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SIGNAL FLUCTUATIONS IN LONG-RANGE OVERWATER PROPAGATION

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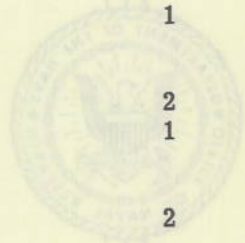
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ABSTRACT

Measurement of overwater propagation in the Pacific on 3 and 9 cm between airborne transmitters and fixed receivers are reported. Within the horizon, the direct and surface-reflected rays formed the usual interference patterns. Beyond the horizon, the 3-cm signal always behaved in general accord with normal-mode theory, the attenuation rate averaging 0.5 ± 0.2 decibels per (nautical) mile. In roughly the first thirty miles past the horizon, the 9-cm signal had a height-gain and an exponential decay rate (0.9 to 1.9 decibels per mile), both reasonably dependent on measured duct strength. On 9 cm only, all greater ranges comprised a "turbulent region" where a new, lower attenuation rate prevailed, averaging 0.17 ± 0.05 decibels per mile, and where there was no average height-gain. Turbulent-region signals were approximately Rayleigh-distributed and the autocorrelation of their fluctuation vanished in, at most, 1.5 seconds. The turbulent-region signal undoubtedly was due to scattering by some high-altitude atmospheric mechanism.

PROBLEM STATUS

This is an interim report; a final report is in preparation.

AUTHORIZATION

R11-08R

SIGNAL FLUCTUATIONS IN LONG-RANGE OVERWATER PROPAGATION

INTRODUCTION

Measurements were made in May 1946 of the propagation of 3300- and 9500-Mc waves ($\lambda \approx 9$ and 3 cm) over an oceanic path northeast of Oahu, T. H. Receiving antennas and recording equipment were located at the water's edge on the eastern side of the island. This equipment received signals from two radar transmitters in an airplane which flew over the water on a radial course of length about 250 (nautical) miles along the prevailing wind. Receiving antennas were mounted at four levels (15, 30, 50, and 106 feet above the mean ocean surface), and the airplane flew at constant altitudes (approximately 50, 100, 150, 200, 400, 700, and 1000 feet). Low-level meteorological measurements were taken concurrently.

The receiving antennas were oriented to maximize the received signal, and the transmitting antennas scanned 90-degree sectors centered approximately on the relative bearing of the tower. Ink recorders recorded (subject to a slight time-constant error) the maximum signal received during each scan. There were about twenty such signal peak observations per mile of flight, or per half-minute of time. Samples of the resulting records are shown in Figure 1. Standard signal generators were used for the calibration, and measurements of transmitter and receiver parameters were made so that the recorded signals could be reduced to absolute units.

From each of about 350 signal records and calibrations a plot was made similar to those of Figure 2. Of the approximately 20 peak deflections in a mile of range, the second highest (quasimaximum, or 95-percentile signal) and the tenth highest (median, or 50-percentile signal) were plotted (in decibels) as ordinate versus range (in nautical miles) as abscissa. The plots reproduced in Figure 2 show, at close ranges, the successive maxima and minima of interference between direct and reflected rays. Beyond the last maximum of this interference pattern, the signals fall off on the plot in an approximate straight line corresponding to the exponential* decay of signal with range predicted by normal-mode theory. In this "exponential region" the fading, indicated by separation of plotted quasimaximum and median values, was always of the slow, shallow type recorded in B, C, D of Figure 1. All 3-cm records which were of sufficient length showed only this exponential-region signal decay and fading at even the greatest observed range, about 150 miles.

In contrast, the 9-cm signal always entered a "turbulent region" at around 30 miles past the optical horizon where the fast, rapid fading shown in A of Figure 1 was typical. The plots correspondingly showed increased separation between quasimaximum and median

* A curve including the theoretical factor $1/R$ would deviate from a straight line in the last 3/4 of any range by about one decibel.

