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# [illegible] CHARACTERISTICS [illegible]

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U. S. NAVAL [illegible] LABORATORY
WASHINGTON, D.C.

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## ABSTRACT
[Secret]

The Project Music radar system was created for the purpose of exploring, with actual moving targets, all of the problems associated with coherence of signals, crosscorrelation, storage, filtering, and ionospheric propagation phenomena in the hf band. This research radar is basically a coherent-pulse doppler radar in which the crosscorrelation and integration is accomplished by an automatic frequency and phase control circuit called an active filter.

The performance of the active filter was measured with inputs of simulated target signals and white noise. Improvement near the theoretical limit for the system in output signal-to-noise ratio over input signal-to-noise ratio was obtained. At the input, the minimum detectable signal was 26.5 db below the noise level, and with this input level the output signal was 16.0 db above the noise level. The performance of the complete Music radar system was measured with actual aircraft targets, and no degradation in results from those obtained with simulated signals was found. These results highlight the ability of the system to reject completely the effects of the enormously large backscatter clutter encountered in the hf band.

## PROBLEM STATUS

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

## AUTHORIZATION

NRL Problem R02-17
Project NR 412-000, Task NR 412-006

Manuscript submitted November 6, 1958

# PERFORMANCE CHARACTERISTICS
# OF THE MUSIC RADAR SYSTEM
[Unclassified Title]

## INTRODUCTION

The Project Music radar system is basically a coherent-pulse doppler radar in which the crosscorrelation and integration is accomplished by an automatic frequency and phase control circuit (afpc), called an active filter, which replaces up to 3600 fixed-frequency narrow-band doppler filters in each range gate. This research radar was created for the purpose of exploring, with actual moving targets, all of the problems associated with coherence, crosscorrelation, storage, filtering, and also line-of-sight and ionospheric propagation phenomena in the hf band.

Earlier, a simulated radar had been developed to determine whether the full theoretical enhancement in signal-to-noise ratio over a one-hit radar was obtainable in a system employing crosscorrelation and storage techniques. Simulated signals were buried in artificial noise in this experiment, and it was found that almost exactly the gain in signal-to-noise ratio predicted by theory was realizable. The successful solution of the problems associated with this system led to the question of how much of the theoretical gain in signal-to-noise ratio can be retained with actual moving targets, where the echos might be degraded in various ways. Consequently Project Music was established to answer not only this question but also many others, as suggested previously. This report is concerned only with the question of determining how much of the theoretical gain in signal-to-noise ratio can be obtained with actual moving targets.

## EQUIPMENT

A simplified block diagram of the Music radar is shown in Fig. 1. Only a single receiving channel and the circuits of one range gate are shown. A more complete description is available elsewhere.* The transmitter operates on 26.6 Mc, with a pulse power of 6.4 kw and a pulse width of 250 μsec. Provision is made for rapidly selecting a pulse-recurrence rate in steps of 2 to 1 from 15-5/8 to 500 pps. A rotatable two-bay Yagi antenna which has a gain of about 12 db is used with the system. A photograph of the Music radar system, exclusive of the transmitter, is shown in Fig. 2. Figure 3 shows the transmitter exciter, driver, final amplifier, and power supply.

Phase coherence is maintained in the system by generating all local-oscillator and timing signals from one master 100-kc crystal oscillator. Double conversion is employed in the receiver. The 400-kc "local-oscillator" signal is a stored copy of the rf transmitter pulse obtained from the storage system. Storage input is derived from the monitor receiver, which is a low-gain device that monitors the transmitter output.

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*G. [illegible] and F. M. Gager, "Crosscorrelation Electronic Storage Radar," NRL Report 5016 (Secret Report, Uncl. Title), Oct. 29, 1957

