

RADIO WAVE PROPAGATION

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experiments. The path is 27 miles long with receivers mounted on a tower at several altitudes. The transmitters operate on the S and X bands and are pulsed. In addition, radar measurements are being undertaken by means of corner reflectors that are spaced at regular intervals along a path 45 miles long. It may be expected that valuable results will soon be received on the completion of these experiments.

EXPERIMENTS IN THE SOUTHWESTERN UNITED STATES

The Navy Radio and Sound Laboratory at San Diego has performed a considerable number of propagation experiments which have substantially aided our understanding of the phenomena of guided propagation. Moreover the meteorological conditions

During the winter of 1942 to 1943, a series of measurements were made on the intensities of artificial fixed echoes of a 700-mc radar located near San Diego,^{126,138} and these were compared with measured temperature and humidity gradients in the lower atmosphere. A pronounced correlation between excessive echo ranges and nonstandard M gradients at once appeared. The quantitative aspects of these correlations will not be discussed here since they are very similar to others of this type already reported.

Another set of observations where the receiver was located in a plane is shown in Figure 12.⁴ The receiving antenna was a Yagi, mounted in the nose of the plane, records being made when the plane was flying over the ocean toward the transmitter which was a 500-mc radar. Figure 12 represents the results of flights at various altitudes on two different days, the maxima of the signal strength curves corres-

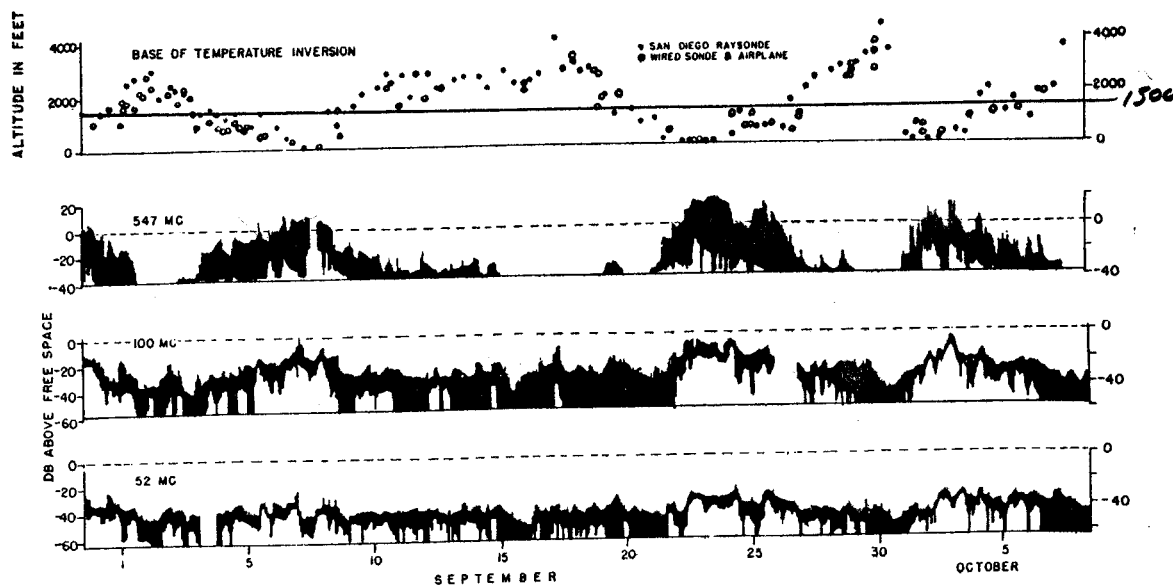


FIGURE 13. Signal strength over 80-mile path, San Diego to San Pedro, correlated with height of temperature inversion.

found in this part of the United States are rather unique; and, while they are not, perhaps, reproduced at many other places of the earth, they are so clear-cut and regular as to facilitate greatly experimental investigations and their interpretations.

The meteorological conditions at San Diego during most of the year are characterized by the presence of a high-pressure area and high-level subsidence. In more concrete terms, there is a surface stratum of comparatively cool and moist air on top of which there is a layer of very dry, warm air. The transition between the two strata is as sharp as can be found anywhere, and the transitional layer is often no more than a few hundred feet thick. The height of the transition layer above the ground is usually between 1,000 and 3,000 ft and sometimes as much as 4,000 ft.

ponding to the "lobes" of the transmitter pattern. On one of these days a duct was present as shown in the inset where M is plotted against height. The dot-and-dash straight line in this diagram represents the condition $dh/dM = \text{constant}$. The most conspicuous feature of Figure 12 is the difference between the signal distribution in the absence and presence of a duct at 500 ft, the lowest level measured, whereas the intensities agree fairly well at the higher levels. This behavior is in full agreement with the general predictions of propagation theory. Nevertheless, the detailed interpretation led to a slightly different result from that expected, as was brought out by subsequent experimental investigations.