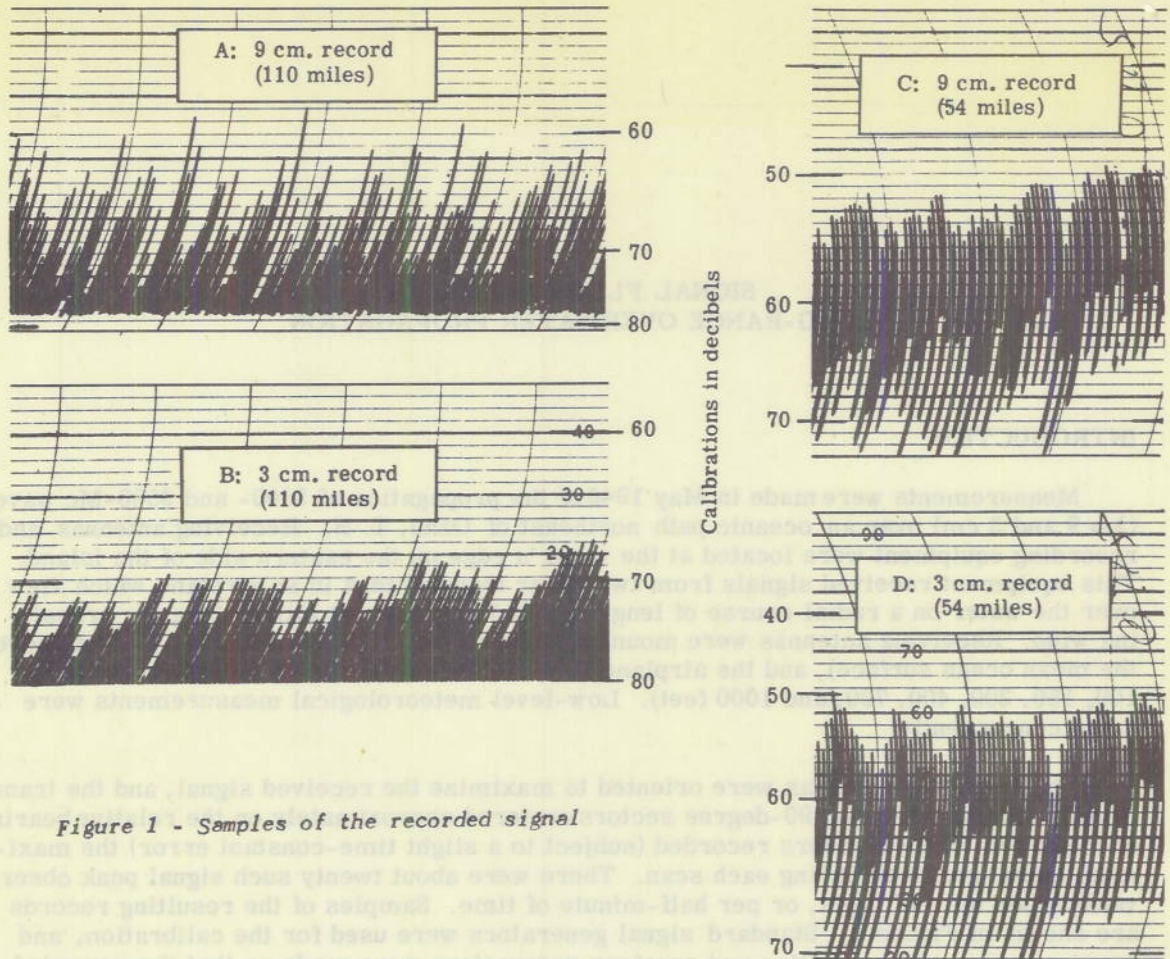


Figure 1 - Samples of the recorded signal

values, and the exponential attenuation rate was markedly lower than that in the exponential region.

From the measurements, height-gain functions up to 106 feet were determined by comparison of simultaneous recordings from the four receiving heights, and from 50 to 1000 feet by comparison of the signal received at a single height from a fixed range and various transmitter heights. The 9-cm height gain up to 106 feet varied, on the average, inversely with duct strength, as anticipated; and the average 9-cm exponential-region field increased linearly with height from 15 to 1000 feet. The 9-cm exponential-region attenuation rate varied roughly from 1.9 to 0.9 decibels per mile with increasing duct strength. The mean 3-cm exponential attenuation rate was 0.5 ± 0.2 decibels per mile, but the signal trends varied inconsistently among the four simultaneous records (much as if two modes were trapped), so that height gains and dependence of attenuation rate on the duct-strength could not be determined.

