NBS

Technical Note No. 302

BIBLIOGRAPHY OF FADING ON MICROWAVE LINE OF SIGHT TROPOSPHERIC PROPAGATION PATHS AND ASSOCIATED SUBJECTS

H. T. Dougherty

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Bibliography of Fading on Microwave Line of Sight Tropospheric Propagation Paths and Associated Subjects

H. T. Dougherty

A collection of titles and abstracts is presented for articles dealing with the microwave fading that has been observed on tropospheric line of sight paths. Selections are included for related subjects such as: measurement of meteorological factors; spatial, frequency and time diversity reception; and attenuation due to trees and buildings. Also included is a subject index and an author index.

Introduction

This bibliography contains over 200 titles and abstracts from the open literature published between 1933 and the first half of 1964. Although most are taken from English language publications, several selections are also included from French, German, Russian, Italian, and Japanese language publications. In general, selections from "in house" publications or reports of limited distribution were avoided. This course was followed not only because such reports are not readily available to all interested parties but also because they generally appear later in a more concise published version.

To properly cover the subject "Fading on Microwave Line of Sight Tropospheric Propagation Paths," it is necessary to also include at least representative selections from associated subjects such as microwave antennas, reflection coefficients, measurement of meteorological factors, attenuation due to trees, etc. The frequency range of phenomena covered here is roughly several hundreds of MHz to several tens of GHz, the region of decimeter and centimeter wavelengths.

The titles and abstracts are grouped by their year of publication and arranged alphabetically (by authors) within each year. Identification numbers are assigned in the same manner; the first two digits indicate the year followed by a hyphen and the number indicating its alphabetically ordered position within that year. The letter "A" preceeds addendum entries.

Special acknowledgement is due Mrs. B. J. Gibson and Mrs. M. A. Molta who typed and proofread the manuscript.

Subject Index

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Schelleng, J. C., C. R. Burrows and E. B. Ferrell (March 1933)
Ultra-short-wave propagation, Proc. IRE 21, 3, p. 427 - 463.

33-1 Abstract: Part I of this paper first describes a method of measuring attenuation and field strength in the ultra-short-wave range. A resume of some of the quantitative experiments carried out in the range between 17 megacycles (17 meters) and 80 megacycles (3.75 meters) and with distances up to 100 kilometers is then given. Two cases are included: (1) "Optical" paths over sea water and (2) "Nonoptical" paths over level and hilly country. An outstanding result is that the absolute values of the fields measured were always less than the inverse distance value. Over sea water, the fields decreased as the frequency increased from 34 megacycles (8.7 meters) to 80 megacycles (3.75 meters), while the opposite trend was found over land. As a rule, the signals received were very steady, but some evidence of slow fading was obtained for certain cases when the attenuation was much greater than that for free space.

Part II gives a discussion of reflection, diffraction, and refraction as applied to ultra-short-wave transmission. It is shown, (1) that regular reflection is of importance even in the case of fairly rough terrain, (2) that diffraction considerations are of prime importance in the case of nonoptical paths, and (3) that refraction by the lower atmosphere can be taken into account by assuming a fictitious radius of the earth. This radius is ordinarily equal to about four thirds the actual radius.

The experiments over sea water are found to be consistent with the simple assumption of a direct and a reflected wave except for distances so great that the curvature of the earth requires a more fundamental solution. It is shown that the trend with frequency to be expected in the results for a nonoptical path over land is the same as that actually observed, and that in one specific case, which is particularly amenable to calculation, the absolute values also check reasonably well. It is found both from experimental and from theory that nonoptical paths do not suffer from so great a disadvantage as has usually been supposed.

Englund, C. R., A. B. Crawford and W. W. Mumford (Aug. 1940) Ultra-short-wave transmission over a 39-mile "optical" path, Proc. IRE, 28, 360-369.

40-1 Abstract: Continuous records of ultra-short-wave transmission on wavelengths of 2 and 4 meters, over a good "optical" path, have shown variations in the received signal strength. These variations can be explained as being due to wave interference; an interference which varies with the changes in the composition of the troposphere.

Some of the variations are due to changes in the dielectric-constant gradient of the atmosphere near the earth. Other variations are explicable in terms of reflections from the discontinuities at the boundaries of different air masses. The diurnal and annual meteorological factors which affect the transmission are discussed.

Norton, K. A. (Dec. 1941) The calculation of ground-wave field intensity over a finitely conducting spherical earth, Proc. IRE 29, 623-639.

41-1 Abstract: Equations and curves are presented which simplify the calculation of ground-wave field intensity over a finitely conducting spherical earth for transmitting and receiving antennas of arbitrary heights and polarization.

Bateman, R. (May 1946) Elimination of interference type fading at microwave frequencies with spaced antennas, Proc. IRE, 34, 662-676.

46-1 Abstract: The element spacing of an antenna array is described which will provide a null in the direction of the ground reflected ray path.

Bergmann, P. G. (Oct. 1946) Propagation of radiation in a medium with random inhomogeneities, Phys. Rev. 70, 486-492.

46-2 Abstract: Approximate formulas, derived from geometrical optics, are shown to correlate the statistical properties of inhomogeneities with fluctuations in signal level. Further, simplification of the formulas permits the prediction of signal fluctuations dependent upon range. --W. N.

Crawford, A. B., and William M. Sharpless (Nov. 1946) Further observations of the angle of arrival of microwaves, Proc. IRE, 34, 845-848.

46-3 Abstract: Microwave propagation measurements made in the summer of 1945 are described. This work, a continuation of the 1944 work reported elsewhere in this issue of the Proceedings of the I. R. E. and Waves and Electrons, was characterized by the use of an antenna with a beam width of 0.12 degree for angle-of-arrival measurements and by observations of multiple-path transmission.

Ford, L. H., and R. Oliver (May 1946) An experimental investigation of the reflection and absorption of radiation of 9 cm wavelength, Proc. Phys. Soc. (London), 58, 265-280.

46-4 Abstract: The paper, which was circulated as a confidential report to the Radio Research Board in October 1944, describes measurements on the reflecting power of various surfaces at a wavelength of 9 cm and angles of incidence ranging from 80° to 45°; these included level and uneven bare ground, vegetation-covered ground, tap water and a 4% salt solution approximating to sea water. Specular reflection was found to occur only from very level surfaces; the absorptions of these surface media were measured, and from the combined measurements of reflection and absorption their electrical constants were derived.

Rough surfaces, either of bare ground or vegetation-covered ground, gave values of reflection coefficient in general agreement with the optical rule that regular reflection is only observed from an uneven surface if the product of the depth of the surface irregularities and the cosine of the angle of incidence is a small fraction of the wavelength.

The calculated values of reflection coefficient corresponding to dry soil, wet soil and sea water for angles of incidence varying from 0° to 85° are given in an appendix to the paper.

Gerlach, G. G. (Dec. 1946) A microwave relay communication system, RCA Rev., 7, 576-600.

46-5 Abstract: This paper reviews the experimental results obtained with a 4000 megacycle multichannel relay system connecting New York and Philadelphia. The system employs a frequency-modulated subcarrier which in turn is used to frequency-modulate the final carrier. Demodulation to the subcarrier frequency is effected at relay stations. The microwave relay equipment, which resulted from this experimental work and which will be installed by the Western Union Telegraph Company in a circuit connecting New York, Washington, and Pittsburgh, is described.

McPetrie, J. S., and L. H. Ford (1946) Some experiments on the propagation over land of radiation of 9.2 cm wavelength, especially on the effect of obstacles, J. IEE Part III-A, 93, 531-538.

46-6 Abstract: The salient results are brought together of a number of experiments on the propagation of radiation of a wavelength of 9.2 cm, carried out during 1943-44. All the measurements described were made over land, some over open country and some over transmission paths which were obstructed by various obstacles. The obstacles included trees, both leafless and in full leaf, brick walls, windows, and other parts of buildings.

