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AMPLITUDE FLUCTUATION IN RADAR ECHO PULSES

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AMPLITUDE FLUCTUATION IN RADAR ECHO PULSES

A. E. Hastings

June 21, 1949

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ABSTRACT

The quality of data from a tracking radar and the value of certain lobing techniques depend upon the fluctuation characteristics of echo pulses. One such characteristic, the amplitude-frequency spectrum of amplitude noise, affects the choice of optimum sequential lobing frequency and the use of simultaneous lobing.

The frequency spectrum of amplitude fluctuations in radar echo pulses has been calculated from experimental measurements for a number of airplane targets at X-band. The spectrum amplitude decreases with frequency with consistently greater slope for smaller planes. Motion of the plane as a whole appears to be the chief cause of fluctuation. Propeller modulation, a very noticeable effect at longer wavelengths, was not observed.

Results indicate that a high lobing rate, simultaneous lobing, and instantaneous automatic gain control can reduce the noise in the output angle of a radar significantly, provided the external fluctuation in angle of arrival and internal receiver noise are relatively small.

PROBLEM STATUS

This is an interim report on one phase of this problem. Work is continuing.

AUTHORIZATION

NRL Problem No. R12-01D

AMPLITUDE FLUCTUATION IN RADAR ECHO PULSES

INTRODUCTION

The quality of data obtainable from a tracking radar is markedly affected by fluctuations in amplitude and apparent angle of arrival of the echo pulses. These fluctuations, which have been called "amplitude noise" and "angle noise," are caused by the complex nature of the reflection process with a moving target of finite size. A detailed discussion of noise in echo pulses and their effects on the output data of radars of various types has been given in a recent report.[1] The value of certain techniques, such as simultaneous lobing, sequential lobing at high rates, and instantaneous automatic gain control (IAGC), was shown to depend on the characteristics of the echo fluctuation.

One of these characteristics, the amplitude-frequency spectrum of amplitude noise, is of importance in the choice of a sequential lobing frequency and in the use of simultaneous lobing. In a frequency band, with limits equal to lobing frequency plus and minus the width of the servo pass band, all the noise appears as output angle noise. It is generally assumed that the amplitude-frequency curve falls off with increasing frequency, so that it is desirable to fix the lobing frequency relatively far into the region of decreasing amplitude and thus to decrease the output angle noise. This report describes measurements of the spectra of several airplane targets and discusses the value of a high lobing frequency and simultaneous lobing.

PROCEDURE

The spectra of amplitude noise were determined by recording echo pulse amplitude as a function of time and subjecting selected portions of the recordings to Fourier analysis. Recording was at X-band, with an experimental radar, with pulse rate about 2000 cps, with unlobed receiver and transmitter, and with beam widths great enough so that with manual tracking the target was at all times on the relatively flat portion of the antenna pattern. This set of conditions eliminated any effects of angle of arrival and made the recording one of echo amplitude alone. AGC, used to maintain constant average recording level, was sufficiently slow to eliminate any effect on the amplitude spectrum except at frequencies below the region of interest. Partly lengthened video pulses, displayed as vertical deflection on an oscilloscope tube, were photographed by a camera with continuous film motion to provide a time coordinate. Target ranges were small in order to include as little receiver noise as possible.

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[1] Hastings, A. E. and Meade, J. E., "Improvement of Radar Tracking," NRL Report R-3424, (Confidential), 24 February 1949.

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The method of obtaining the frequency spectra and a theoretical discussion of the process are given in a previous report.[2] Four portions of the amplitude-time recordings were selected for each of several planes and courses. Each piece was enlarged, printed on paper, and transferred to opaque paper by a tracing machine to polar coordinates with amplitude as radius and time as polar angle. The polar plot was cut along the function line and the remaining disc rotated at constant rate about the polar axis so as to intercept light falling on a photocell. An electronic wave analyzer determined the line spectrum of the periodic photocell current. A logarithmic average was taken of the spectra obtained from the four pieces of data representing one type of plane on one course.