For the 9-cm turbulent region the attenuation rates varied from 1.0 to 2.2 decibels per mile, with an average value of 0.17 ± 0.05 . At 100 miles, the median turbulent-region signal averaged 53 ± 5 decibels below the free-space signal, with no average height dependence. In one 14-mile stretch of turbulent-region record, the signals, stronger than the median, were found to be Rayleigh-distributed. At 100 miles the straight lines fitting

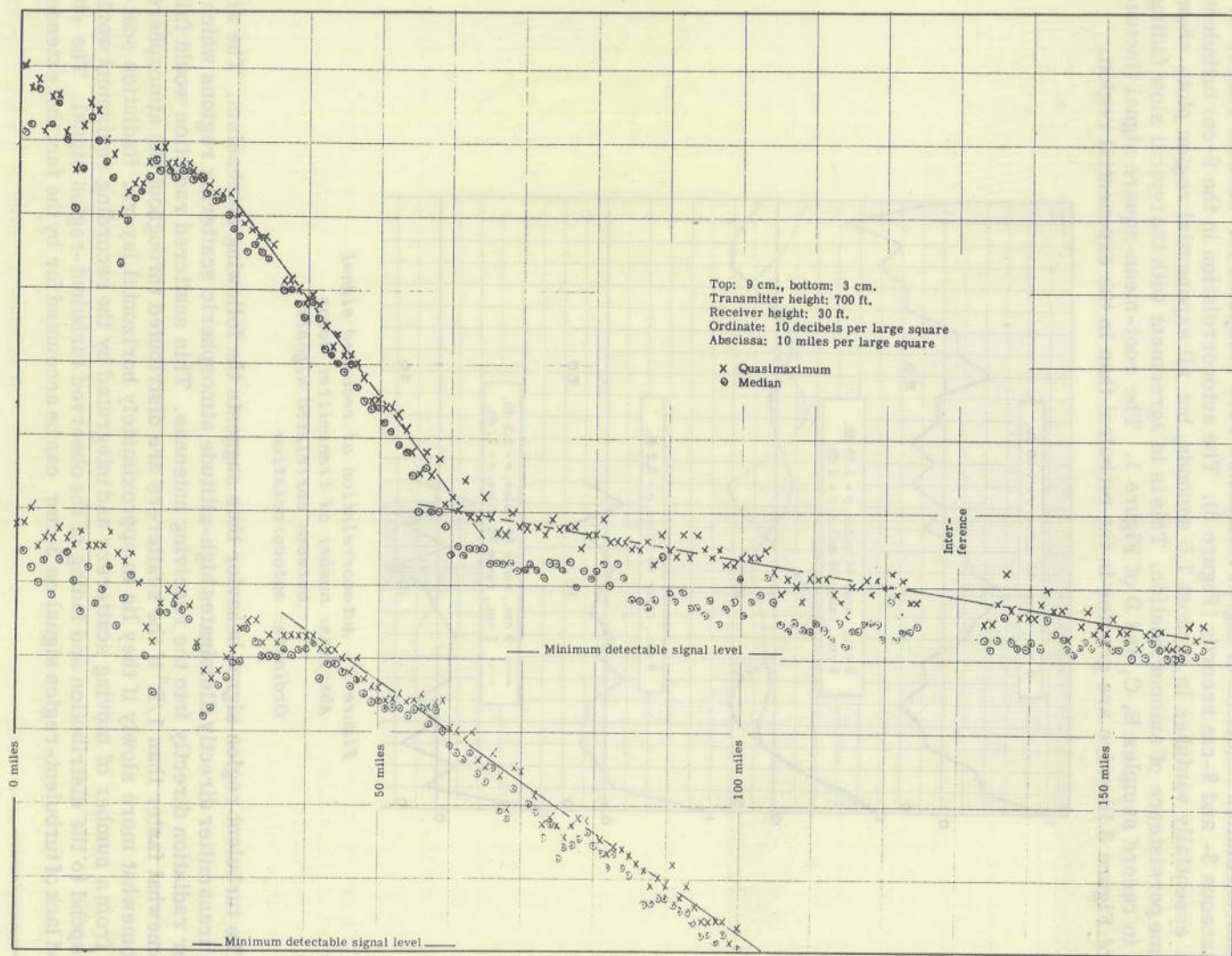


Figure 2 - Samples of signal plots

the plotted quasimaxima and medians were always separated by 4 to 7 decibels, roughly in accord with the Rayleigh distribution.