Many of the obstacles caused such large attenuations that they should generally be regarded as opaque objects round which diffraction takes place. Stone buildings, groups of trees so dense that the sky cannot be seen through them, and the trunks of trees come into this category. Semi-transparent obstacles (causing a loss of signal of 10 db or less), include windows, tile or slate roofs, the sides of a light wooden hut, and thin screens of trees when the transmission path goes through the branches.

Megaw, E. C. S. (1946) Experimental studies of the propagation of very short radio waves, J. IEE Part 3A 93, 79-97.

46-7 Abstract: The paper presents a survey of the experimental work on the propagation of very short waves, and especially of centimetre waves, carried out in this country during the war. Although much of the paper is necessarily descriptive, and by no means all the problems are solved, it has been written with the aim of providing the radio engineer with applicable results where they have been established.

After referring to the main differences in propagation characteristics between these waves and longer radio groundwaves, the state of the art at the beginning of the war is briefly noted and the development of the war-time experimental work is outlined. Some simple theoretical characteristics are then described to provide a background for the experimental results which follow.

Preliminary experimental studies over land and sea paths are described, with a summary of the tentative conclusions to which they led.

The main experimental programme consisted of measurements of 3-cm, 9-cm, and 3½-m waves over sea paths 57 miles and 200 miles in length; and of 9-cm waves over a single 38-mile land path. The measurements were continuous over some of these paths for periods between two and three years; and, particularly as regards detailed correlation with meteorological measurements, the work is still in progress.

In a concluding Section some investigations into special aspects of very-short-wave propagation are described; data on reflection from sea and land, and on the effect of obstacles, are included in this Section.

Millington, G. (Jan. 1946) Curved earth geometrical optics, Marconi Rev., 9, 1-12.

46-8 Abstract: In this paper the effect of the earths curvature in the geometric-optical treatment of propagation within the visual range is presented as a correction to the flat earth geometry. Factors to be applied to the flat earth values of the angle of elevation at the point of reflection and of the path difference between the direct and reflected waves are derived by a simple graphical process, and also the divergence factor arising from the increased divergence on reflection from the convex surface of the earth is obtained. Asymptotic values are given for points very near to the horizon.

Robertson, S. D., and A. P. King (April 1946) The effect of rain upon the propagation of waves in the 1- and 3- centimeter regions, Proc. IRE, 34, 178P-180P.

46-9 Abstract: This paper presents some experimental results which show the effect of rain upon the transmission of electromagnetic waves in the region between 1 and 4 centimeters.

At a wavelength of 1.09 centimeters, the waves are appreciably attenuated, even by a moderate rain. Attenuations in excess of 25 decibels per mile have been observed in rain of cloudburst proportions.

The attenuation of waves somewhat longer than 3 centimeters is slight for moderate and light rainfall. During a cloudburst, however, the attenuation may approach a value of 5 decibels per mile.

Sharpless, William M. (Nov. 1946) Measurement of the angle of arrival of microwaves, Proc. IRE 34, 837-845.

46-10 Abstract: This paper describes a method of measuring the direction from which microwaves arrive at a given receiving site. Data which have been collected on two short optical paths using a wavelength of 3 1/4 centimeters are presented to illustrate the use of the method. Angles of arrival as large as 1/2 degree above the true angle of elevation have been observed in the vertical plane, while no variations greater than ± 1/10 degree have been found in the horizontal plane. These results indicate that radar directions for low angles of elevation may be in error by several tenths of a degree during times when anomalous propagation conditions are present. Possible solutions to the problems introduced by variations in the angle of arrival are suggested.

Smith-Rose, R. L (1946) A preliminary investigation of radio transmission conditions over land and sea on centimetre wavelengths, J. IEE Part III A 93, 98-100.

46-11 Abstract: Papers already presented at this Convention have surveyed both the circumstances that gave rise to, and the steps that were taken to implement, a detailed and systematic investigation of the mode of propagation of radio waves within the centimetre wavelength band. The present contribution surveys the analysis of the data obtained in some of the investigations described by Megaw. The results of this analysis provide some of the essential basic information which the engineer designing either a radiolocation system or a communication link requires in order that he may assess in advance the performance and reliability of the service to be expected under a variety of conditions.

Thompson, L. E. (Dec. 1946) A microwave relay system, Proc. IRE, 34, 936-942.

46-12 Abstract: A method of double-frequency modulation suitable for long-distance transmission of multichannel signals by means of radio-relay stations is described. Propagation, radio-frequency bandwidth, and radio-frequency power are discussed briefly. The signal-to-noise ratio and distortion of the system are shown by theory and experiment. An experimental circuit between Philadelphia and New York is described and the results are given.

Bullington, K. (Oct. 1947) Radio propagation at frequencies above 30 megacycles, Proc. IRE, 35, 1122-1136.

47-1 Abstract: Radio propagation is affected by many factors, including the frequency, distance, antenna heights, curvature of the earth, atmospheric conditions, and the presence of hills and buildings. The influence of each of these factors at frequencies above about 30 megacycles is discussed, with most of the quantitative data being presented in a series of nomograms. By means of three or four of these charts, an estimate of the received power and the received field intensity for a given point-to-point radio transmission path ordinarily can be obtained in a minute or less.

The theory of propagation over a smooth spherical earth is presented in a simplified form that is made possible by restricting the frequency range to above about 30 megacycles, where variations in the electrical constants of the earth have only a secondary effect. The empirical methods used in estimating the effects of hills and buildings and of atmospheric refraction are compared with experimental data on shadow losses and on fading ranges.

Domb, C., and M. H. L. Pryce (July 1947) The calculation of field strengths over a spherical earth, J. IEE, Part III, 94, 325-339.

47-2 Abstract: Curves and formulae are given for the calculation of field strength at any height and distance from the transmitter for the case of horizontally-polarized electromagnetic waves over a curved earth or sea. Sufficiently within the optical range the field is calculated by ray theory, and appropriate quantities for calculating path difference and divergence of reflected ray are given. At exact optical cut-off the field is calculated by an approximate method believed to be accurate to 1 db, and is presented in the form of contour curves of equal field strength on a plot of receiver height against transmitter height. Sufficiently far beyond optical cut-off the field is given by the first term in the diffraction-formula series. To calculate the field near optical cut-off, a curve should be drawn of field against distance for the heights of transmitter and receiver in question which joins smoothly the ray-theory curve for inside optical range to the one-term curve for the region beyond and passes through the point determined for the actual cut-off distance. The case of vertically polarized waves is also briefly discussed, and curves and formulae are given for the reflection coefficient (including surface-wave term) where ray theory is applicable, and for one term of the diffraction formula in the region well beyond optical cut-off.

Hey, J. S., S. J. Parsons, and F. Jackson (Sept. 1947) Reflexion of centimetric electromagnetic waves over ground, and diffraction effects with wire-netting screens, Proc. Phys. Soc., 59, 847-857.

47-3 Abstract: Difficulties in the operation of centimetric wavelength radar equipment at low angles of elevation (less than 10°) have led to a detailed consideration of the influence of ground reflexion. A technique is described for the determination of the relation between the signal strength of the echo from an isotropic reflector and the angle of elevation of the reflector. Measurements obtained over natural ground sites are shown to be in accordance with simple theoretical considerations. The effect of wire-netting artificial screening has been examined, the experimental results being in general agreement with those derived by theoretical treatment of diffraction using Sommerfeld's formula.

Jelonek, Z., E. Fitch, and J. H. H. Chalk (Feb. 1947) Diversity reception, Wireless Eng., 24, 54-62.

47-4 Abstract: The diversity gain is defined as the reduction of transmitter power permissible on the introduction of a diversity system for the same proportion of time loss of signal.

Curves and formulae are obtained for this gain, which is shown to depend on the proportion of time loss allowed for the service, the number of received signals used, the correlation between fading in these signals and a parameter characterizing the propagation conditions. This parameter is discussed; in order to obtain a better estimate of its value, it is suggested that more data on propagation conditions should be accumulated for links on which diversity reception is contemplated.

Katzin, Martin, Robert W. Bauchman and William Binnian (Sept. 1947) Three-and nine-centimeter propagation in low ocean ducts, Proc. IRE, 35, 891-905.