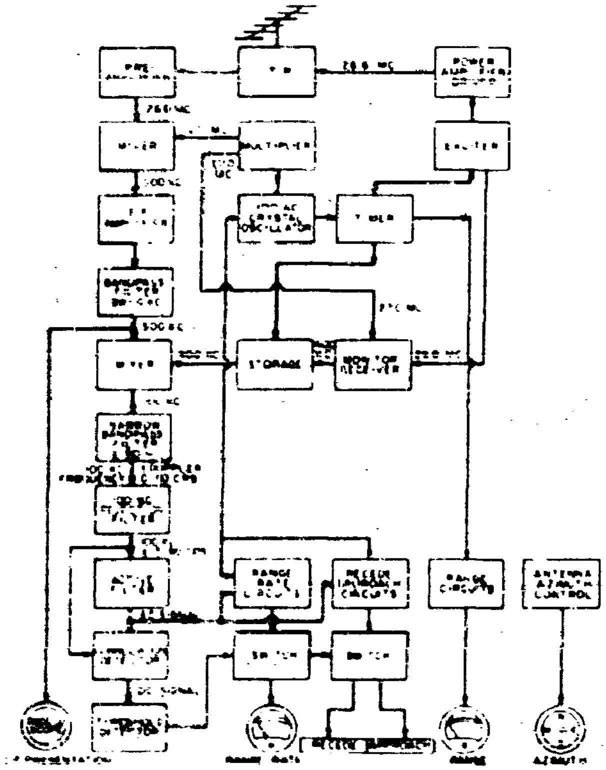

Fig. 1 - Simplified block diagram of Music system

Since the signal readout of storage is a 400-kc copy of the transmitter pulse, it effectively gates the main receiver on for the time of one range element. The delay in readout after the [illegible] of the rf transmitter pulse determines the range position of this gate. In turn, the readout delay is controlled by the timer unit. Thus the mode of operation is to set the gate at, for example, 150 naut mi; airborne targets will be subject to detection upon entering an area 20 naut mi deep (at this range) and as wide as the antenna beam. If circuits for the other gates were included, then all areas illuminated by the antenna beam could be placed under surveillance. (Within a given range gate, multiple targets cannot be discriminated. In order to distinguish more than one target within a range gate, active filters may be paralleled, with the obvious limitation that perhaps no more than three or four can be practically utilized.) Storage was added to the system to provide the flexibility of various coding and modulations of the transmitter output.

Fig. 2 Basic radar system exclusive of the transmitter

The final receiver i-f frequency was deliberately made equal to 100 kc, the frequency of the master crystal oscillator, to simplify range-rate determinations, as will be discussed later. A narrow-bandpass filter and a narrow rejection filter, both centered on 100 kc, follow next in the 100-kc chain. The purpose of these filters is twofold. At this operating frequency, enormously large backscatter echos (potentially 100 db above minimum detectable signal) are received from very long ranges (1000 to 1500 mi). Since the radar normally operates with shorter base ranges, these signals are unresolvable and ambiguous, hence they completely obscure all but very close-in large targets. The characteristics of this backscatter were extensively investigated, particularly with respect to its spectral bandwidth.* It was found that the sideband energy was down to the level of the antenna and receiver noise in a filter bandwidth of 1/20 cps at plus and minus 4.0 cps from the i-f carrier frequency. In other words, all of the backscatter signal energy that could raise the threshold of detection of a crosscorrelation system is contained in the ±4-cps band around each repetition-rate

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* C. K. Jensen and C. L. Uniacke, "Spectral Bandwidth of Backscatter Signals," NRL Report 4976 (Secret Report, Uncl. Title), Aug. 1957

component of the pulse spectrum. Consequently, it is apparent that if a rejection filter with a slightly wider bandwidth and with sufficient attenuation in the stop-band is connected in the i-f chain, the backscatter can be completely eliminated. The only penalty is the loss of the first five cycles of the doppler band; this is of little consequence in the proposed applications of the system. Since pulse shape does not need to be retained, the system may simply narrow-band around only the carrier component of the signal, the other spectral components being rejected by the narrow-bandpass filter which precedes the rejection filter. Otherwise, if all spectral components are admitted to the product detector of the crosscorrelator, then a rejection filter to eliminate backscatter must be designed for each component frequency.