Autocorrelation functions of signal fluctuation were computed for several ranges of simultaneous 3- and 9-cm records (Figure 3). The autocorrelation in the 9-cm turbulent region essentially vanishes in at most 1.5 seconds, but all exponential region plots show the same persistence of autocorrelation. This is in agreement with the typical slow fading shown in record samples B, C, and D of Figure 1. The root-mean-square signal fluctuations of Figure 3 likewise are greater in the turbulent than in the exponential region.

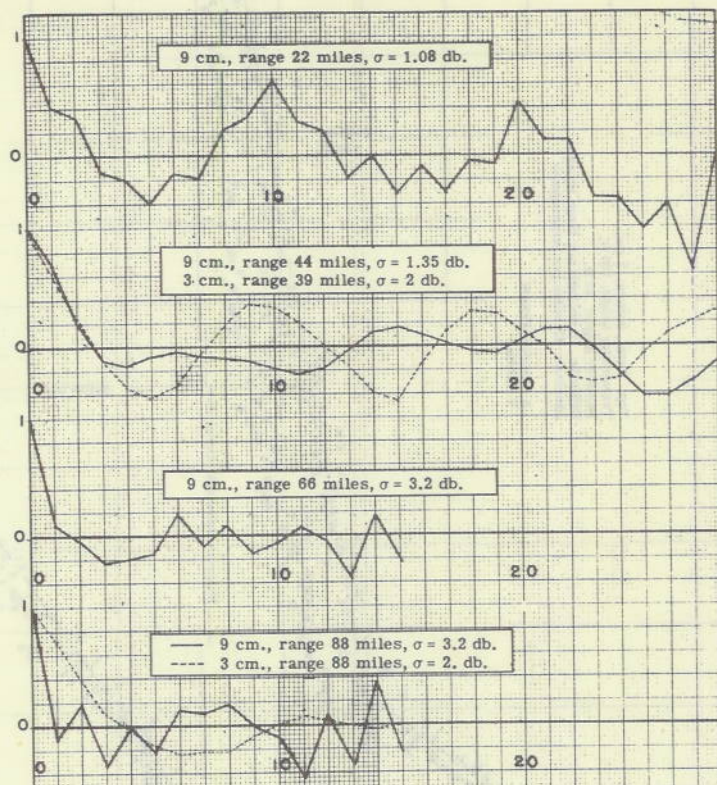


Figure 3 - Autocorrelation of recorded signal
 Abscissa: number of transmitter scans
 between correlated signals
 Ordinate: autocorrelation

The turbulent-region signal behavior thus suggests the following mechanism. The airborne transmitter directly illuminates high-altitude atmospheric scattering regions which scatter radiation directly into the receiving antennas. This scattered radiation would fall off somewhat faster than $1/R^2$ if the scatterers are distributed throughout the atmosphere, and somewhat more slowly if they lie in approximately horizontal layers. Radiation scattered from a number of moving scatterers and integrated by the recording equipment would correspond to the distribution and fading of the observed turbulent-region signal. The observed lack of turbulent-region signal on 3 cm† can be accounted for by the fact that extended

† Exclusive of antenna gains, the 9-cm links were about 7 decibels more sensitive than the 3-cm links; 9-cm turbulent signals of order 12 decibels above minimum detectable were generally observed at the maximum ranges of the 3-cm signals.

scatterers scatter most heavily in the forward direction of the incident radiation, with the "beam width" of the forward scattering roughly proportional to wavelength. Thus the receiving antennas may have been within the 9-cm scattered beam but below the narrower 3-cm beam.

An attempt was made to check this hypothesis by correlating the 9-cm turbulent-region signal levels at 100 miles with high-level atmospheric turbulence as estimated from contemporaneous cloud observations. No significant correlation was found. The need for further meteorological observations is indicated.

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