47-5 Abstract: One-way radio propagation measurements on 9 and 3 centimeters between ship and shore, coupled with meteorological measurements on ship and ashore, were made in the Atlantic tradewind area off the east coast of Antigua, British West Indies, early in 1945. Persistent low-level ducts, averaging 20 to 50 feet in height, within effective strength of 5 to 10 M units, were found to exist all the time. The height and strength of the duct appears to depend on the wind speed, low winds producing low ducts of moderate strength while higher winds result in higher but weaker ducts.

Various antenna-height combinations were explored to determine the optimum heights for utilization of the duct. Very effective trapping was found on 3 centimeters, the optimum height being between 6 and 15 feet, depending on duct conditions. On 9 centimeters the degree of trapping was only partial, and the strongest signals were obtained with the highest heights available (46 feet transmitting and 94 feet receiving). Rates of decrease of signal averaged 0.85 decibel per nautical mile on 9 centimeters up to about 80 miles, and 0.45 decibel per nautical mile on 3 centimeters for all ranges. Beyond 80 miles the rate of decrease of signal on 9 centimeters was much less, about 0.2 decibel per nautical mile. Rain squalls had no observable effect on the strength of received signals.

Measurements inland from the shore site showed that the duct is destroyed within one-quarter mile from the water's edge, but that effective radio transmission can be obtained with installations up to at least a mile inland if the terrain is flat and low-lying. The duct reforms the leeward side within a distance of 2 miles offshore.

Radar measurements of 3 centimeters gave results substantiating the one-way measurements. Ranges up to 47 miles on a small vessel were obtained with the antenna at 6 feet, lower maximum ranges being obtained with higher heights of radar antenna, in agreement with the findings of the one-way measurements.

Lamont, H. R. L., R. G. Robertshaw, and T. G. Hammerton (Nov. 1947) Microwave communication link, Wireless Eng., 24, 323-332.

47-6 Abstract: A description is given of a single-channel duplex radio-telephone on a wavelength of 3.2 cm. A single parabolic mirror is used as aerial for both transmitted and received signals which are separated in a waveguide system. The transmitter is a klystron oscillator of about 75 m W output. The superheterodyne receiver is fitted with automatic-frequency control and automatic-gain control. Operation over optical paths up to 70 miles long is described. A signal-to-noise ratio of about 55 db is obtained over a 57-mile path.

Norton, Kenneth A. and Arthur C. Omberg (Jan. 1947) The maximum range of a radar set, Proc. IRE 35, 4-24.

47-7 Abstract: Formulas are derived which may be used to calculate the maximum range of a radar set. It is shown that the maximum range obtainable with a given radar set depends upon (1) the energy in the pulse, i.e., the peak power times the time duration of the pulse or the average power divided by the pulse-recurrence frequency; (2) the transmitting and receiving antenna gains; (3) the transmission line, antenna, and transmit-receive-box losses; (4) the "effective width" or time duration of the transmitted pulses; (5) the "effective bandwidth" of the receiver; (6) the radio frequency of the transmitted waves; (7) the recurrence frequency of the transmitted pulses; (8) the "noise figure" of the receiver; (9) the cosmic, atmospheric, and man-made noise picked up by the antenna; (10) the attenuation during passage of the radio waves through the atmosphere due to the absorption by the atmospheric gases and rain drops; (11) the "effective echoing area" of the target; (12) the directivity of the transmitting and receiving antenna in elevation and azimuth, and (13) the effect of the ground, which, in turn, is inextricably associated with the particular site used, the height of the target above the ground, and the polarization of the transmitted radiowaves.

Smyth, J. B., and L. G. Trolese (Nov. 1947) Propagation of radio waves in the lower troposphere, Proc. IRE, 35, 1198-1202.

47-8 Abstract: The effect of tropospheric layers on the propagation of high-frequency radio waves has been experimentally investigated. A theory is proposed which is in agreement with the salient propagation characteristics observed on a nonoptical link. Fields beyond the optical horizon are governed by the layer height and the refractive index change through the layer. For low layers the higher frequencies have the advantage because of height gain, whereas for higher layers the lower frequencies have the advantage of higher reflection coefficients.

Wickizer, G. S., and A. M. Braaten (July 1947) Propagation studies on 45.1, 474, and 2800 megacycles within and beyond the horizon, Proc. IRE, 35, 670-680.

47-9 Abstract: Continuous recordings of field strength on 474 and 2800 megacycles, over a period of 13 months, revealed maximum values three to four times the free-space field at distances of 42.5 and 70.1 miles from the transmitting site atop the Empire State Building, New York City. Recordings on 45.1 megacycles during the same period, on a reduced schedule, did not exhibit the large variation found on the higher frequencies. Refraction was found to be greater in the summertime, the strongest periods occurring at night or in the early morning. Refraction greater than normal was not evident when the average wind velocity was above 13 miles per hour. A study of weather conditions during the periods of strongest refraction indicated that roughly 60 per cent of the gradients were of the frontal type, involving different air masses, and approximately 60 per cent of the gradients were higher than 100 feet above the earth's surface.

Durkee, A. L. (Feb. 1948) Results of microwave propagation tests on a 40-mile overland path, Proc. IRE 36, 197-205.

48-1 Abstract: This paper gives the results of a series of microwave radio propagation tests over an unobstructed 40-mile overland path. The purpose of the tests was to investigate the transmission characteristics of such a path at centimeter wavelengths over a long period of time. Statistics on the transmission results at wavelengths ranging from 1.25 to 42 cm are given. The tests extended over a period of about two years.

Hamlin, E. W. and W. E. Gordon (Oct. 1948) Comparison of calculated and measured phase difference at 3.2 centimeters wavelength, Proc. IRE 36, 1218-1223.

48-2 Abstract: Radio propagation and associated meteorological measurements, made by the Electrical Engineering Research Laboratory of the University of Texas during April, 1946, on a path from Gila Bend to Sentinel in the Arizona desert, show that, for meteorological conditions that could be represented by a linear M curve, the magnitude and phase of the field resulting from propagation over a 27-mile path on 3 cm could be calculated on the basis of a direct wave, and one reflected from a surface tangent to the actual profile at the point of reflection. Apparent reflection coefficients between 0.3 and 0.8 were found for desert sand on 3 cm for this path.

Megaw, E. C. S. (Jan. 1948) Some effects of obstacles on the propagation of very short radio waves, J. IEE, Part III, 95, 97-105.

48-3 Abstract: The paper deals with effects of localized obstacles, including reflection as well as shadowing, which are of practical importance in radio communication and radar, particularly on decimetre and centimetre wavelengths. In a digest of available theoretical results, later compared with the experimental findings, attention is drawn to some unresolved difficulties. In most of the practical problems discussed, prediction to a useful approximation is, however, shown to be possible.

The experimental work described has been carried out by or for the Admiralty, and much of it had its origin in the special problems of naval communications and radar. It has, however, wider applications at almost every point; applications to radar navigation are specifically discussed.

Smith - Rose, R. L. (Jan. 1948) Meteorology and the propagation of radio waves, Nature, 161, 145-146.

48-4 Abstract: Provides a review of experimental investigation of the meteorological factors affecting propagation. - HTD.

Straiton, A. W., and J. R. Gerhardt (July 1948) Results of horizontal microwave angle-of-arrival measurements by the phase-difference method, Proc. IRE, 36, 916-922.

48-5 Abstract: This paper gives the results of horizontal microwave angle-of-arrival measurements made at a location on the King Ranch, a few miles south of the Naval Air Station at Corpus Christi, Texas. Small deviations of the angle of arrival in a landward direction from the geometric path were noticed at nearly all times. Sixty per cent of the measurements showed angular deviations less than 0.015°, and 90 per cent showed deviation less than 0.03°. The angular deviation is directly proportional to path length if constant gradient persists over the path. Under this condition, deviations greater than 0.10° will be expected, 10 per cent of the time, on a path 23 miles long. The measured angular deviations show a general correlation with the measured horizontal gradient of index of refraction. Meteorological soundings showed overwater ducts present nearly all of the time, with a maximum difference of approximately 50 M units between the surface of the water and the 38-foot level.

