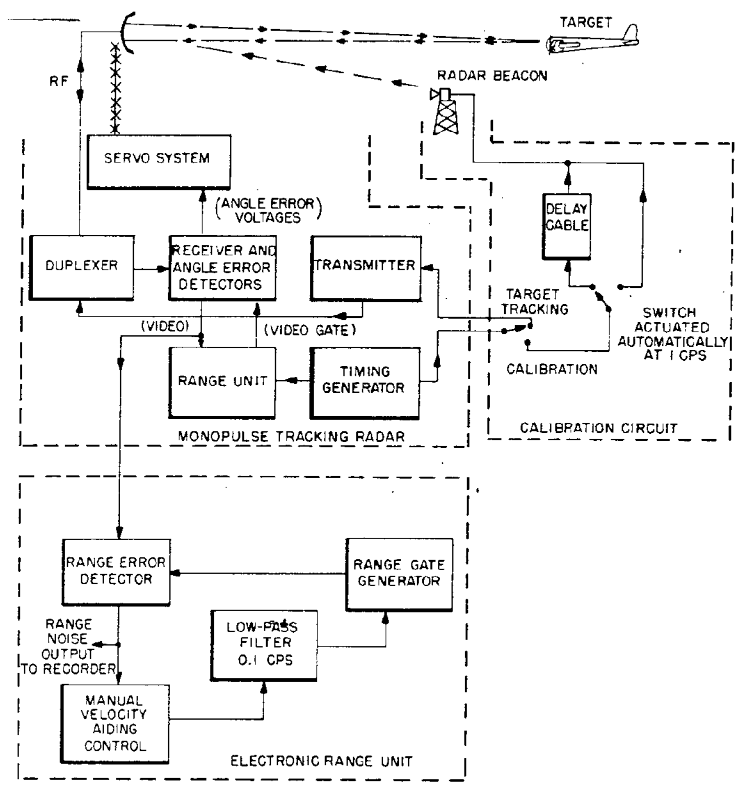

Fig. 1 - Block diagram of the range noise measuring system

[2]The split video type range error detector was used and is described in Appendix A.

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The calibration system shown in Fig. 1 is used to obtain a calibtation factor for the measuring system of volts output of the range error detector per yard range. The calibration is accomplished by delay-modulating a radar beacon with an effective delay of 15 yards peak-to-peak radar range at 1.0 cps. The peak-to-peak range error detector output voltage divided by 15 yards determines the calibration factor.

Range noise data is taken as the target is flown over prescribed courses with nose view, tail view, or side view (circular constant range course) with respect to the radar. The target is picked up visually by a handstand and placed in track by the radar at the beginning of each run. When the operator of the electronic range unit has the unit tracking automatically on target the recording of the range noise data begins.

RANGE NOISE ANALYSIS TECHNIQUE

Sample range noise time function plots are shown in Fig. 2; however, data in this form does not provide a convenient means of comparison or describing its characteristics. To facilitate the noise studies the noise data is analyzed in terms of its power spectrum and amplitude distribution function. The power spectrum presents a convenient picture of the frequency composition of the noise and provides a plot which may be integrated to determine a figure for the total rms noise and the rms noise in the 0- to 1.0-cps band. The amplitude distribution function is a plot of the percentage of time that the apparent center of the target falls at any point on or about the target. This plot is of particular interest in determining, for example, the radar's ability to resolve closely spaced targets. All data is presented in units of yards^2 which are independent of the radar and easily visualized in terms of target dimensions.

Since the range noise signal has a very low-frequency composition which would be difficult to record directly, the range noise is placed on a carrier of 100 cps before recording on magnetic tape. The normal data run is approximately 80 seconds allowing 40 samples of 0.5-cps noise, the lowest frequency component analyzed. This magnetic tape recorded at 1/2 inch per second is spliced into a 40-inch tape loop for analysis of the recorded noise.

The spliced tape loop of the recorded data is played back continuously into a General Radio Wave Analyzer at thirty times the recorded speed to expand the noise spectrum over a convenient range for analysis. The data is analyzed automatically by motor-driving the analyzer frequency control dial linearly through the frequency range and recording the analyzer output on a Sanborn Recorder. To obtain a smooth recording, the output is integrated over a full revolution of the data loop. The recorded spectrum, such as the samples shown in Figs. 3 and 4, is then replotted in power in yards^2/cps bandwidth as explained in Appendix B.

The noise data is incomplete below 0.5 cps as explained in the previous section; however, in the plot of the power spectrum the noise is assumed to remain flat from 0- to 0.5-cps. This assumption is based on the knowledge that noise does exist in this frequency range and does not deviate radically from the value of 0.5 cps. Even large deviations from this assumption would have little effect upon the value of rms noise, however, since the bandwidth in question is so small.

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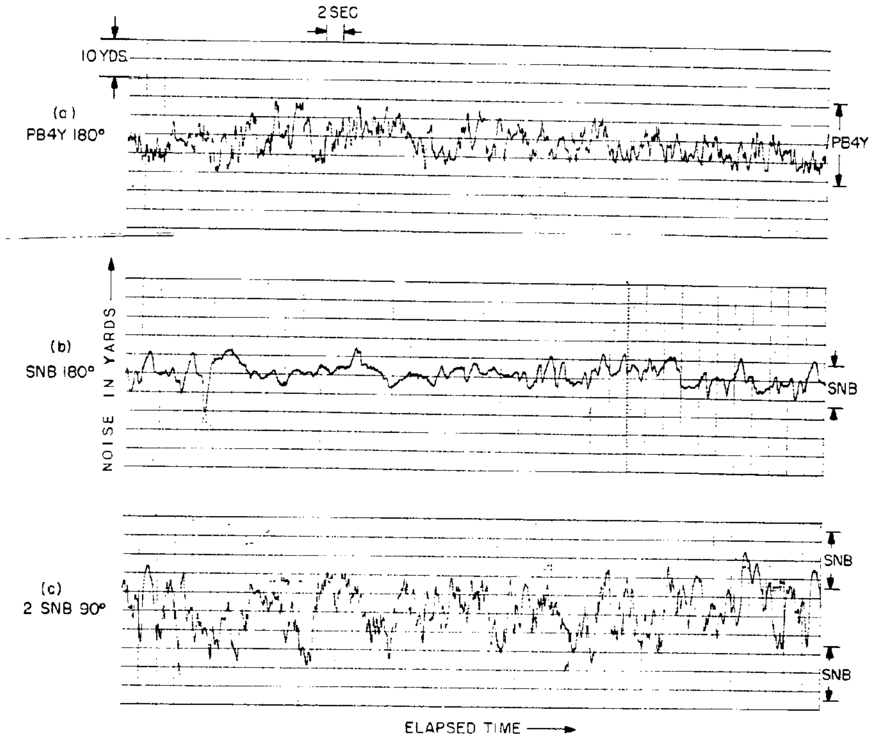