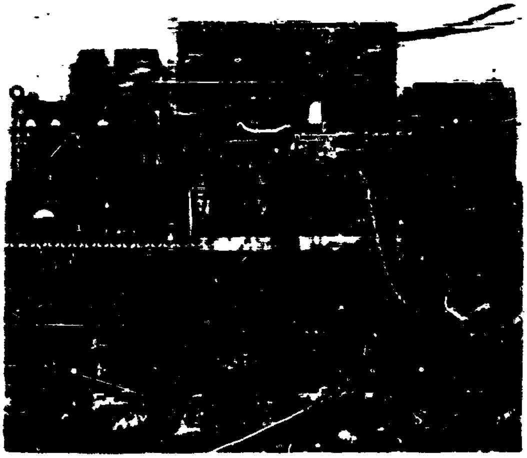

Fig. 3 - Transmitter exciter, driver, and final amplifier

The output of the 100-kc rejection filter drives the active filter. In the Music radar system, the active filter (Fig. 4) performs the crosscorrelation function by multiplying the signal with a reference and then integrating or narrow-banding around it. The cutoff frequency of the low-pass filter is such that the effective output bandwidth is less than 1/20 cps. In the absence of backscatter signals, the input bandwidth as determined by a filter preceding the active filter may be as large as desired, if one wishes to compare the performance of the active filter with a conventional radar; however, this bandwidth ideally should be no wider than necessary (for largest signal-to-noise ratio at the input) to pass the most signal energy and the least noise energy, where it is desired to preserve a semblance of pulse-envelope shape. For a 250-μsec pulse, the bandwidth may be as narrow as 4.0 kc. For the Music radar system, a narrower bandpass filter may be used just ahead of the active filter, subsequent to range gating, as previously described (Fig. 1). The overall bandwidth narrowing will remain the same, but the input dynamic range requirements of the active filter will be reduced because of reduced noise power. when backscatter signals are present this is very necessary.

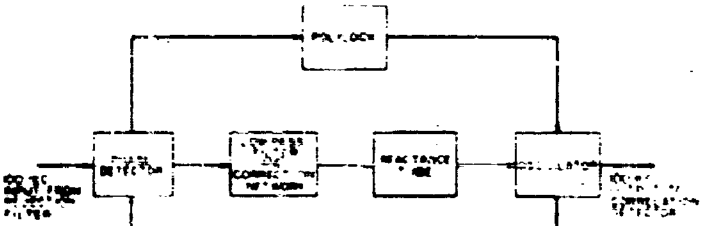

Fig. [illegible] - Block diagram of the active filter

The active filter is tuned to operate in a band of doppler frequencies centered on 100 kc. It will automatically lock onto a doppler signal either above or below 100 kc, corresponding to approaching or receding targets, even though the signal is buried many db in noise. At the same time that it acquires targets, it effectively acts as a very narrow-band filter, providing a large degree of signal-to-noise enhancement. The operating theory of an afpc circuit has been published* and will not be repeated here. An evaluation of this circuit will be given later in this report.

When the active filter has acquired a target, its doppler signal will appear at the output of the active filter, still at the i-f frequency, but with a much larger signal-to-noise ratio. This enhanced signal may now be directed to the range-rate circuit, as indicated in Fig. 1, where it is compared with the master 100-kc frequency to measure its actual doppler frequency. Once the doppler frequency is known, radial range rate is also known. Likewise, the active filter output is fed to a second circuit which determines whether the doppler frequency is above or below the master 100 kc, to provide the recede or approach indication.

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*G. J. Jensen and J. E. McGeogh, "An Active Filter," NRL Report 4630 (Unclassified), Nov. 1955

Range in the system is determined by the delay between the transmitter keying pulse and the receiver gating signal. Azimuth is obtained from the heading of the Yagi antenna.

The correlation detector and threshold detector are included in the system to give a positive indication when the active filter acquires a target. Figure 5 shows the correlation detector. The phase detector and low-pass filter in the correlation detector are similar to those in the active filter. A 90-deg phase shifter is placed in the essentially noise-free reference signal received via the connection from the active filter. Thus the correlation detector compares the phase coherence of the output signal of the active filter with the noisy input signal to the active filter and, if there is a phase lock, provides a maximized dc output voltage proportional to input signal strength; otherwise only noise appears here. Since the bandwidth at this point is 1/20 cps, as determined by the single-section RC low-pass filter, the full enhancement in signal-to-noise ratio from bandwidth narrowing occurs between here and the receiver input. Actually, two enhanced outputs are used, one from the active filter and the other from the correlation detector. The signal-to-noise ratio at the output of the correlation detector will never exceed that of the active filter, and furthermore there will be no signal at this point if the active filter has not acquired a target. Conversely, the active filter may have a greater output signal-to-noise ratio under certain circumstances than the correlation detector, because of its narrower bandwidth. The dc voltage, therefore, may be used to operate a threshold detector which is preset to actuate appropriate indicators upon detection of a target that causes an output dc voltage to rise a predetermined number of db above the noise level in the 1/20-cps bandwidth. The correlation detector also provides a satisfactory means of measuring the performance of the active filter, as will be described.