Thompson, Leland E. (1948) Microwave propagation experiments, Proc. IRE 36, 671-676.

48-6 Abstract: Propagation tests at frequencies between 3000 and 4000 Mc. are described. The effect on the received signal of changes in the index of refraction of the atmosphere are discussed, and means are suggested for minimizing signal variations with particular regard to the application of microwave-relay communication systems. Theoretical data is given on diffraction at these frequencies.

Davies, H. (Nov. 1949) A preliminary study of some results from the radio-meteorological investigation conducted in Canterbury, Trans. Royal Soc. of New Zealand, 77, 78-85.

49-1 Abstract: The mechanics of orthodox propagation of cm waves in a well mixed atmosphere are discussed, including lobe distribution above the horizon due to interference of direct and reflected rays. Anomalous propagation in a duct is considered and the effect of a land-sea transition on the vertical structure of potential temperature, specific humidity, modified refractive index and duct shape in a typical NW advective duct are illustrated. These cause considerable superrefraction of wavelengths of 3 and 10 cm. (Met. Abs. 8I-57)--C. E, P. B.

Gough, M. W. (1949) VHF and UHF propagation within the optical range, Marconi Review No. 95, 121-139.

49-2 Abstract: The mechanism of VHF and UHF propagation can be explained in terms of five major factors, namely;—

(1) Atmospheric refraction;
(2) Ionospheric reflections;
(3) Tropospheric reflections;
(4) Diffraction;
(5) Ground reflections.

(5) is the dominant influence on propagation within the optical range, and it is with this aspect of the problem that this article is concerned.

From the ray concept of propagation, a technique has been evolved using simple microwave field strength measurements to forecast the behavior of VHF and UHF transmissions over a specific optical path. In particular the method predicts, without further measurement, the best height for the receiving aerial on any frequency in the VHF or UHF band.

The process is based on the assumption that ground reflection is confined to a point. This assumption becomes increasingly invalid with increasing wavelength and may lead to errors. However, these can be corrected to a large extent by invoking Fresnel's zone theory, which defines what region of the path is involved in reflection. Furthermore, by examining the ground irregularities in this region the reflecting power of the ground can be assessed.

This article develops the theory of the microwave survey technique and describes and interprets a survey made over a test path, from which the behavior of specific longer waves is predicted. It concludes with a description of confirmatory experiments made over the same path which verify the predictions.

The "calibration" of optical paths by the use of microwaves eliminates the necessity for tests on operational wavelengths, and coupled with the lightness and compactness of microwave equipment, saves experimental labour, particularly if the path is to carry transmissions on more than one wavelength.

Grün, A., and W. Kleinsteuber (Sept. 1949) Der durch den Feuchtigkeits- und Temperaturgang der unteren atmosphärischen Schichten verursachte Interferenzschwund im Dezimetergebiet, Archiv der Elektrischen Übertragung, 3, 209-219. (The interfering fading in the decimeter band, caused by the temperature and humidity variation of the lower layers of the atmosphere.)

49-3 Abstract: Since the changeable curvature of a ray is due to the weather dependent gradient of the index of refraction, the difference in variation of both rays (i. e., the direct and the earth reflected) gives simple formulas for calculation of the field strength. Observational results evaluated by this method were found in good agreement with available meteorological observations.
(Met. Abs. 81-60)--W. N. (Bibliog, 64-6)

Israel, H., and K. Sommermeyer (Jan. 1949) Über partielle Reflexion elektromagnetischer Wellen in der Troposphäre, Z. Meteorologie 3, 32-39. (Partial reflection of electromagnetic waves in the troposphere.)

49-4 Abstract: A marked partial reflection of electromagnetic waves by atmospheric formations can only occur if the dielectric constant at the reflecting surface changes considerably in a distance shorter than or at the most, of the same order as the wavelength. Most reflections at inversions, etc., are limited to waves of a few hundred meters or more. Decimeter waves can be reflected by water vapor discontinuities in transient turbulent eddies, mostly over the sea, and in thunderclouds and the space above them. Uniform ionization density in a thundercloud cannot explain reflection, and authors suggest ionization in discharge channels.
(Met. Abs.1.11-175)--C.E.P.B.

Jones, F. E., and E. C. Cornford (Sept. 1949) The measurement of the velocity of propagation of centimetre radio waves as a function of height above the earth, Part 2, Proc. IEE, Pt. 3, 96, 447-452.

49-5 Abstract: Part I[1] of the paper gave an account of the measurement of the velocity of propagation of centimetre waves over a sea path at low level, and concluded that the velocity is 186 217 ± 16 miles/sec. Part 2 gives the results of experimental flights observed from two Oboe ground stations in order to measure the velocity of propagation as a function of height above the earth. The results indicate higher velocities than those previously calculated. The most probable values for the mean velocity of propagation between ground and aircraft at 10 000, 20 000, and 30 000 ft. are 186 233, 186 246, and 186 256 miles/sec respectively, the metric equivalents being 299 713, 299 733, and 299 750 km/sec respectively.

Lehfeldt, Wilhelm (1949) Die Ausbreitung der Ultrakurzen (quasioptischen) Wellen, Archiv der Elektrischen Ubertragung, 3, 137-142, 183-186, 221-228, 265-269, 305-312, 339-346 (July-Dec.) (Propagation of ultrashort (quasi-optical) waves.)

49-6 Abstract: This detailed study contains two main parts. The first part discusses such problems as: (1) refraction of the ray in a homogeneous atmosphere, (2) refraction and reflection in an inhomogeneous atmosphere, (3) reflections and blurred boundaries, (4) influence of ions upon reflection and refraction, (5) suppression by scattering and absorption. Influence of the earth's surface. In the second part, devoted to discussion of the results obtained by measurement, the following topics are highlited: (1) the technique of measurements, (2) measurements of over-land propagation, (3) statistical over-land results, (4) measurements over the sea, and at 9 cm wavelength over plain lowland, (5) ranges. (Met. Abs. 8I-67) -- W.N. (Bibliog., 64-6).

McPetrie, J. S., B. Starnecki, H. Jarkowski and L. Sicinski (March 1949) Oversea propagation on wavelengths of 3 and 9 centimeters, Proc. IRE 37, 243-257.

49-7 Abstract: This paper summarizes the results obtained from tests extending from 1943 to 1946 which were made to determine the meteorological factors controlling the propagation of centimeter waves. Oversea paths of 60 and 200 miles off the West Coast of Great Britain were used for the experiments. Continuous records of radio field strengths and frequent measurements of the meteorological conditions along the paths were made. The correlation between the radio results and the various meteorological parameters is studied in the light of current theories of microwave propagation.

Millington, G. (Oct - Dec 1949) The reflection coefficient of a linearly graded layer, Marconi Rev. 12, 140-151.

49-8 Abstract: The curves given in this paper refer to the specific problem of the reflection of a horizontally polarized plane wave incident obliquely on a layer in which there is a linear variation of dielectric constant, and hence of the square of the refractive index, from some constant value on one side of the layer to some other constant value on the other side of the layer. They have a particular application to the propagation of ultra high frequency radio waves in the troposphere, and should, therefore, be a useful contribution to our knowledge of long distance transmission on these frequencies.

It is to be noted that the curves refer only to the case of horizontal polarization. The analysis for vertical polarisation has been worked out, but it is different in form from that for horizontal polarisation. It is well known, for instance, that in the case of reflection at a sharp boundary there is a zero or minimum reflected wave at the Brewster angle that does not occur with horizontal polarisation. It does, however, happen that when the changes in refractive index is very small and the wave is incident at a nearly glancing angle, the reflection coefficient for vertical polarisation is numerically almost the same as for horizontal polarisation, though its analytical form is different.

Under these strictly limited conditions, the curves for horizontal polarisation give also the numerical value of the reflection coefficient for vertical polarisation to the accuracy to which they can be used. When the change of refractive index is small, this may mean that the two cases are practically equivalent over the range for which the reflection coefficient is appreciable, but as this equivalence is solely a matter of numerical approximation, while analytically the two cases remain fundamentally distinct, it is perhaps best to limit the use of the curves to the case of horizontal polarisation to which alone they strictly refer, even where they may happen to give an approximate numerical value for vertical polarization.