Fig. 2 - Sample time function plots of range noise from the (a) PB4Y at 180 target angle, (b) SNB at 180 target angle, and (c) SNB pair

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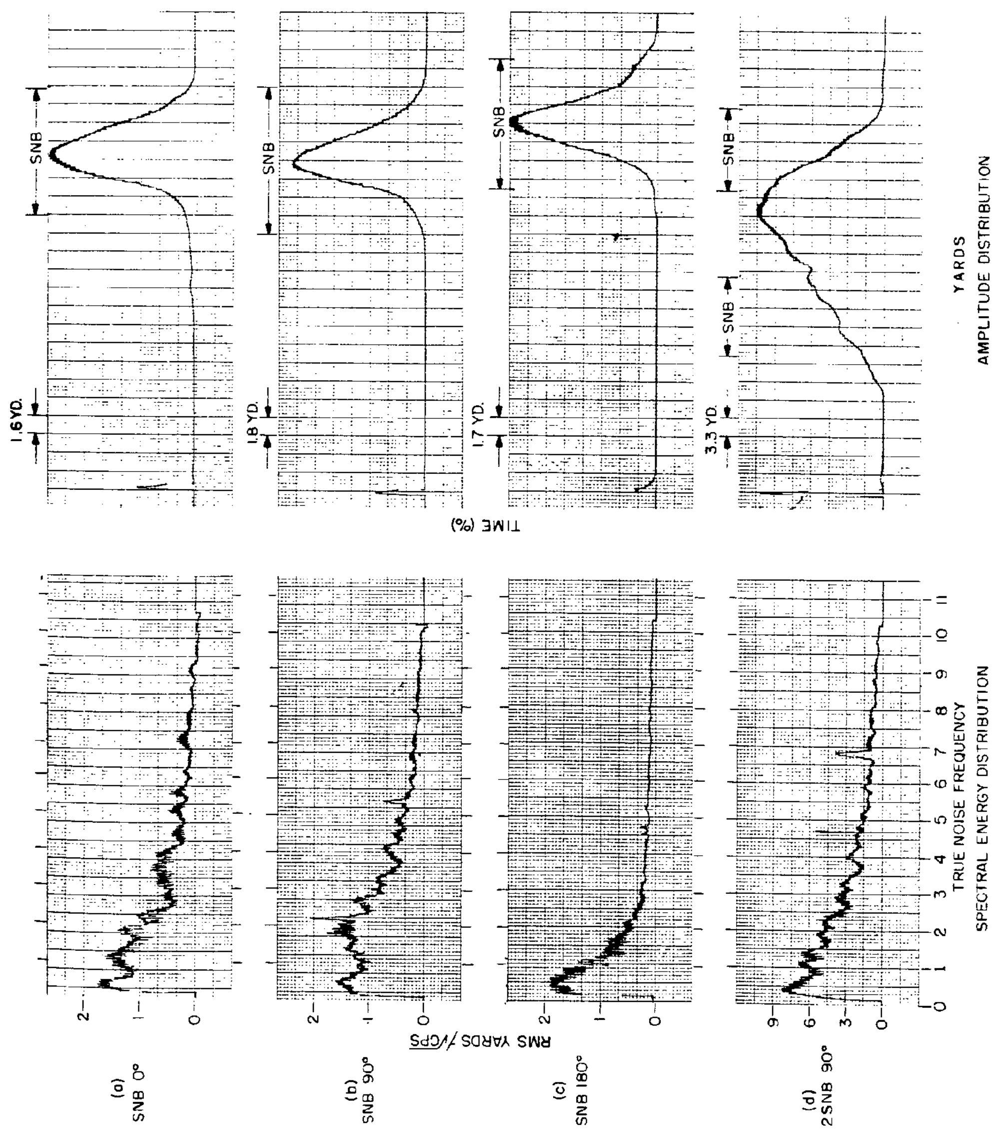

Fig. 3 - Sample spectra obtained for the SNB at target angles of (a) 0°, (b) 90°, (c) 180°, and for (d) the SNB pair