A sample of the resulting line spectrum is shown by the points in Figure 1, where there is considerable random scattering of the data. The straight line, determined by the method of least squares, represents the continuous spectrum of the original nonperiodic amplitude-time function.[3] For each straight line calculated, representing one type of plane on one course, the slope in db per decade was found.

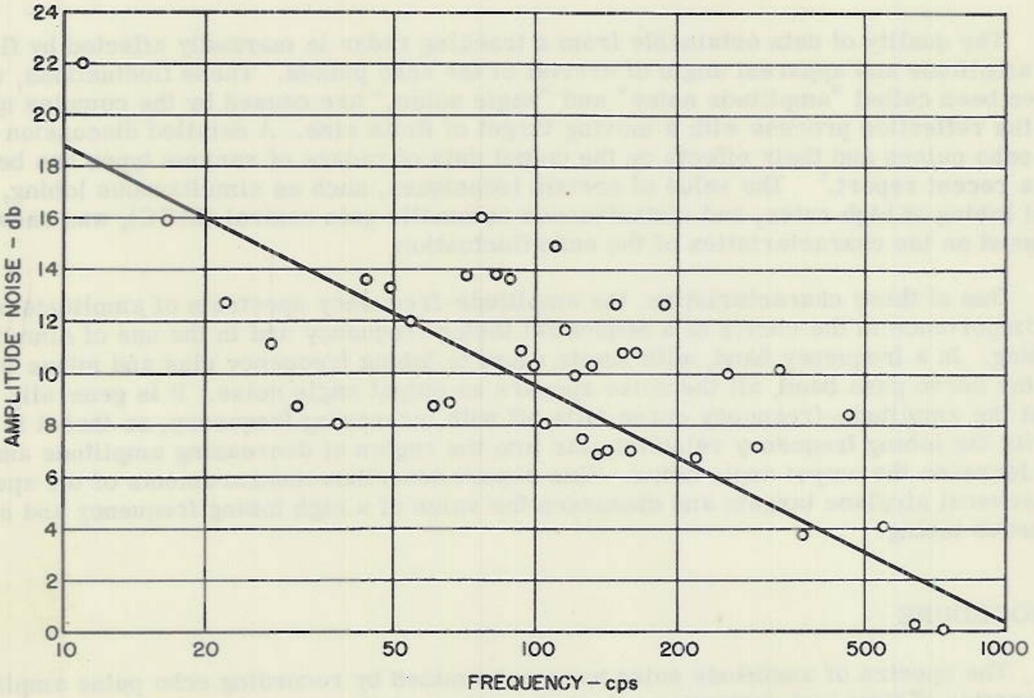

Figure 1

EXPERIMENTAL RESULTS

Table 1 shows the results of the experimental measurements and spectrum calculations. For each type of course, the planes are listed in order of increasing size, and the slopes may be seen to decrease in absolute value with size for all types of courses. Because

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[2] Hastings, A. E., "Methods of Obtaining Amplitude-Frequency Spectra," NRL Report R-3466, (Unclassified) 16 May 1949.

[3] Hastings, op.cit.

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of the large amount of work involved, only 11 slopes were calculated, and this very consistent behavior of the slopes may be somewhat a matter of chance. This is further indicated by the facts that the slopes for different planes do not always vary consistently with the type of course and that the slopes for the C47 seem too high for its size. The speed of the planes, a factor not known, probably affected the slopes. In general, however, the data indicate a dependence of slope on plane size averaging -8 db per decade, a relationship of more importance than any dependence on type of course.