Bremmer, H. (Nov. 1950) Voortplanting van radiogolven in de troposfeer, Nederlandsch Tijdschrift voor Natuurkunde, 16, 275-280 (Propagation of radio waves in the troposphere)

50-1 Abstract: A discussion of superrefraction, radio ducts and other aspects of radio wave reflection and propagation in the troposphere is illustrated by schematic diagrams and examples. - M.R.

Bussey, H. E. (Dec. 1950) Reflected ray suppression, Proc. IRE, 38, 1453.

50-2 Abstract: The use of Fresnel zone screens is described as a means of suppressing ground reflections on line of sight microwave paths.

Day, J. P., and L. G. Trolese (Feb. 1950) Propagation of short radio waves over desert terrain, Proc. IRE 38, 165-175.

50-3 Abstract: Results are given of an experimental investigation of the effect of relatively simple topography and meteorology upon the propagation of short radio waves over an optical 26.7-mile path and a nonoptical 46.3-mile path. Two types of meteorological conditions were encountered during the course of the experiments performed in the Arizona desert. In the daytime the atmosphere was well mixed with the index of refraction distribution nearly standard. At night a small scale duct was formed, due to a temperature inversion arising from the cooling of the ground by radiation. Measurements of the vertical distribution of field strength over a 190-foot interval were made under these two meteorological conditions for frequencies of 25, 63, 170, 520, 1,000, 3,300, 9,375 and 24,000 Mc. The effect of the diurnal meteorological cycle on the field strength is discussed for both the optical and nonoptical path. Diffraction effects on the short path due to small scale irregularities of the terrain are also discussed.

Millar, J. Z., and L. A. Byam (June 1950) A microwave propagation test, Proc. IRE 38, 619-626.

50-4 Abstract: A description is given of a microwave propagation test which was conducted over a period of a year with simultaneous transmission on wavelengths of 16.2, 7.2, 4.7, and 3.1 cm over an unobstructed 42-mile overland path. Comparative charts depict variations in daily fading range, illustrate diurnal and seasonal characteristics of fading, and reveal the marked disparagement between winter and summer fading. Curves are presented showing relative field-strength distribution for both winter and summer periods, and also the distribution of hourly minima. These curves may be useful in considerations bearing on continuity of service that may be expected with relation to wavelength and to time of day, winter or summer.

Phillips, W. E. (July 1950) The permittivity of air at a wavelength of 10 centimeters, Proc. IRE, 38, 786-790.

50-5 Abstract: This paper reports measurements of the permittivity of moist air under different conditions of pressure, temperature, and water-vapor content taken at a frequency of 3,036 Mc. The method and apparatus used are described. Results of observations made are given, and their probable accuracy is discussed.

Saxton, J. A. (Jan. 1950) Reflection coefficient of snow and ice at V.H.F., Wireless Eng., 27, 17-25.

50-6 Abstract: A review is given of the nature and composition of snow, and of the experimental knowledge of the dielectric properties of ice at very high radio frequencies. From this information an estimate has been made of the dielectric properties of snow. The presence of a layer of ice or snow on the earth's surface will produce a modification in the resultant reflection coefficient of the surface as a consequence of multiple reflections within the layer. A general formula is given in the paper by means of which the resultant reflection coefficient for plane waves in the presence of such a layer may be calculated. The formula is in terms of several basic parameters which have been determined for frequencies of 30, 300, 3,000, and 30,000 Mc/s. To illustrate the effect of these layers, the resultant reflection coefficients of a stratum of ice on sea water and of one of snow on land have been calculated for frequencies of 300 and 3000 Mc/s, at angles of incidence of 0^{o} (normal incidence), 45^{o}, and 80^{o}, and for radiation polarized with the electric vector either parallel to or in the plane of incidence. It thus appears, for example, that the vertical-coverage diagram of a very high frequency radio transmitter may be appreciably modified by the presence of layers of ice or snow in depths likely to occur in practice.

Smith-Rose, R. L. (Jan. 1950) The speed of radio waves and its importance in some applications, Proc. IRE, 38, 16-20.

50-7 Abstract: This paper comprises a review of the present state of knowledge of the speed of transmission of radio waves under the practical conditions of certain applications in which such knowledge is important. It is shown first that, for radio waves in a vacuum, their speed of transmission is equal to the velocity of light (299,755 km/s), to within the limits of experimental error. When waves of frequencies in the neighborhood of 100 kc/s are propagated at a height of a fraction of a wavelength above the earth's surface, their speed is reduced by an amount dependent upon the electrical conductivity of the earth. For overland transmission, the speed is about 299,250 km/s. For higher frequencies propagated at a height of several wavelengths, the speed of the waves is determined by the refractive index of the air, rather than by the properties of the ground. Since the refractive index decreases with the height of transmission, so does the speed of the waves increase toward the velocity of light. For example, centimeter waves propagated at heights of a few hundred feet have been observed to travel at a speed of about 299,260 km/s. When the waves are transmitted between ground and aircraft flying at a height of 30,000 feet (9,800 meters) this speed is increased to about 299,750 km/s.

Brocks, K. (1951) Probleme der "Radiometeorologie", Ann. der Meteorologie, 4, 78-86 (Problems of radio-meteorology).

51-1 Abstract: A discussion of the effect of the atmosphere on radio waves 1 cm to 10 m. The equations of the "relative beam-curvature" (negative gradient of refractive index times earth's radius) are set out and constants of pressure and vertical gradients of temperature and humidity tabulated. Other measures of refraction in use are defined. Diurnal variations at Quickborn are discussed.
(Met. Abs. 8I-106)-- C.E.P.B.

Kerr, D. E. (1951) Propagation of short radio waves, McGraw-Hill,
51-2 N.Y. [Text]

Peters, O. F., Bo. K. E. Stjernberg, and K. H. Forsgren (1951) Microwave propagation in the optical range, Chalmers Tekniska Hogskola, Handelinger, Goteborg, Sweden, No. 108, 19 pp.

51-3 Abstract: In 1946 when these propagation tests began in the vicinity of Goteborg, Sweden, access to reports on similar works by foreign scientists was not possible. The results presented are nevertheless valuable for studying the influence of local weather and consist of: transmission field strength, attenuation, refraction, fading and diurnal variation of 10, 3, and 1 cm wavelengths. Equipment, sites of installations and records are shown in photographs.
(Met. Abs. 8I-124)-- W.N.

Bogle, A. G. (1952) Some aspects of microwave fading on an optical path over sea, Proc. IEE Part B, 99, 236

52-1 Abstract: Long-term measurements of microwave transmission over a 39-mile optical path have shown fading too deep to be easily accounted for by simple theory.

It is concluded from experimental evidence that both scattering from turbulence and movements of the interference pattern contribute to the fading.

Chavance, P. (1954) Etude de propagation des ondes centimétriques dans le Nord de la France, Annales des Télécomm. 7, 254-261. (The study of centimeter wave propagation in the north of France.

52-2 Abstract: An investigation of 3.2 and 9.5 cm wave propagation is described which was undertaken essentially for the purpose of obtaining statistical data for a path with insufficient clearance. Markedly apparent are the diurnal and seasonal effects. Finally an effort is made to analyze a few typical examples of fading and to draw certain information from recordings made at high speed.—H. T. D.

Crawford, A. B., and W. C. Jakes, Jr. (Jan. 1952) Selective fading of microwaves, Bell Sys. Tech. J. 31, 68-90.

52-3 Abstract: The results of an extended survey of microwave propagation over two line-of-sight paths in New Jersey are described. Angle-of-arrival measurements at 1.25-cm wavelength and selective fading observations in a 450-mc frequency band centered at 3950-mc show that the severe fading can be explained in terms of multiple-path transmission. A computer of the analogue type was built to simulate the more complicated selective fading patterns.