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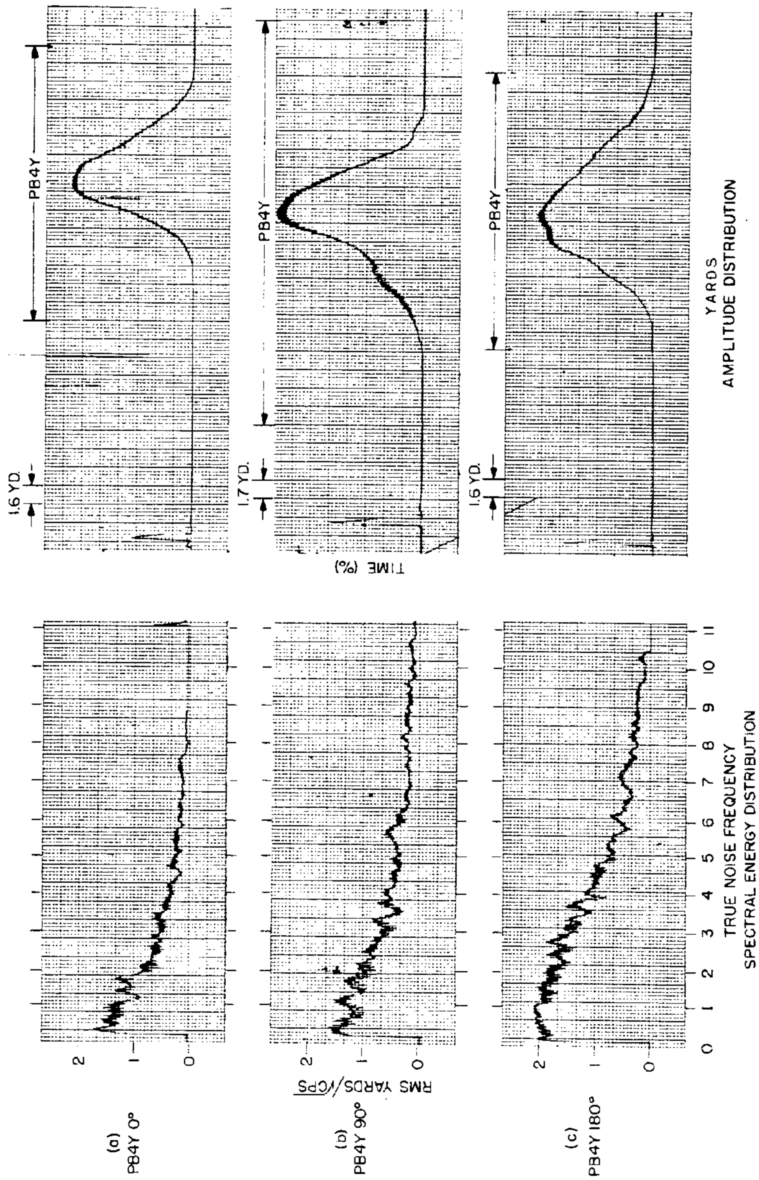

Fig. 4 - Sample spectra obtained for the PB4Y at target angles of (a) 0^0, (b) 90^0, and (c) 180^0

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The amplitude distribution functions such as those shown in Figs. 3 and 4, are recorded on the Sanborn Recorder in a manner similar to that used for the energy spectrum recordings, with the distribution analyzer replacing the spectrum analyzer. The distribution analyzer contains a circuit which will give an output whenever the input falls within a small voltage increment. The output is integrated to determine the total time the signal falls within this increment. This increment is slowly scanned through the full range of the noise voltage by use of motor-driven potentiometers. The scale of the plot is then converted to percent time as a function of yards range.

RESULTS

Radar external range noise measurements were taken for the nose, tail, and side views of the SNB and PB4Y aircrafts (Figs. 5 and 6), and a few measurements were made on a side view of a two-target configuration consisting of two SNB aircrafts flying side by side with a wing-tip separation of 15 yards. Several data runs were made for each aspect of the SNB and PB4Y targets and the information from these runs is summarized in Figs. 7 and 8, and similar plots for the SNB pair are shown in Fig. 9. This data is presented as a plot of the range noise power spectrum from the data runs having the maximum and minimum rms noise and a plot of the average power spectrum of all data for the target. The total rms noise, σ_r, and rms noise in the first cycle, A_R, is indicated for each spectrum plot. This range noise data shows the value and spread of rms range noise and its frequency composition to be expected for the SNB and PB4Y under standard flying conditions. Unusual flying conditions, however, may alter the spectrum shape with possible masking of power in the low-frequency region.

DISCUSSION

A point of greatest interest in the study of external radar noise is the relationship one might draw between target configuration and the resultant range noise. This information would allow one to predict the range noise to be encountered from a particular target with only the knowledge of the target's size and shape. There is insufficient range noise data at present to determine definite functions relating target and range noise similar to the results of external angle noise studies,[3] but enough evidence exists to show that a close analogy exists between range and angle noise phenomena.

Extensive theoretical and experimental studies of external angle noise[3] have shown the total rms angle noise, σ_{ang}, to hold to the relation $\sigma_{ang} = ck_t$ where k_t is the radius of gyration of the target's reflectivity about the tracking axis and c is a constant equal to 0.707. A similar relation could be expected to exist between external range noise and target configuration.

The target configuration seen by the range system is the distribution of reflecting areas along the line from radar to target. For example, in a 0° run the range unit sees the configuration running from nose to tail. Analysis of the range noise data in terms of target configuration is difficult for a single target since the radius of gyration of the target is difficult to approximate. A fair approximation of the radius of gyration of the configuration of a typical aircraft is a $\cos^2 x$ function falling to zero at the target extremities. The radius of gyration, k_t, of this distribution is 0.19 times the distance between the extremities, d.

[3] Meade, J. E., Report to be published on external radar angle noise, and Lewis, B. L., "Simulating the Radar Characteristics of a B-17 Using Smaller Aircraft," NRL Report 4348 (Confidential), October 12, 1954

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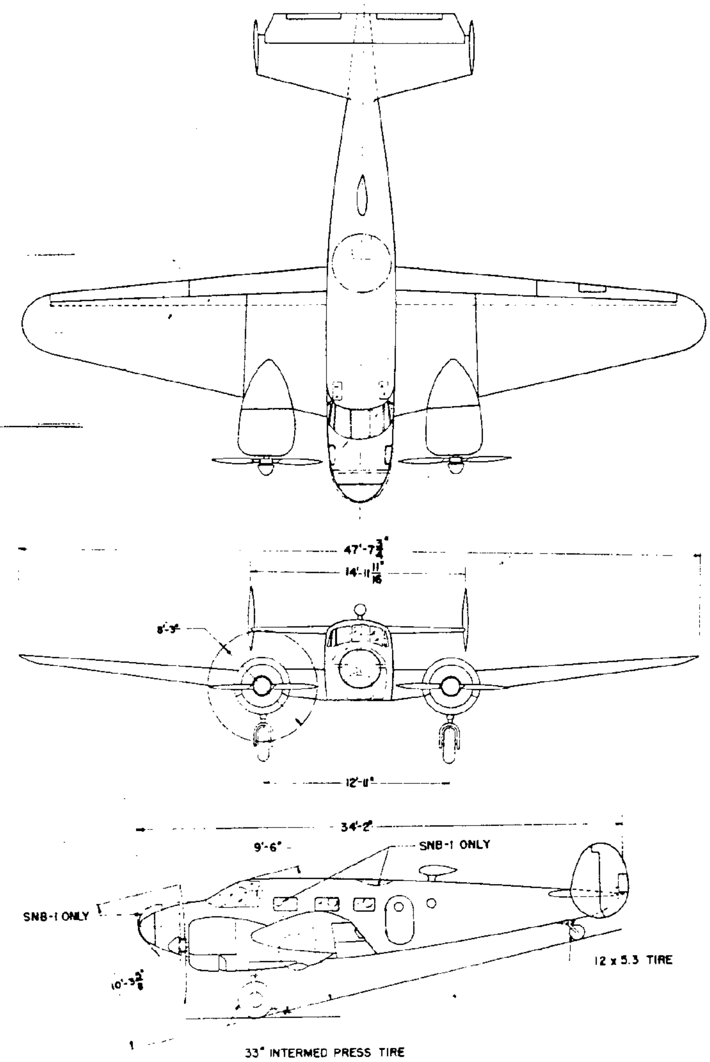