In 1944 a one-way transmission path was operated between San Pedro and San Diego, an over-water

path^{10,159} 80 miles long with both terminals at an elevation of 100 ft, which were thus well below the optical horizon. Three fairly low frequencies, 52, 100, and 547 mc, were used. Figure 13 shows a field strength diagram of bihourly means for a period of about six weeks in the early fall of 1944. At the top of these diagrams is shown the height of the base of the temperature inversion, which is a quantitative measure of the height of the elevated duct. In order to compare these data with the results of duct theory, Figure 14 shows the number of lowest modes, trapped in the elevated duct, plotted against the signal strength. For each point indicated, the number of trapped modes is calculated by simple waveguide theory from the measured M curves while the field strength is that simultaneously measured on the transmission path. For the lowest frequency, 52 mc, the duct is always beyond cutoff and no trapping should occur; nevertheless, the field strength record shows considerable fluctuation.

As seen from Figure 14 there is no correlation between the field strength and the number of modes

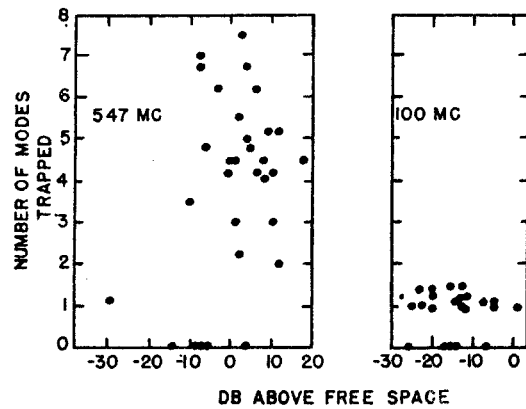


FIGURE 14. Computed number of modes trapped versus observed field strength, San Diego Bay.

that, theoretically, are transmitted by the duct. On the other hand, there is a very pronounced inverse correlation between the height of the inversion layer and the strength of the received signal. This is just what should be expected on the basis of reflection, as

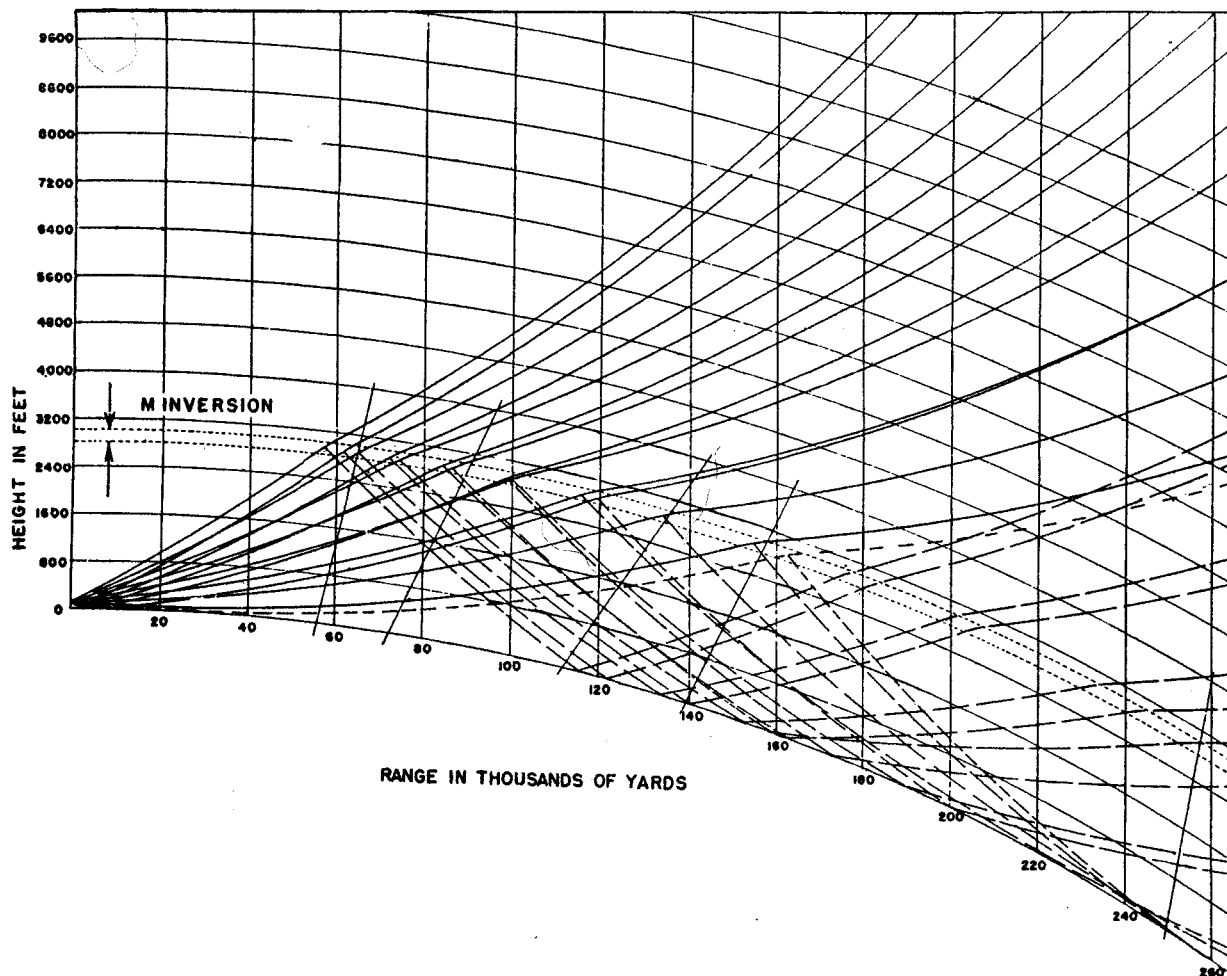


FIGURE 15. Ray tracing diagram including rays reflected from elevated inversion layer, San Diego Bay. M changes by 50 units through the inversion.