Cumming, W. A. (July 1952) The dielectric properties of ice and snow at 3.2 centimeters, J. App. Phys., 23, 768-

52-4 Abstract: A knowledge of the permittivity and loss tangent of snow and ice is essential in studying both radar echoes from snow-covered terrain and the attenuation of microwave energy through snowstorms. To provide this information, a program was carried out at the National Research Council of Canada to measure the permittivity and loss tangent of ice and snow, and also to determine the reflection coefficients of snow-covered surfaces, at a wavelength of 3.2 centimeters.

As a result of these investigations values have been obtained for the permittivity and loss tangent of snow of varying density, temperature, and water content. Theoretical values of the reflection coefficients of snow-covered surfaces, calculated from these data, are compared with the values obtained from the direct measurement of reflections from natural snow surfaces.

De Lange, O. E. (Jan. 1952) Propagation studies at microwave frequencies by means of very short pulses, Bell Sys. Tech. J. 31, 91-103.

52-5 Abstract: Microwave pulses with a duration of about 0.003 microseconds were transmitted over a 22-mile path from Murray Hill, N. J. to Holmdel, N. J., in order to determine the effects of the transmission medium upon such pulses. During "fading" periods multi-path transmission effects with path differences as great as 7 feet were observed, as well as some other effects. A microwave frequency of 4000 megacycles was employed.

Kiley, D. G., and W. R. Carter (1952) An experimental study of fading in propagation at 3-cm wavelength over a sea path, Proc. IEE Part III, 99, 53 .

52-6 Abstract: The paper describes an experimental study of fading in propagation over a sea path within the radio horizon at a wavelength of 3 cm carried out between July 1950 and January 1951. Horizontal polarization was used. The object of the investigation was to record the general fading characteristics (i.e. depth, duration and frequency of occurrence) for summer, autumn and winter and to present the results in such a form that the effects of fading on the operational ranges of radar experiments would be readily appreciated. An initial assessment of the transmitter power required for reliable operation of a beacon under given conditions has also been made.

Bean, B. R. (April 1953) The geographical and height distribution of the gradient of refractive index, Proc. IRE, 41, 549-550.

53-1 Abstract: Charts are presented of the Feb. and August distribution of effective earth radius factor over the United States.

Bussey, H. E., and G. Birnbaum (Oct. 1953) Measurement of variations in atmospheric refractive index with an airborne microwave refractometer, NBS J. Res., 51, 171-178.

53-2 Abstract: A microwave refractometer for aircraft use is described, and some of the sources of error in the measurement of variations of atmospheric refractive index with this instrument are discussed. Observations were made up to 10,000 feet on 2 days near Washington, D. C. Two refractive-index soundings taken 1 ½ hours apart showed changes that, in the coarser aspects, resembled changes shown by radiosonde data. The fluctuation intensity changed erratically with time and place, but was usually greatest where the vertical gradient was changing. A rough analysis of the data showed that the larger fluctuations occurred over distances of several hundred meters, whereas over distances less than 5 meters the fluctuations were negligible (the response of the instrument would have allowed the detection of fluctuations occurring within 0.5 meter). Large increases in index were observed on entering cumulus clouds and intense fluctuations were noted within the clouds.

Byam, L. A., and J. Z. Millar (1953) Notes on propagation, IRE Conv. Rec. Pt. 2 Ant. and Comm., 68-76.

53-3 Abstract: A brief discussion of the fading which occurred during an extended microwave propagation experiment, operated at a frequency of 4000 Mc. Attention was directed primarily to those fades which dropped 15 db or more from the normal signal level. For each such fade, the essential data were extracted and tabulated, including information with respect to the corresponding level of the diversity (or main) signal.
E.K. (Bibliog. 64-6)

Committee on Wave Propagation (May 1953) Tropospheric propagation: A selected guide to the literature, Proc. IRE, 41, 588-594.

53-4 Abstract: A subcommittee of the IRE Committee on Wave Propagation selects references designed to direct the non specialist through the mazes of an extensive literature to information on certain specific aspects of the propagation of short radio waves through the troposphere.

Crain, C. M., A. P. Deam, and J. R. Gerhardt (Feb. 1953) Measurement of tropospheric index-of-refraction fluctuations and profiles, Proc. IRE, 41, 284-290.

53-5 Abstract: This paper presents measurements of index-of-refraction fluctuations and profiles made with a direct reading microwave refractometer over the Atlantic Ocean and coastal areas near Lakehurst, N. J., in April 1951 and over the vicinity of Wright-Patterson Field, Dayton, Ohio, in June 1951.

Crain, C. M., A. W. Straiton, and C. E. Von Rosenberg (Oct. 1953) A statistical survey of atmospheric index-of-refraction variation, Trans. IRE, AP-1, 43-46.

53-6 Abstract: This paper presents a statistical survey of index-of-refraction variations as recorded by an airborne microwave refractometer. Scales and intensities of the index variations are given, as well as the parameter $\overline{\Delta N^2/\iota}$, for data taken over southwest Ohio during summer months and over the Pacific Ocean off the west coast of Washington in August and of California in October. Heights from 2,000 to 25,000 feet, msl, were considered with most of the data taken between 2,000 and 12,000 feet. Approximately 1,200 samples taken on 34 flights were analysed. The composite of the data gave the following median values:

Index scale = 130 feet

Index Intensity = 0.3 N

$$\frac{\overline{\Delta N^2}}{\iota} = 7 \times 10^{-4} N^2/\text{ft}$$

Kaylor, R. L. (Sept. 1953) Statistical study of selective fading of super-high frequency radio signals, Bell Sys. Tech. J. 32, 1187-1202.

53-7 Abstract: The results of two months of comprehensive frequency-sweep measurements of selective fading in the band between 3750 and 4190 mc over a radio relay path in Iowa are reported. An abridgement of the data, general conclusions derived from the data and an example of the use of the data in connection with frequency diversity measures for radio relay systems are given.

Klein, W., and L. J. Libois (1953) Essais de transmission par faisceau hertzien sur un long trajet en visibilite optique entre la France et la Suizze. L'Onde Electrique, 33, 664. (Communication experiment with radio beams on a long line-of-sight path between France and Switzerland.)

53-8 Abstract: The results of an experimental investigation of propagation conditions is presented for a long (160 km) line-of-sight path over mountainous terrain. The propagation path had clearances of several Fresnel zone radii for a $k = 4/3$ effective earth's radius factor but had zero clearance for $k = 1$. Observations of the received field at 3000 MHz over a three month period provided fairly stable values of attenuation relative to free space. Some correlation between the recorded fields and the meteorological conditions was observed. - HTD

Matsuo, Saburo, Shigetaka Ugai, Kiyoshi Kakita, Fumio Ikegami and Yoshinori Kono (Nov. 1953) Microwave fading, Reports of ECL, Japan, 1, 38-47.

53-9 Abstract: This paper deals with summary of fading characteristics, evaluation of fading range, and methods of decreasing fading, taken from the analytical materials obtained from the propagation tests performed on 4000 Mc microwave during the period of past 3 years by Electrical Communication Laboratory of Nippon Telegraph and Telephone Corporation. Since this investigation was made mainly for the purpose of obtaining necessary materials for design of 4000 Mc FM super multi-channel telephone relay network, this paper has been prepared for discussion along that line.

Microwave fading, depending upon the causes, may be classified into three types; namely, scintillation fading, K-type fading, and duct-type fading. Of these three types, the scintillation fading, with its small amplitude of variation, does not give any practical problem, but the latter two types do give much effect on propagation, so that the investigation was directed to these two types of fading.

Norton, K. A. (Jan. 1953) Transmission loss in radio propagation, Proc. IRE, 41, 146-152.

53-10 Abstract: The utility of the concept of transmission loss in radio propagation analysis is explored. The transmission loss of a radio system is defined to be the ratio of the power radiated from the transmitting antenna to the resulting signal power available from a loss-free receiving antenna. After discussing some methods of measuring transmission loss, its calculation for representative systems is discussed. It is shown that a measure of transmission loss often adopted, namely the attenuation relative to the free-space value, sometimes leads to errors and confusion in the presentation of the results of measurements and in applications to radio systems; the use of the over-all transmission loss of a system avoids these pitfalls.