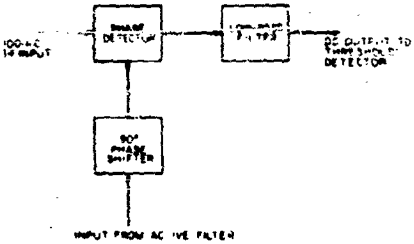

Fig. 5 - Block diagram of the correlation detector

## PERFORMANCE OF THE ACTIVE FILTER

Since the improvement in signal-to-noise ratio with crosscorrelation in this radar system occurs in the active filter, the active filter's performance has been measured both with simulated signals and with actual targets as a part of the radar system.

## Measuring System

Figure 6 shows the experimental setup employed in the investigation of the active filter's performance. A correlation detector, or crosscorrelator, was used to measure the response of the active filter to the various input signals. A signal generator tunable ±90 cps from 100 kc provided the simulated low-level doppler target signals. Likewise, a noise generator supplied white noise extending over a wide band centered on 100 kc. These signals are next added in a linear circuit. The circuit is linear in the sense that the signals and noise produce currents and voltages which are simply additive without the complicated intermodulation effects between different frequency components such as occur in nonlinear systems. The linearity of the adder may easily be verified by measuring various combinations of input powers and the output power with a true-power-reading instrument. Linearity is important in a crosscorrelation system for optimum results. Care has been exercised in both the experimental measuring setup of Fig. 6 and the complete radar system of Fig. 1 to maintain linearity in all circuits from input to narrow-band output.

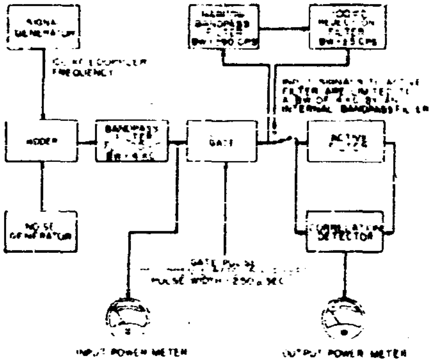

Fig. 6 - System for measuring the active filter

Referring again to Fig. 6, a band-limiting filter restricts the bandwidth of the white noise and signal output of the adder. The bandwidth of this filter was made 4.0 kc, to make it comparable with a conventional radar; this results in the optimum signal-to-noise ratio for a 250-μsec pulse width. Obviously no excessive bandwidth exists, yet the pulse-envelope shape is approximately preserved. The input signal-to-noise ratio is measured here (thus a common base exists for comparing the Music system with a one-hit radar). The signal and noise are next gated, which does not change the signal-to-noise power ratio, and then they pass either directly to the active filter and correlation detector or via a narrow-band filter and 100-kc rejection filter with characteristics previously described. It can be shown that the overall improvement in signal-to-noise ratio is the same either way. The output at the correlation detector is measured with a true-power-reading instrument. The total improvement in signal-to-noise ratio achieved from the 4.0-kc-bandwidth filter output to the correlation detector output can be determined from the power measurements.

## Measuring Procedure

Special precautions must be taken to insure that all measurements of signal and noise levels are true power readings. The measuring instrument may be either a true-power-measuring device such as a thermocouple meter or some other type of instrument which has been calibrated to read power for the particular waveforms used in the measurement. The thermocouple meter and other instruments may also be calibrated in rms volts. Sometimes it is more convenient to use an oscilloscope at the input to examine and measure the signal and noise levels. The rms voltage of the signal can easily be determined by measuring the peak-to-peak voltage of the sine wave with the oscilloscope and then by calculation finding the rms value. Determination of the rms voltage of white noise is not readily accomplished at first, but with experience good accuracy can be achieved. If a known level of white noise is impressed on the oscilloscope, it will be found that the peak-to-peak voltage level at which only 0.01 percent of the noise peaks exceed the level is 7.8 times the rms voltage of the noise. With experience, this level can be read with good accuracy; thus the rms voltage value of the noise can also be measured with an oscilloscope. The above factor divided by two is known as the peak factor of thermal noise.