Fig. 5 - Diagram of the SNB

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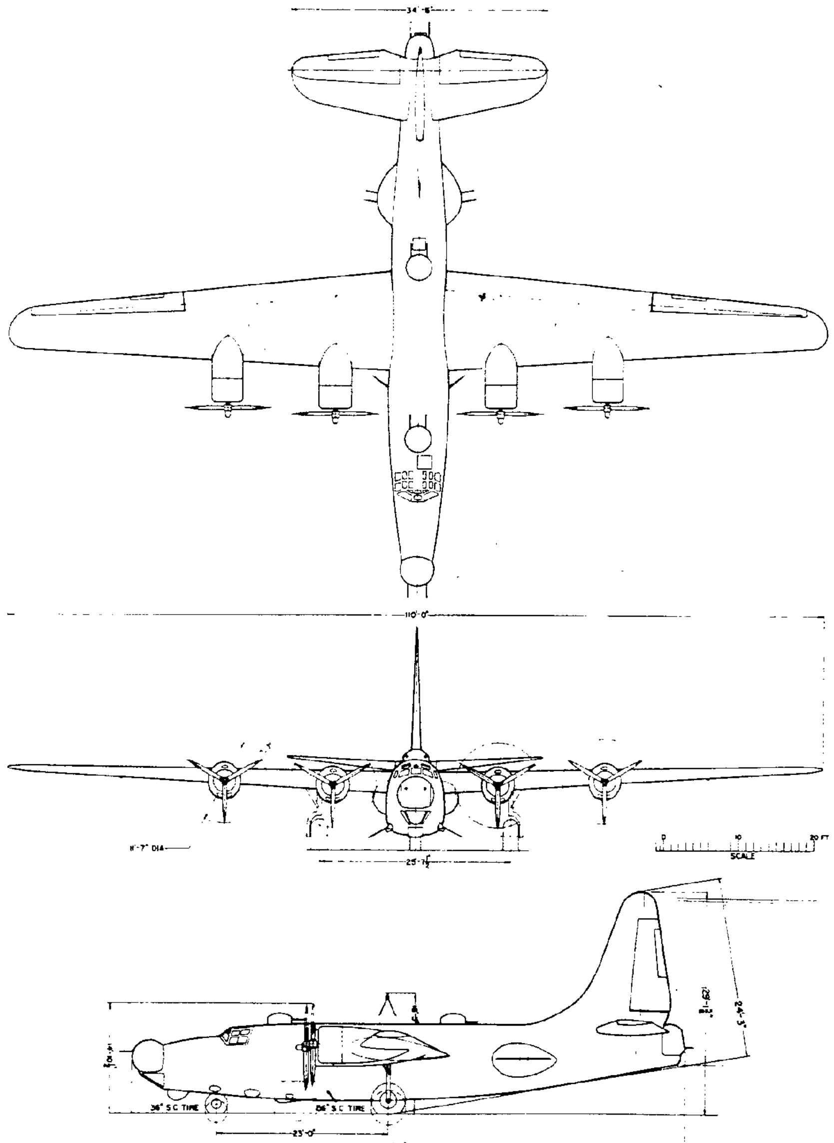

Fig. 6 - Diagram of the PB4Y

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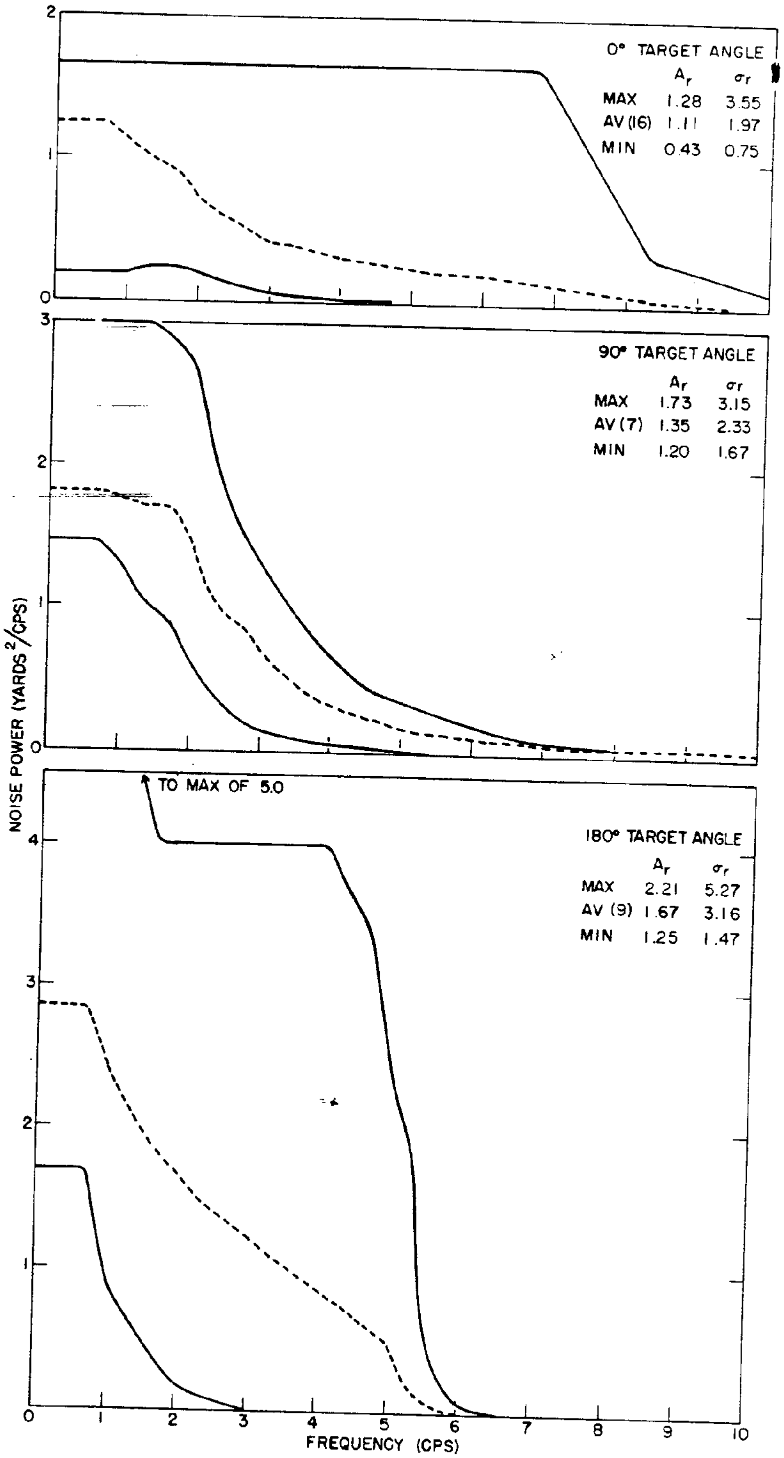