A discussion is given of the expected variation with time (fading) of the transmission loss expected for radio systems involving ionospheric or tropospheric propagation. This discussion involves the theory of the Rayleigh distribution and its limitations in such applications.

A definition is then derived for the effective noise figure of a radio system which includes the external noise picked up on the receiving antenna. This definition is used to explain the method of determining the maximum range of a radio system.

Finally a discussion is given of the maximum range of a radio system as limited by interference from other radio signals plus noise rather than from noise alone.

Perlat, A., and J. Voge (Dec. 1953) Attenuation des ondes centimetriques et millimetriques dans l'atmosphere, Ann. des Telecomm., 8, 395-405 (Attenuation of centimeter and millimeter waves in the atmosphere).

53-11 Abstract: The authors delineate the effects of the atmosphere on very short waves and the importance of atmospheric attenuation. In the first section results obtained by American and English workers are surveyed in connection with absorption by rain, snow, hail, fog and clouds. Attenuation by atmospheric ozone and by water vapor is also considered, taking into consideration the effects of altitude and temperature. The second section is a statistical study presenting precipitation, fog, water vapor and temperature data of France and North Africa. In the third section a method is worked out for calculating atmospheric attenuation over a given path for specified percentages of given time periods. --E.K. (WN Bibliog. 64-6)

Bean, Bradford R. (May 1954) Prolonged space-wave fadeouts at 1,046 Mc observed in Cheyenne Mountain propagation program, Proc. IRE 42, 848-853.

54-1 Abstract: During the first year of continuous operation of the Cheyenne Mountain propagation program, recordings of 1,046-mc fields at receiving locations within the radio horizon have exhibited "fadeouts" or prolonged periods of attenuation often in excess of 20 db below the monthly median level and lasting from a minute up to several hours. The occurrence of these fadeouts has been found to coincide with widespread super-refraction as evidenced by enhanced signals beyond the radio horizon and ground modification of the refractive index profile.

Bullington, K. (Aug. 1954) Reflection coefficients of irregular terrain, Proc. IRE, 42, 1258-1262.

54-2 Abstract: Radio relay paths with strong ground reflections experience more fading than similar paths with negligible ground reflections. In order to minimize fading the route survey for the transcontinental microwave-relay system included measurements of ground reflection coefficients on most of the proposed repeater sections. In most cases the reflection coefficients at 4,000 mc were in the range from 0.2-0.4. Attempts to correlate these results with the path profiles and to obtain a suitable theoretical explanation indicate that no simple relation exists but that a statistical relationship can be found to fit the observed data.

Chavance, P., L. Boithais and P. Blassel (1954) Etude de propagation d'ondes centimétriques dans le region Mediterranéenne, Annales des Telécomm. 9, 158-185. (A study of centimeter wave propagation in the Mediterranean Region.)

54-3 Abstract: This paper presents the results obtained to date by C.N.E.T. in a study of centimeter wave propagation in the Mediterranean region. The first part, I, constitutes a general description of the investigation. It specifies the points of interest for the paths investigated; one between Corsica and the continent and the other along the Mediterranean coast and indicates the different types of experience encountered on these paths. The second part, II, is devoted to the equipment employed; transmitters, receivers and special arrangements. The third part, III, presents the results obtained during the different experiments: a statistical study of the Corsica-continent path at 1400 and 3150 Mc/s; a comparison for horizontal and vertical polarization; the distribution of the atmospheric index (of refraction) along the beam; the influence of path's clearance upon its stability; improvement by vertical space diversity; a study of a short path high above the sea surface. Although this study is not as yet complete, interesting results from the practical as well as the scientific point of view have already been furnished. H.T.D.

Cox, C. and W. Munk (1954) Statistics of the sea surface derived from sun glitter, J. Marine Res. 13, 198-227.

54-4 Abstract: Aerial photographs of the sun's flitter on the sea surface, taken under carefully chosen conditions in the Hawaiian area, were coordinated with measurements of winds (1-27 knots) from a vessel. Statistics of the glitter, interpreted in terms of the statistics of the slope distribution of the sea surface, gave the following results: (1) As a first approximation the slope distribution is found to be Gaussian; this can be accounted for by an arbitrarily wide continuous spectrum of ocean waves, but not by a spectrum consisting of a few discrete frequencies. (2) The ratio of the up/downwind to crosswind components in mean square slope is less than two; this indicates a directional "beam width" in excess of 130° for the relatively short waves that contribute to the slope spectrum. (3) The mean square slope, regardless of direction, increases linearly with wind speed and reaches a value of $(\tan 16°)^2$ for a wind speed of 14 m sec^{-1}; this empirical relation follows in form and to an order of magnitude from a spectrum proposed by Neumann on the basis of wave amplitude observations. A spectrum proposed by Darbyshire cannot be reconciled with our observations.

Further results which have not been interpreted are: (4) An up- and down-wind skewness which increases with increasing wind speed is such as to make the most probable slope a few degrees rather than zero, with the azimuth of ascent pointing downwind. (5) A peakedness, which is barely above the limit of observational error, is such as to make the probability of very large and very small slopes greater than Gaussian. (6) Oil slicks laid by the vessel over an area of one quarter square mile reduce the mean square slope by a factor of two or three and eliminate skewness but leave peakedness unchanged.

The distribution of particle acceleration is closely related to the distribution of slope. Accordingly, the total mean square acceleration increases linearly with wind speed and reaches a value (at the surface) of $(0.4\ g)^2$ at a wind speed of 14 m sec^{-1}

Kahn, L. R. (1954) Ratio squarer, Proc. IRE, 42, 1704.

54-5 Abstract: An optimal output signal to noise ratio is derived for the linear adding diversity combiner.

Kiely, D. G. (1954) Some measurements of fading at a wavelength of 8 mm over a very short sea path, J. Brit. IRE, 14, 89-92.

54-6 Abstract: The results of a pilot experiment designed to investigate the magnitude of atmospheric refraction effects in the 8-mm wavelength band are described. Records of signal fading on a 1-mile over-sea path with a low transmitter and a high receiver indicate that these effects are very large.

Brennan, D. G. (Oct. 1955) On the maximum signal-to-noise ratio realizable from several noisy signals, Proc. IRE, 43, 1530.

55-1 Abstract: A derivation is presented of the output signal to noise ratio for an nth order maximal (S/N) ratio combiner.

British IRE (1955) Abstracts of papers which have appeared in the Journal over the past 15 years (Vols. 1-15, 1939-1955), British IRE, 48 pp.

55-2 Abstract: The abstracts cover the principal papers published in the past 15 years in this journal which, prior to 1939, was referred to as "The Proceedings". The sections of radio meteorology including propagation and instrumentation are listed under Radio Communication (621.396) and subdivided according to the latest amendments to the U.D.C. system. (Met. Abs. 14.7-112)-- (W.N. Bibliog., 64-6).

Cabessa, R. (1955) Realization de liasons par faisceaux hertzian de qualité sur des trojets maritimes en Gréce, L'Onde Electrique 35, 714-727. (The achievement of reliable radio communication links on over-water paths in Greece.

55-3 Abstract: The successful performance of several communication links, 24 overwater paths and 8 overland paths, is described. The frequencies of operation ranged from 1.7 to 2.3 Gc/s and space diversity reception was employed. The choice of terminal sites was determined in the light of the following sources of fading on line-of-sight microwave paths: superrefraction (ducting); substandard refraction (earth-bulging); interference between direct and reflected waves; and interference due to reflections from elevated layers.—H. T. D.

Court, G.W.G. (1955) Determination of the reflection coefficient of the sea, for radar-coverage calculation, by an optical analogy method, Proc. IEE, Pt. B, 102, 827-830.

55-4 Abstract: An approach to the solution of the problem of the effect of a rough sea surface on the vertical coverage of a radar set, by means of an optical analogy, is suggested. The reflection of light waves by a ground-glass surface is considered, and the results of optical experiments are applied to the case of radio waves reflected by the surface of the sea. The method does not yield a precise solution to the problem, but the result achieved does not conflict seriously with practical results which have been recorded up to the present.