The output of the correlation detector consists of a dc voltage, which is proportional to input signal level, and a noise voltage superimposed on the dc voltage by addition (the entire system is linear at every point). Since the output bandwidth is 1/20 cps, the noise fluctuations will occur at a very slow rate. This requires that any power measurement must integrate over at least several minutes to realize an accurate reading of noise power. A sensitive thermocouple meter with a very long time constant was developed for this measurement, but other instruments may also be used, such as a recording dc voltmeter on which integration time is represented by storage or chart time, and a dc vacuum-tube voltmeter, where the integration time must come from the operator's memory. In the cases of the recorder and vtvm, these instruments must have an ac frequency response up to 1/2 cps, which selected ones do have, to insure a faithful display of signal and noise voltage fluctuations. The signal voltage is read off the recorder chart by noting the average displacement of the trace between a signal-off and a signal-on condition. The peak-to-peak noise voltage is determined by noting the plus and minus levels which are exceeded by only 0.01 percent of the noise peaks. At least several minutes of chart must be examined to fix these levels. Once the peak voltage of the noise is known, the rms value is obtained by dividing by the peak factor. The same procedure may be used with a vtvm with nearly the same accuracy.

## Theory

Before a measurement of the improvement in signal-to-noise power ratio from input to output of the active filter and correlation detector, consideration should be given to the maximum of theoretical improvement possible. A cross-correlator such as the correlation detector with a noise-free reference and a phase-coherent cw input signal with no gating of noise or signal will have an improvement I of

$$I = \frac{P_{so}/P_{no}}{P_{si}/P_{ni}},$$

where

$P_{so}$ is the output signal power
$P_{no}$ is the output noise power
$P_{si}$ is the input signal power
$P_{ni}$ is the input noise power.

The output-power signal-to-noise ratio is

$$P_{so}/P_{no} = (B_{in}/B_{on_{eff}})(P_{si}/P_{ni}).$$

Hence

$$I = B_{in}/B_{on_{eff}}$$

where

$B_{in} = \pi/2 B_i$, the input noise bandwidth
$B_{on_{eff}}$ = the effective output noise bandwidth
$B_{on} = \pi/2 B_o$, the output noise bandwidth
$B_i$ = the input 3-db bandwidth
$B_o$ = the output 3-db bandwidth.

Where the input noise bandwidth is determined by a single resonant circuit, it can be shown that the noise bandwidth of the circuit is $\pi/2$ times the bandwidth at the 3-db points, as measured with a signal generator. Likewise, the output noise bandwidth of the single-section low-pass RC filter is $\pi/2$ times the 3-db bandwidth. The effective output bandwidth is

$$B_{o_{eff}} = 2\left(\frac{1}{2\pi RC}\right) = \frac{1}{\pi RC}.$$

The effective output bandwidth is twice the cutoff frequency of the filter, because with conversion to zero i-f the noise powers of both sidebands are folded together, resulting in more noise than that due to simple bandwidth narrowing. Also, the effective output noise bandwidth is $B_{on_{eff}} = 1/2RC$. Thus the overall improvement would seem to be

$$I = \pi B_i RC.$$

However, the improvement is actually

$$I = 2\pi B_i RC. \qquad (1)$$

Equation (1) contains a factor of 2, which arises from the fact that the output signal voltage is a constant peak dc voltage, because the output has been maximized on a peak made possible by the active filter locking onto the doppler signal. If the signal had been an ac doppler signal, as normally would be the case in the absence of an active filter, an ac output voltage would exist whose rms value could be measured. However, with the active filter, a dc output voltage is obtained at an amplitude equal to the peak value of the ac voltage signal. Since the signal and noise powers must be expressed in the same units, the output signal-to-noise power ratio will be increased by the factor of two.