Fig. 7 - Summary plot of spectral power distribution for the SNB at various target angles

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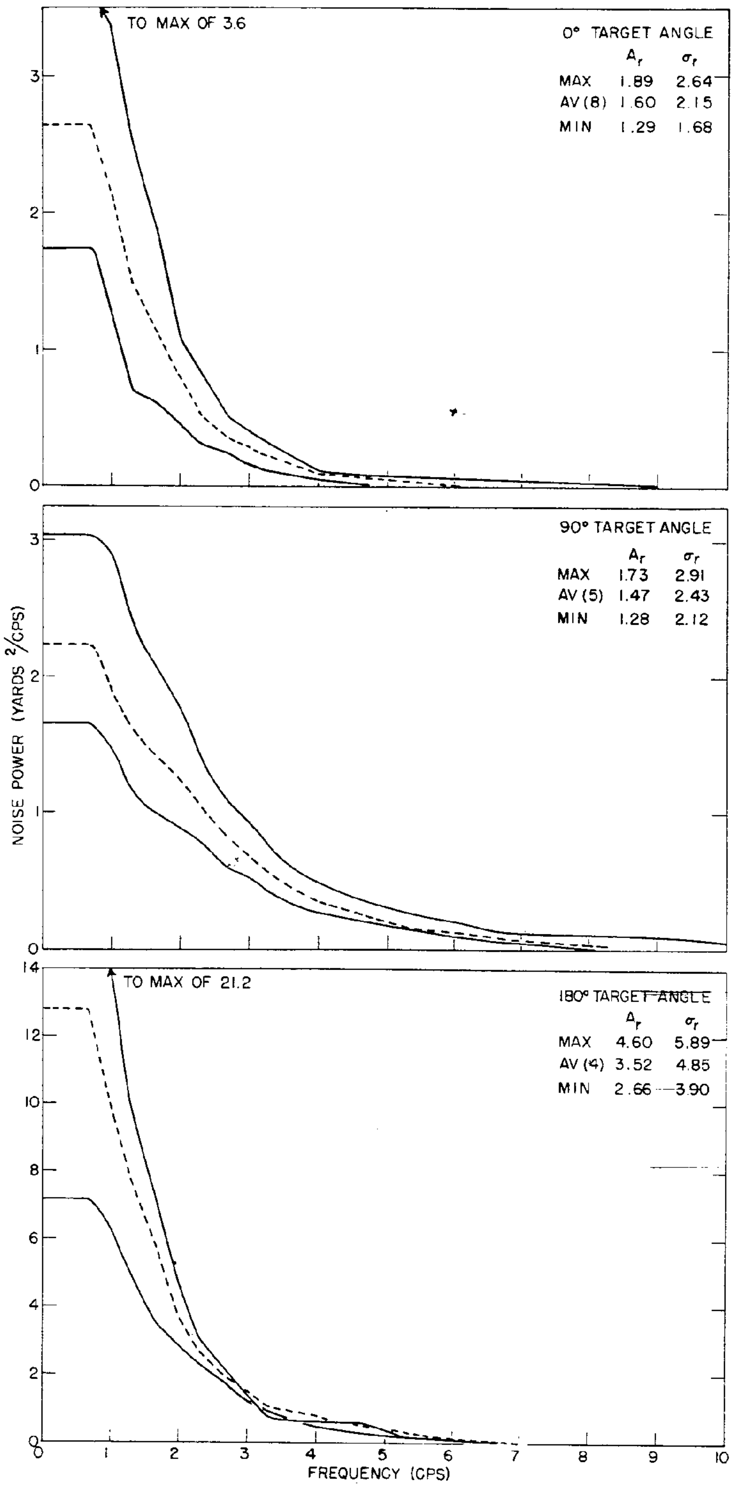

Fig. 8 - Summary plot of spectral power distribution for the PB4Y at various target angles