distinguished from ray bending, from the elevated layer of M inversion. The principle of this reflection phenomenon has previously been outlined at the end of Chapter 2, on page 17. Further study shows that the rate of change of the field intensity and its variation with frequency are just of the magnitude required by the theory. Figure 15 shows a ray-tracing diagram on which the paths of the reflected rays are indicated. Summarizing the results of this experiment, it may be said that the phenomenon of reflection from an elevated layer has been well established qualitatively and, in some respects, quantitatively. The meteorological conditions at San Diego are rather singular, and so far such reflection occurring in a systematic fashion has not been described elsewhere though indications of similar effects have occasionally been reported.

Another transmission experiment was made by the Navy Radio and Sound Laboratory in the Arizona desert in December 1944.¹⁸⁸ The path was nonoptical, 47 miles long, and the frequency used was 3,200 mc. The desert air is extremely dry so that the contribution of water vapor to the refractive index is small and the change in M owing to changes in humidity with height is nearly negligible. During the clear nights a pronounced temperature inversion develops from radiative cooling of the ground, a ground-based duct thus being formed. The received field strength varied in close correlation with the formation and disappearance of the duct, with a pronounced diurnal period. The overall results of this experiment are again in excellent qualitative agreement with the predictions of the duct theory. At the same time the experiment also furnished an opportunity for studying the development over land of low temperature inversions which are valuable for radiometeorological forecasting.

EXPERIMENTS AT ANTIGUA

Operational experience in the Pacific Ocean led to the conclusion that low ducts are very common over the ocean surface in subtropical and tropical climates. In order to study these ducts, an experiment was undertaken by the Naval Research Laboratory in the spring of 1945.¹⁹⁴ The island of Antigua, one of the Leeward Islands of the Lesser Antilles in the British West Indies, was chosen as the site. The prevailing winds there are northeasterly and the air has an over-water trajectory of several thousand miles before arriving at the island and is therefore considered characteristic of large portions of the central Atlantic and Pacific oceans. There is almost no diurnal and only a limited seasonal variation in the air at the lowest levels.

Equipment for the transmission experiments was comprised of S-band and X-band sets provided by the Radiation Laboratory, MIT. The transmitters

with parabolic antennas were mounted on a ship at heights of 16 and 46 ft. There were two parabolas for each height and each frequency, one set pointing to the stern and one to the bow, so that measurements could be made on both the outward and inward runs of the vessel. Receivers were located at heights of 14, 24, 54, and 94 ft on a tower at the edge of the water. Monitoring and automatic recording were similar to those used in the transmission experiments previously described. Records were obtained while the ship was traveling away from the receiving station and again on its return. Signals could usually be detected up to 190 miles for some combination of transmitter and receiver heights. Direction finding equipment was used for keeping the ship on its course, and fading of the signal caused by the ship's being off course could be readily detected and rectified.

An extensive program for measuring low-level M curves paralleled the transmission measurements. Since the weather conditions at Antigua are quite steady there is little variation in these curves, as shown by two typical ones illustrated in Figure 11 of Chapter 3. The low-level duct indicated by these graphs has been found present at all times in this location.

Typical field strength records for the S band and the X band are shown in Figures 16 and 17, respectively, the most outstanding feature being the variation of field strength with antenna heights. For the S-band transmission, the field strength increases slightly with increasing antenna height but not nearly so fast as it would under standard conditions. For the X band, on the other hand, the field strength, as a rule, is increased by lowering the antennas. This behavior can be explained on the basis of the mode theory of duct propagation as outlined in Chapter 2. For the shorter wavelength X band, we have genuine trapping, so that the field strength is greatest when the transmitter or receiver or both are in the duct. In terms of the height-gain functions of equation (27), Chapter 1, it appears that these functions of the lowest mode or modes have a pronounced maximum in the duct and decrease rapidly above it. For S-band transmission there is a transition between the complete cutoff, indicated by a highly simplified waveguide theory, and complete trapping. This intermediate effect is caused by some leakage of this wave train from the duct and the retention by the duct of a portion of its wave-guiding properties. The height-gain functions, while still much larger in the duct than in the case of standard propagation, no longer have distinct maxima but show a gradual increase with height from the ground. This case is particularly interesting because it clearly exemplifies the possible variety of conditions in intermediate between trapping, as described by the ray tracing of geometrical optics, and the diffraction around the earth's surface characteristic of standard propagation.

Figure 16 shows two regions with distinctly