Equation (1) is the expression for improvement when no gating of signal or noise input is involved. When both signal and noise input to the crosscorrelator are gated, as they are in the system, then

$$I = 2\pi B_i RCd, \qquad (2)$$

where duty factor $d = \frac{\tau}{T}$

$\delta$ = pulse length

$\tau$ = repetition period.

If values as used in the system are assigned, then

$f_r = 4.0$ kc

$d = 1/8$

$$B_{eff} = \frac{1}{2\pi RC} = \frac{1}{2\pi(1\times10^5\times10\times10^{-6})} = 1/20 \text{ cps},$$

and I = 44.8 db from Eq. (2). This is the maximum improvement to be expected, based on a noise-free reference. With the larger values of input signal-to-noise ratio, the active filter does provide an essentially noise-free reference to the correlation detector. The bandwidth of the low-pass filter incorporated in the active filter has been made one-fifth the width of the correlation detector's bandwidth to help insure this. However, the active filter does have a lower limit of operation below which it fails to lock and acquire targets with very low-input signal-to-noise ratios. Therefore a considerable departure from theoretical improvement should be expected in this region. The pull-in range of the active filter decreases with lowered input ratios, reaching zero pull-in at the point at which it fails to lock. Since detection is required over the full ±90-cps doppler band, the minimum detectable signal is considered to be at the level at which the pull-in range of the active filter is ±90 cps. At this signal level, the target-acquisition time is 10 to 20 sec. With larger signals, this time rapidly diminishes.

## Results

The performance of the active filter and correlation detector was measured with the experimental equipment shown in Fig. 6. A series of input signal and noise levels was used, and the resulting output signal and noise levels were noted. In all cases, the peak-to-peak input voltage of the signal and noise combination was maintained at the largest possible amplitude to insure that the full linear dynamic range of the bandpass filter circuit, which represents the input of the system, was utilized. Because there is a minimum usable signal level, this helps insure the possibility of nearing the limits of theoretical improvement. The radar system is also customarily operated in this way.

The results of the measurements are plotted on Fig. 7. Both input and output signal-to-noise ratios have been plotted as a function of the correlation-detector dc output voltage. This voltage is proportional to the input-signal amplitude. The graph shows that the smallest detectable signal is 28.5 db below the noise level and that the minimum detectable signal level at which the pull-in range is ±90 cps is 26.5 db below the noise level. At this input level, the output signal is 16.0 db above the output noise level. Hence the total improvement here is 42.5 db. With larger input levels, the total improvement reaches very nearly 44.8 db. In automatic alarm radars, where output signal-to-noise ratios of 12 db and up are required, very nearly all of the total improvement in signal-to-noise ratio would be usable, from the minimum-requirement standpoint. The threshold detector in the Music system is adjustable, permitting a choice of positive-output signal-to-noise ratios lying anywhere from zero db to 20 db. Once the signal dc output voltage exceeds the selected level, the several indicators are switched on to announce the acquisition of a target and at the same time to make the target information available. Data have been taken with the narrow-bandpass and 100-kc rejection filter both in and out of the chain, with identical results; therefore only one graph is shown.

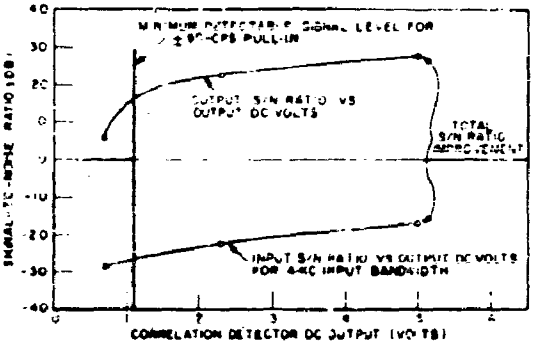

Fig. 7 - Performance characteristics of the active filter

The improvement shown on Fig. 7 is for a duty factor of 0.125. When the input signal and noise has a duty factor of 1.0, it is found that the input signal-to-noise-ratio curve is moved 9.0 db lower. Then the minimum detectable signal level is 35.5 db below the noise level, instead of 26.5 db. Data were taken with a duty factor of 1.0, but it was not presented graphically. Conversely, if the duty factor is reduced, the input signal-to-noise-ratio curve will move upward, reducing the overall improvement.