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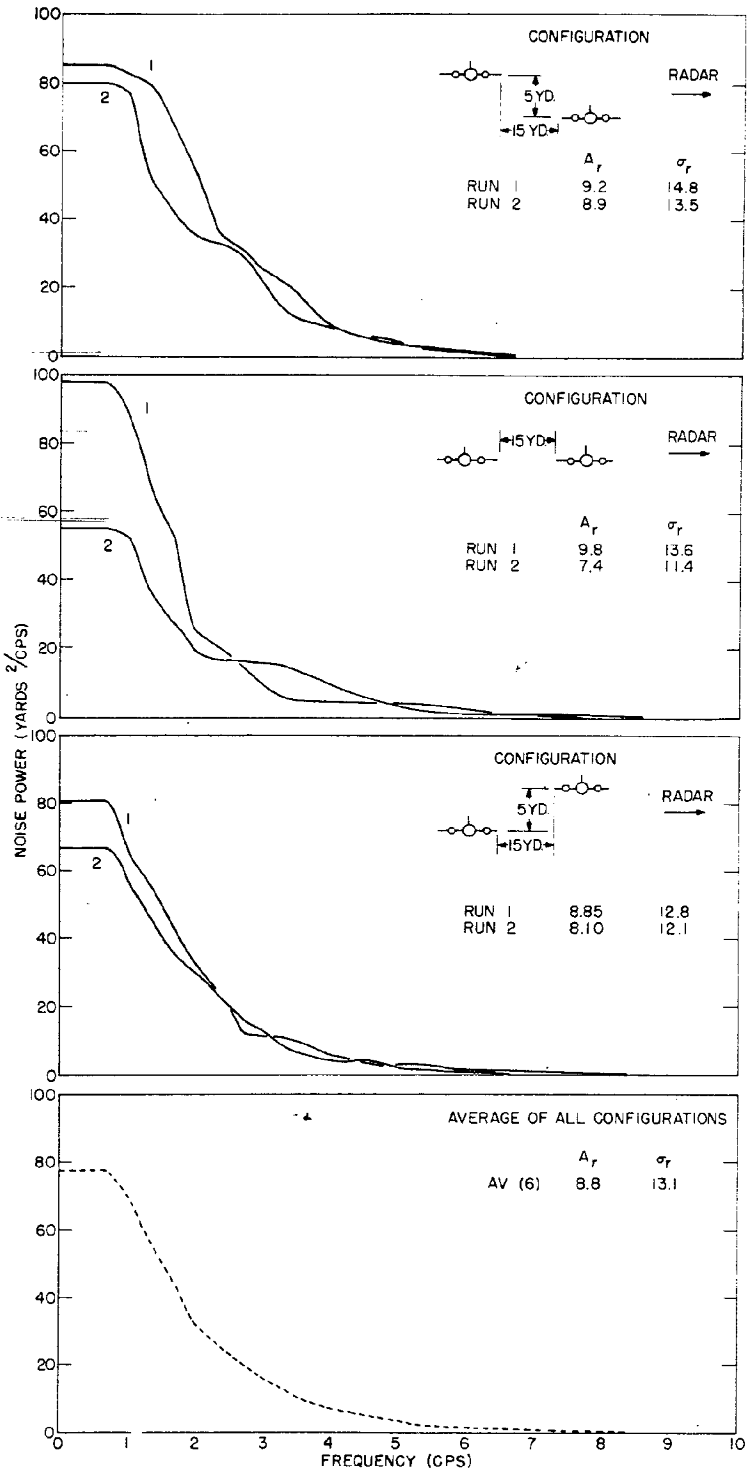

Fig. 9 - Spectral power distribution for the SNB pair for individual runs using various target configurations

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The values of the constant c to complete the equation $\sigma_r = ck_t$ assuming the $\cos^2 x$ distribution (Table 1) remain within 0.35 to 1.46 for the individual target views. This variation may be accounted for by the probable error in estimation of k_t and the normal variation to be expected in noise measurements. Since the average of all views should fall close to the estimated k_t the over-all average value of c, 0.83, may be established as a good figure for estimating the range noise to be expected of a target of known size and shape.

TABLE 1
Calculation of the Constant c Relating
Range Noise and Target Configuration

Target	Target Angle (deg)	Average rms Noise σ_r (av)	Target Span, d (yd)	c*
SNB	0	1.97	11.4	0.91
	90	2.33	15.9	0.77
	180	3.16	11.4	1.46
PB4Y	0	2.15	24.9	0.45
	90	2.43	36.7	0.35
	180	4.85	24.9	1.03
SNB pair	---	---	---	0.83

*Calculated from $\sigma_r = ck_t$, where $k_t = 0.19$ d assuming a $\cos^2 x$ distribution

This value can be seen to be very close to that obtained for angle noise, hence, it appears that a close analogy does exist between angle and range noise phenomena. This is indeed fortunate since so much angle noise data exists to serve as guide lines in future range noise studies. The information from the range noise measurements plus the angle noise data available provide a basis for predicting the range noise to be expected of targets other than those measured in these range noise studies.

The power spectrum plots show a definite trend in the frequency composition of range noise. The spectrum shape of all range noise data for all targets appears to have approximately the same shape with most of the noise power falling below 2 cps and noise components becoming insignificant above 10 cps. The uniformity of the spectrum shape between runs is also indicated in the ratio of the average of the A_R to the average of the σ_r for each target configuration which is within 0.5 to 0.8 for all targets. This indicates that for all targets, essentially one-half of the noise power falls below 1.0 cps. This data, however, was taken under relatively good flying conditions and alterations of spectrum shape would be expected to result from unusual maneuvering or abnormal flying conditions. In general, increased target yaw, vibration, or other motion about its center is expected to spread the noise spectrum to higher frequencies, but should not change the total power.

The two SNB target configuration could supply other information of interest, but time was not available to obtain sufficient data to support additional conclusions. However, one question which normally arises is whether two targets of a given separation may be resolved by the range system. The voltage distribution of each of these runs indicate no resolution of the targets with the approximate 15-yard spacing between wing tips. The 1/4-μsec radar pulse and range gate are equivalent to 40 yards of radar range and the lack of resolution for targets within a 40-yard range increment may be expected.

CONCLUSIONS

1. Fire-control radar range information contains noise resulting from the finite size of the target similar to angle noise.

2. The range noise power spectra for the SNB, PB4Y, and two SNB targets show that all the power is below 10 cps and, in general, one-half the range noise power is below 1 cps. Similar power spectra would be expected for all similar individual aircraft in normal flight.

3. The total rms range noise, σ_r in yards, may be predicted from a knowledge of a target's size and shape since σ_r has been found to be closely approximated by a value 0.83 times the magnitude of the estimated radius of gyration of the reflectivity distribution of the target about its center of reflectivity. The rms value of noise by nature will fluctuate from sample to sample about this value.