TABLE 1

Course	Run	Plane	Slope
Receding	3	F6F	-12.1
″	13	C47	-10.1
Approach	5	F6F	-10.4
″	12	SNB	- 8.1
″	9	B25	- 6.7
″	10	B25	- 5.8
″	1	C54	- 3.4
Pass	4	F6F	-11.9
″	11	SNB	- 8.2
″	7	B25	- 5.5
Turn	2	C47	-10.4

DISCUSSION

The results indicate (1) that a sequentially-lobed radar might gain on the average about 8 db in signal-to-noise ratio if the lobing frequency were increased to ten times the existing frequency and (2) that a simultaneously-lobed radar, or one with instantaneous automatic gain control (IAGC), might be even more advantageous. Whether these advantages can be realized depends on the relative magnitudes of the effects of the three types of noise: amplitude noise (external), angle noise (external), and receiver noise (internal). These magnitudes are in general a function of target range, angle noise predominating at short ranges, amplitude noise at medium ranges, and receiver noise at long ranges. The extent of each range depends on radar characteristics such as transmitted power, antenna beam width, and receiver sensitivity. At sufficiently (but perhaps impractically) short ranges, angle noise always predominates; at sufficiently long ranges, receiver noise is greatest. Amplitude noise predominates, if at all, between these extremes. Without knowledge of the relative magnitudes of these three noise sources, the real advantage of high lobing frequency or other such techniques cannot be estimated.

The source of amplitude noise is the interference of reflected fields from many parts of the target in radial motion relative to the radar. This motion occurs when parts of the target are in vibration or when the whole target rotates. From another viewpoint, the reflection pattern of a plane is very complex, with many maxima and minima. Rotation of this pattern with target rotation and variations in the pattern due to vibration of the parts cause amplitude variations in the echo signal.

Some thought has been given to the cause of the observed dependence of spectrum on plane size and to the two possible sources of amplitude noise — vibration of parts and motion of the target as a whole. Even an approximate analysis is very complex, but a simple consideration of interference from multiple sources is useful. Suppose the target to consist of discrete reflecting areas over its length. The reflection pattern, from the analogous optical diffraction problem, will then contain many maxima and minima, the number increasing and the spacing decreasing with target length. If all planes oscillated in flight with the same product of frequency and amplitude, a large plane with many maxima and minima in its reflection pattern would produce a relatively extended noise spectrum with small slope, as has been observed. Nothing to justify the assumption of constant product has been found in the literature, and some variation with plane speed might be expected. If vibration of parts of the target is a major cause, however, the larger plane with its larger parts would supposedly have a spectrum more restricted than that of the smaller plane. That this is not observed indicates motion of the target as a whole is the more probable cause of amplitude noise.

Somewhat similar conclusions are given in another recent study of amplitude noise,[4] in which the spectrum was investigated from d.c. up to, in general, somewhat lower frequencies than in the present work. The extent of the spectra is shown to depend on plane attitude and on rate of turn. The slopes of the spectra are not given, but for all extended spectra, they fall within the limits shown in the present report.

The absence of any significant peaks in the spectra, or of apparent periodicities in the pulse recordings due to propeller rotation, is an unexpected finding. In the past, measurements at longer wavelengths have shown large percentages of amplitude modulation at frequencies associated with the angular velocity of the propeller. Absence of this phenomenon in the present case can be explained by the assumption of a high level of random amplitude variation at shorter wavelengths, so that the variation due to propeller motion is entirely masked. Such an assumption can be justified by the more complex reflection pattern occurring at shorter wavelengths. Another explanation can be based on the larger number of wavelengths in the propeller length and width when operating at shorter wavelengths. The reflection of the propeller is then less dependent on its position.

CONCLUSIONS

This study at X-band indicates that a high sequential lobing frequency, simultaneous lobing, and IAGC can reduce the noise in the angle output data of a tracking radar significantly, provided external angle noise and internal receiver noise are relatively small. Some evaluation of the relative magnitudes of angle and amplitude noise is required before the advantages of these techniques can be stated for any particular radar requirements. External amplitude noise appears to be caused largely by target motion as a whole rather than by vibration of parts. The frequency spectrum of amplitude noise is more extensive for larger planes. Since propeller modulation was not observed, it is believed to be a much smaller effect at shorter than at longer wavelengths.

ACKNOWLEDGMENT

J. H. Dunn and W. S. Sunderlin carried out the lengthy experimental measurements and calculations for obtaining the spectra.

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[4] Muchmore, R. B., and Weiss, L. H., Tech. Memo 212, Hughes Aircraft Co., 30 Nov. 1948.