## PERFORMANCE OF THE SYSTEM

Now that the performance of the crosscorrelation circuits with simulated signals is known, the question arises, will any degradation in performance occur with actual target signals? Degradation primarily refers to an undesirable increase in the minimum detectable signal level due to certain characteristics of the target. Therefore, to determine the possible existence of degradation it is necessary to use target signals with levels near the minimum detectable level (-26.5 db). A calibrated active-filter correlation detector system will readily provide values for the input and output signal-to-noise ratios, but a second independent measurement of the input signal-to-noise ratio is necessary if a meaningful determination of degradation is to be achieved.

Measurement of a signal many db below the noise level is a difficult task without correlation. One method is actually to select and measure a target echo at the output of the 4.0-kc-bandwidth filter that is above the noise level, then drop the transmitter power a known amount, such as 20, 26, 32 db, etc., the assumption being that the received echo will also be reduced by the same number of db. This is the method that was employed. The input signal-to-noise level to the crosscorrelation system was measured at the output of the receiver, where the signal and noise are narrowed to 4.0 kc by the 4.0-kc-bandpass filter (Fig. 1). At the same time, the output of the correlation detector was measured both with the high-level signal and the reduced-level signal. The output signal-to-noise ratio was measured in both cases.

With a knowledge of the correlation-detector output dc voltage, the input signal-to-noise ratio that the correlation system claims to see in a 4.0-kc-input bandwidth can be read from a calibration graph such as Fig. 7. This can be compared with the independent measurement of input signal-to-noise ratio both at high and low levels. At high levels, a close agreement between the two readings should be found, provided the independent reading is made with due caution, as will be discussed later. If agreement exists, then the methods employed in both the measurement and calibration of the correlation system and the measurement of the independent signal-to-noise ratio will in large part be validated. With low levels, a close agreement between the two readings will indicate little or no degradation of the performance of the crosscorrelation system with actual targets. Additionally, the total improvement of the system will also be known.

The high-level-input signal-to-noise ratio was measured at the output of the 4.0-kc-wide, 500-kc bandpass filter, as shown on Fig. 1. An oscilloscope was used to display the i-f signal directly without rectification. This was done to maintain linearity in the display as well as in the system. Consequently, the peak factor of the white noise will be the same as in the previous discussion, and the same measuring methods can be used. The pulse signals as well as the noise will be bipolar. The noise level is obtained by selecting a point on the scope trace free of signals and reading the peak-to-peak voltage and then dividing by twice the peak factor. Likewise, the signal amplitude is determined by selecting a pulse signal which is clearly above the noise level and reading the peak-to-peak value of the signal plus noise, since noise rides on the signal. This peak-to-peak reading is determined in the same manner as the noise, because it is the sum of the two that is desired. Since the signals simply add, the noise can be subtracted from the signal plus noise, leaving only the value of the signal. Hence the ratio of the two may be taken.

Signals well above the noise level were selected for measurement to eliminate the signal-to-noise-ratio enhancement effects of integration by scope or observer such as would occur with small signals just below the noise. Here, repetitive signals will be enhanced by persistence of the phosphor and the eye of the observer. Another reason also exists for selection of large signals, and that is the fact that long-range backscatter folds over and completely obscures all signals in the 162-naut-mi range interval established by a 500-pps recurrence rate used in the crosscorrelation studies. In order to uncover the signals and to resolve the backscatter, a lower recurrence rate was used when measuring the input ratio only. The input signal-to-noise ratios measured at the lower recurrence rate are identical, when large signals are used, to those measured at 500 pps. This was demonstrated by varying the recurrence rate over the full range on the occasional day when no backscatter was present and observing the signal and noise levels. In this case, only a change in intensity could be noticed.

When measuring input and output signal-to-noise ratios, compensable errors can arise due to other causes. The most obvious error is due to movement of the target within the receiver gate during the time required to make the input measurements and the output measurements. This procedure requires several minutes, because the input and output ratios must be taken, then the power dropped, time allowed for the narrow-band acquisition, readings taken, power restored, and finally input levels rechecked. The input signal-to-noise ratio can be read whether the signal is in the gate or not, but the crosscorrelation system cannot perform without a signal in the gate. Therefore if the signal has moved partly out of the gate, a suitable compensation must be made; this is readily accomplished.