4. The radar range system with a 1/4-μsec radar pulse and range gate (equivalent to 40 yards of radar range) apparently cannot resolve two targets of the SNB type with separation of centers of approximately 30 yards and would not be expected to resolve similar targets with closer spacing.

FUTURE RANGE NOISE STUDIES

The information from this data brings to mind many other questions which can be answered only by further experimental and theoretical investigation of range noise. It is proposed to make a thorough investigation of external noise in the range tracking problem. Such an investigation would involve a study of each practical type of range error detection system to obtain noise data similar to the data of the range noise in the split-video detector presented in this report and would answer many questions of interest such as:

1. Range separation of two targets necessary for resolution.
2. Effect of evasive tactics on range noise and tracking.
3. Possible countermeasures to range tracking.
4. Effect of tracking lag on range noise.

These future plans will include a corresponding theoretical analysis to substantiate the results and guide experimental analysis.

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APPENDIX A
Split-Video Range Error Detector

The split-video type range error detector used to measure the range noise compares the occurrence time of the radar echo and the range gate pulse and generates a dc voltage proportional to the difference in the time of occurrence. The split-video error detector gets its name by its operation of forming the video pulse into a double pulse consisting of the original video pulse followed by its image of opposite polarity as shown in Figs. A1(a) and A1(b). This double pulse is called an S-shaped wave which provides a voltage function that may be sampled, and the polarity and magnitude of the sample provides information as to which side of the center of the wave is sampled and how far from center. This information is considered accurate only between the peaks of the wave.

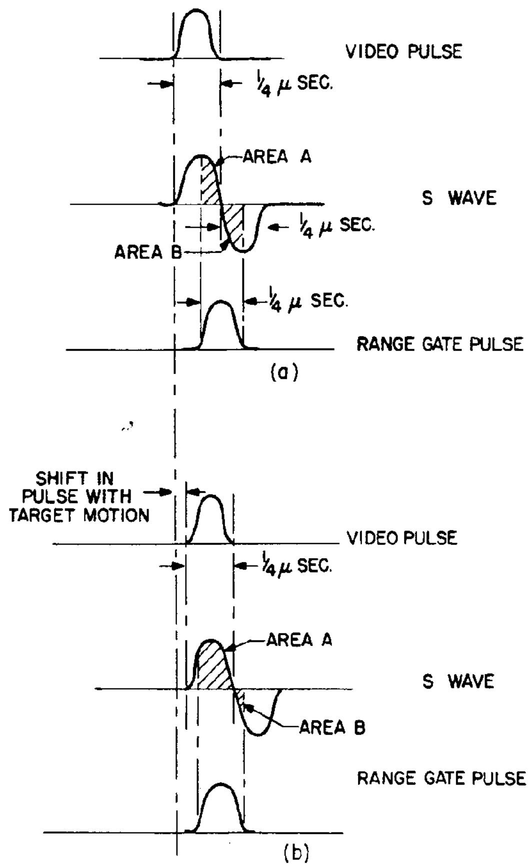

Fig. A1 - Range error detector operation
(a) Range gate position correct, area A = area B
(b) Change in target position from that in (a) causes area A to be greater than area B, and the resultant error voltage will correct the range information and gate pulse position

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The sampling of the S wave is accomplished by a range gate pulse which samples by integrating a portion of the S wave. If the range gate is centered on the S wave the integrated area is zero as shown in Fig. A1(a). If the range gate is off center as shown in Fig. A1(b) the integrated area will have a resultant positive value indicating an error in position of the gate pulse to the left.

As shown in Fig. A2, the S wave is formed by the video pulse at the output of V1 plus its reflected image from the shorted end of the 1/8-μsec delay line. This delay locates the negative image immediately following the original 1/4-μsec video pulse. The range gate pulse causes V2 and V3 to conduct effectively shorting one end of C1 to ground. Capacitor C1 will then assume a charge proportional to the area of the S wave during the conduction period. At the end of the gate pulse V2 and V3 are held at cutoff by the charge built up on C2 and C3. Capacitor C1 is left floating with its charge and the resultant voltage is fed to a dc amplifier. The components R4 and C4 filter the error information to average from pulse to pulse.

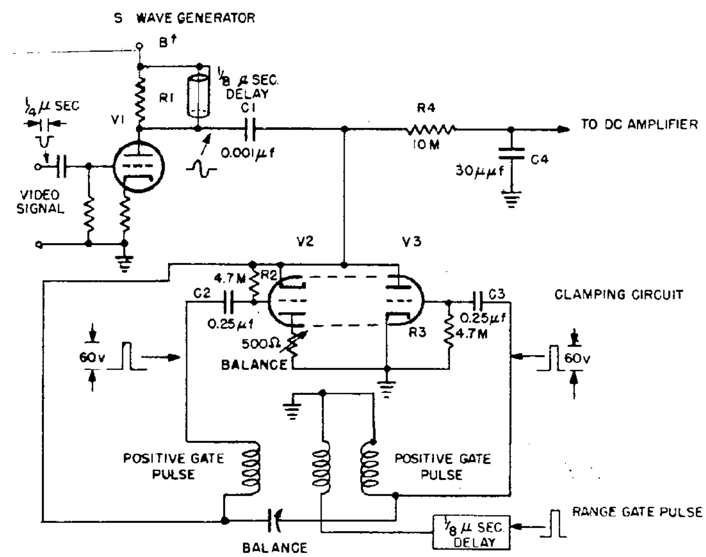

Fig. A2 - Range error detector schematic

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APPENDIX B
Computation of Range Noise

The Sanborn recording of the range noise voltage spectrum is used to plot the noise power spectrum from which the total rms noise, σ_r, and rms noise in the 0-to 1-cps band, A_R, are computed. Conversions are made in the computations to express the results in the more convenient form of rms yards independent of the radar sensitivity, and to normalize the noise data reference bandwidth of measurement to unity cps of true noise frequency.

In measurement of the spectrum of noise one must qualify the data by the bandwidth of the measuring equipment, since noise power is proportional to bandwidth and does not exist at any one point of zero bandwidth in the spectrum. The noise power measured at 200 cps with a General Radio Wave Analyzer, for example, is the noise power in the band from 198 cps to 202 cps and may be expressed as x units of power per 4-cps bandwidth at 200 cps and not simply as x watts of noise power at 200 cps.