A second source of error is a change in input signal-to-noise level occurring within the measuring time. This is corrected by a recheck on the input ratio.

Spike noise is also a source of error that is difficult to correct. It is easier to avoid this noise. This is done by selecting observation times relatively free of spike noise.

Accelerating targets can be expected to modify the performance of the active-filter correlation system. However, the accelerations involved in fast turns of jet and commercial aircraft, the source of target echos reported herein, do not appear to increase the minimum detectable signal level.

Data have been taken on many aircraft targets. Figure 8 shows the deviation of the high-level-input signal-to-noise ratio of the active-filter correlation-detection system from the measured high-level-input signal-to-noise ratio for a number of observations. The deviations reach as much as 6.0 db, which may be explained by the difficulty of the measurements. However, the important point to note is that the deviations center on zero db. Hence, on the average, the agreement between the correlation-system calibration and the input measurements is good.

Performance of the active-filter correlation-detector system with signals near the minimum detectable level is shown on Fig. 9. Here a comparison is made of the deviation of the correlation system's low-level-input signal-to-noise-ratio reading from the measured input signal-to-noise ratio reduced by the amount

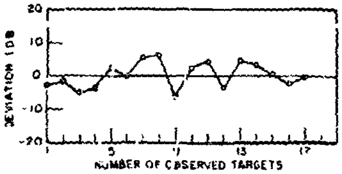

Fig. 8 - Comparison of active-filter input S/N ratio with the high-level measured input S/N ratio

of the drop in transmitter power. Again, the deviation is sizable, but the average is zero db. Thus, once more the agreement is good. This is an important finding, for it indicates that there is little degradation in the performance of the active filter and correlation-detector system with the type of targets mentioned, even with the target signals buried in noise. Conversely, this also indicates little incoherence in aircraft echos at this operating frequency.

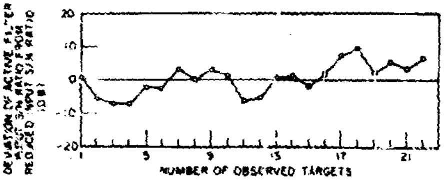

Fig. 9 - Comparison of active-filter input S/N ratio with the low-level measured input S/N ratio

The total improvement in signal-to-noise ratio may also be obtained from the data. Figure 10 shows the improvement realized with reduced power, when the input signal was just above the minimum detectable level. The curve shows a 2.5-db spread, with the upper limits approaching the theoretical improvement. Thus good agreement with theory exists.

These results highlight another accomplishment, and that is the ability of the system to detect moving targets with no loss in crosscorrelation efficiency through range-ambiguous backscatter (clutter), which often reaches amplitudes in excess of 60 db over the receiver noise level. As previously mentioned, the backscatter is rejected by the narrow-band rejection filter in the 100-kc i-f chain.

## CONCLUSIONS

Measurements of the active filter with simulated signals and noise indicate that near-theoretical improvement in output signal-to-noise ratio over input signal-to-noise ratio can be achieved. When the performance of the complete Music radar system is measured with actual aircraft targets, no degradation in results from those obtained with simulated signals can be found. At the input, the minimum detectable signal level is 26.5 db below the noise level, and with this input level the output signal level is 16.0 db above the noise level. These results also show that the system is fully capable of completely rejecting the effects of large backscatter clutter encountered in the hf band.

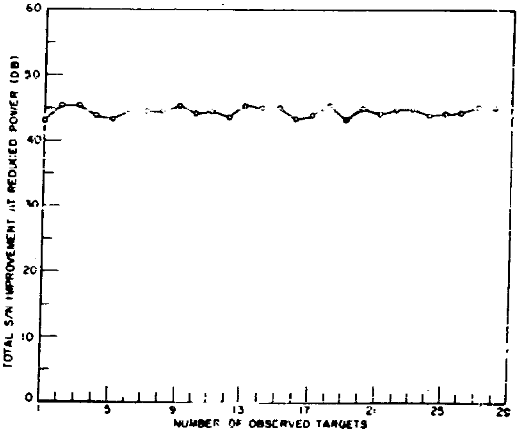

Fig. 10 - Total improvement in S/N ratio

* * *

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