The power spectrum of the noise may be plotted as shown in Fig. B1(a) from the wave analyzer output by plotting the square of each rms voltage reading at discrete intervals of frequency. The power spectrum will be noise in volts^2 per 4-cps bandwidth as a function of frequency. The average height of each 4-cps interval of the spectrum, as shown in Fig. B1(a) is the total power within the interval. To obtain total noise power one may add the average height of each interval which is effectively integrating the spectrum with an abscissa scale of unity for every 4-cps interval as indicated in Fig. B1(a).

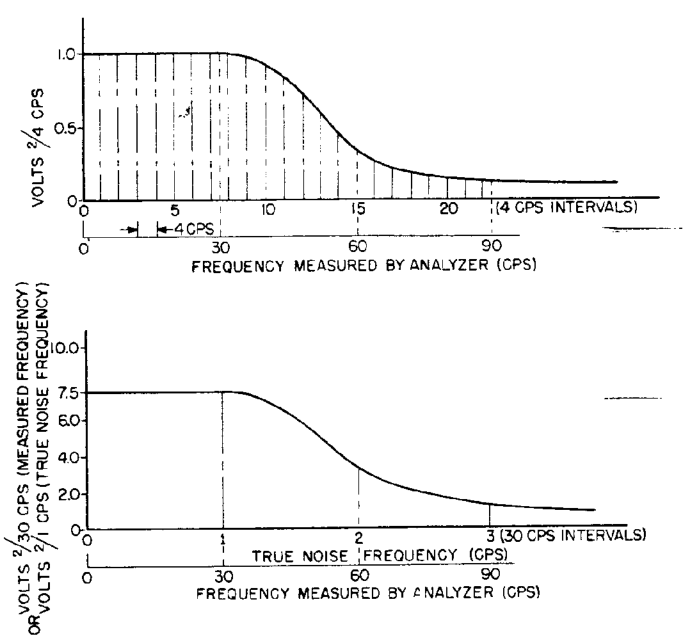

Fig. B1 - Effect of measurement bandwidth on noise spectrum plots
(a) Measured noise power spectrum
(b) Noise power spectrum with converted scales

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A different scale from the original measurements may be desired. For example, it may be more convenient to plot the spectrum in Fig. B1(a) in volts^2 per 30-cps bandwidth where the average height of the 30-cps interval will represent the total power over that interval. This replot is shown in Fig. B1(b) where the interval of bandwidth on the abscissa is expanded 30/4 or 7.5 times with a similar compression of the ordinate scale to 7.5 for unity in plot (a). This conversion may be checked intuitively by considering the power in the first 30 cps of the two plots. In plot (a) the power in the first 30 cps is the sum of the average height of the first 7.5 intervals. Since each average height is unity the power is 7.5 volts^2 in the 0- to 30-cps range. In the second plot this power is the average height of the first interval which is also 7.5 volts^2.

To integrate plot (b), as explained above, it is necessary to change the abscissa scale to unity for each interval. In the range noise data, because of speeded-up playback, the true noise frequency is one cps for every 30 cps of measured frequency and plot (b) as scaled for integration is also conveniently scaled in terms of true noise frequency and the ordinate may be labeled volts^2 per cps true noise frequency.

The range noise data is also converted from volts to yards to give values independent of the radar set. This conversion is accomplished by use of the 15-yard peak-to-peak square-wave calibration recording. When a magnetic data tape loop has been analyzed with the spectrum analyzer the tape is removed and a tape loop with the calibration signal is played back into the analyzer as the analyzer is driven through the first harmonics of the calibration square wave. Figure B2 shows the spectrum recorded on the Sanborn Recorder followed by a recorded spike which is the first harmonic of the 15-yard 1-cps calibration square wave.

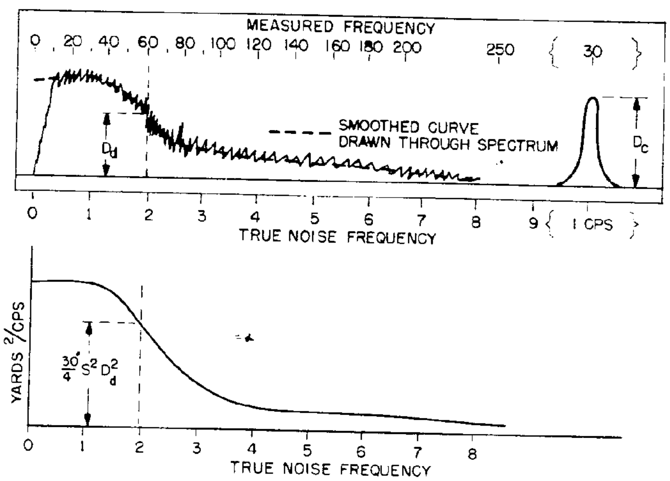

Fig. B2 - Power spectrum plotted from analyzer recording
(a) Sanborn Recording spectrum plot
(b) Replot of spectral energy distribution recording as a spectral power distribution.

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The conversion factor S in yards per division of ordinate scale is given by

$$S = \frac{H_c}{2.3\ D_c} \quad \frac{G_c}{G_d} \qquad \text{(B1)}$$

where H_c is the peak-to-peak value of the calibration square wave in yards, $H_c/2.3$ is the rms value of the first harmonic in yards, D_c is the height of recorded calibration first harmonic in divisions (Fig. B2), G_c is the gain of wave analyzer during recording of calibration tape, and G_d is the gain of wave analyzer during recording of data spectrum.

By multiplying the height D_d in divisions of any point of the data spectrum by S yards/division, one obtains a reading of yards or, by squaring, yards^2 indicating noise power per 4-cps measured frequency. As explained in previous paragraphs, the noise power P in yards^2 per cps true noise frequency is then given by

$$P = \frac{30}{4} \quad S^2 \quad D_d^2. \qquad \text{(B2)}$$

The power spectrum is a plot of P for values of D_d taken from the original Sanborn recording at discrete intervals of frequency.

* * *

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