A typical coverage diagram derived by this method is given to show the effect on the coverage of the variation of sea-surface condition as indicated by the sea-state scale.

Deam, A. P., and B. M. Fannin (Oct. 1955) Phase-difference variations in 9,350-megacycle radio signals arriving at spaced antennas, Proc. IRE 43, 1402-1404.

55-5 Abstract: The phase difference between 9,350 megacycle-persecond radio signals received from a common transmitter at two horizontally spaced antennas was measured by the Electrical Engineering Research Laboratory of the University of Texas during March, 1955. The transmitter was located on Cheyenne Mountain in Colorado and the site of the receiver was at Fort Carson, 3.5 miles distant. The elevation angle of the transmitter as seen from the receivers was 9 degrees. This paper presents and discusses the results of these measurements.

Herbstreit, J. W., and M. C. Thompson (Oct. 1955) Measurements of the phase of radio waves received over transmission paths with electrical lengths varying as a result of atmospheric turbulence, Proc. IRE, 43, 1391-1401.

55-6 Abstract: A system for the measurement of the variations in electrical lengths of radio propagation paths is described. The observed path-length instabilities are considered to be caused by the same atmospheric turbulence responsible for the existence of very high frequency and ultra high frequency fields far beyond the radio horizon. Results obtained on 172.8 mc and 1,046 mc along 3½-, 10-, and 60-mile paths are reported. It is pointed out that measurements of this type provide a powerful tool for the study of the size and intensity of the refractivity variations of the atmosphere giving rise to the observed phenomenon.

LaGrone, A. H., A. W. Straiton and H. W. Smith (April, 1955) Synthesis of radio signals on overwater paths, Trans. IRE AP-3, 48-52.

55-7 Abstract: The fluctuations of radio signals at microwave frequencies on overwater paths are explained on the basis of a periodic rise and fall of the water level. From this study, it is seen that the variations in the radio signal strength will contain the frequency of the water-level cycles and also the second and third harmonics of the water-level cycles.

The same model predicts that the cross-correlation function of the fluctuation of the radio signal at two vertically-spaced antennas will drop from unity to zero as the separation distance is changed from zero to one-half of a lobe width of a height-gain interference pattern.

Although the model assumes reflection from a plane surface, the results of the study successfully explain most of the features of the observed fluctuations of the radio signals on two overwater paths.

Muchmore, R. B., and A. D. Wheelon (Oct. 1955) Line-of-sight propagation phenomena—I. Ray treatment, Proc. IRE 43, 1437-1449.

55-8 Abstract: The effect of variations in index of refraction on line-of-sight propagation of electromagnetic waves in the troposphere is investigated using, in this paper, a ray theory approach. Mean-square variations in phase delay and phase correlation between two paths are calculated. It is shown that these quantities are relatively insensitive to the form of space correlation function assumed for the index of refraction. The mean-square phase is proportional to $\overline{\Delta N^2} \ell_o$ where ℓ_o is scale length and $\overline{\Delta N^2}$ the mean-square variation in index of refraction, whereas in beyond line-of-sight propagation the received power is proportional to $\overline{\Delta N^2} / \ell_o$.

Variations in angle of arrival are also calculated and it is shown that here the assumed space correlation of index of refraction is critical in determining the angle of arrival characteristics. It is shown, however, that a certain portion of the angle-of-arrival spectrum is insensitive to the choice.

Norton, K. A., L. E. Vogler, W. V. Mansfield and P. J. Short (1955) The probability distribution of the amplitude of a constant vector plus a Rayleigh-distributed vector, Proc. IRE 43, 1354-1361.

55-9 Abstract: Formulas, tables, and graphs are given for the probability distribution of the instantaneous resultant amplitude of the sum of a constant vector and a Rayleigh-distributed vector. It is emphasized that two distributions are required to describe a Rayleigh-distributed vector: the distribution of its amplitude and the distribution of its phase. A summary is presented of physical conditions which must be satisfied for a given phenomenon to exhibit statistical properties of a Rayleigh-distributed vector. References are made to ways in which these distributions may be used to describe random variables occurring in ionospheric, tropospheric, and irregular terrain propagation problems. Finally, a discussion is given of amplitude and phase distributions of two other random vectors encountered in tropospheric propagation studies.

Saxton, J. A., and J. A. Lane (May 1955) VHF and UHF reception effects of trees and other obstacles, Wireless World, 61, 229-232.

55-10 Abstract: Some experiments to determine the attenuation caused by screens of trees and thick woods at frequencies of 100, 540, and 1,200 Mc/s are described, and these and other data are used to estimate the attenuation over the frequency range 30-3,000 Mc/s. This work carried out as part of the programme of the Radio Research Board. The nature of the diffraction loss and variation of field strength behind opaque obstacles of various kinds for the same frequency band is examined on the basis of the Fresnel theory of diffraction.

Sherwood, E. M., and E. L. Ginzton (July 1955) Reflection coefficients of irregular terrain at 10 cm, Proc. IRE, 43, 877-878.

55-11 Abstract: Reflection coefficients measured at 10 cm wavelength are presented as a function of polarization and angle of incidence for a variety of terrain and water surfaces.

Wheeler, B. F., and H. R. Mathwich (Oct. 1955) Use of distribution curves in evaluating microwave path clearance, Trans. IRE, PGI-4, 31.

55-12 Abstract: Distribution curves for the duration of fades as a function of mean fade duration and type of fading are presented and their application is described.

Wheelon, A. D. (Oct. 1955) Near field corrections to line-of-sight propagation, Proc. IRE 43, 1459-1466.

55-13 Abstract: This study considers the line-of-sight propagation of electromagnetic waves in a turbulent medium. Interest here centers on the received signal's phase stability. The field equation describing propagation through a region characterized by random dielectric fluctuations is first developed. Solutions of this equation which represent the scattered field are derived with ordinary perturbation theory. These solutions are next used to calculate the rms phase error for an arbitrary path in the troposphere. This approach includes both a three dimensional and near-field description for the multipath, scattered amplitudes; thereby overcoming the limitations of previous treatments. The phase correlation between signals received on two parallel transmission paths is derived last to illustrate the role of overlapping antennae beams.

Wheelon, A. D., and R. B. Muchmore (Oct. 1955) Line-of-sight propagation phenomena—II. Scattered components, Proc. IRE 43, 1450-1458.

55-14 Abstract: The foregoing investigation of line-of-sight propagation through a turbulent atmosphere is continued and enlarged. Generalizations of the ray calculation to include scattering contributions by off-axis blobs are given. It is found that the previous expressions for rms phase errors are substantially maintained. The dependence of these fluctuations on receiving antenna beamwidth is adduced. These techniques are then applied to estimate phase scintillation for transmission through a rainstorm. Meteorological data are used to relate such errors to rainfall intensity and inter scintillation frequency spectra. Numerical values for these effects are given for representative atmospheric conditions.

Beard, C. I., I. Katz, and L. M. Spetner (April 1956) Phenomenological vector model of microwave reflection from the ocean, Trans. IRE, AP-4, 162-167.

56-1 Abstract: A model of one-way transmission of microwave electromagnetic signals over the ocean surface is developed from experiment. The received signal is described as a vector sum of a constant direct signal, a coherent reflected signal, whose amplitude and phase are fixed by geometry and sea state, and a fluctuating reflected component of random amplitude and phase. By interpreting experimental data in the light of this phenomenological model it has been possible to relate, quantitatively, the coherent and incoherent reflected signal and total signal to geometry and sea state. The results give support to the theoretical expression previously derived by Ament and others relating the coherent reflected signal to "apparent ocean roughness". In addition, the general shape of the curve relating the incoherent scattering to "apparent ocean roughness" has been established and its asymptotic value found.

Barsis, A. P. (Oct. 1956) Some aspects of tropospheric radio wave propagation, Trans. IRE, PGBTS-6, 1-10.

56-2 Abstract: The Tropospheric Propagation Research Section of the Radio Propagation Engineering Division, National Bureau of Standards, has conducted extensive measurements of programs in the 100-1000 Mc frequency range. A variety of transmitting and receiving antenna heights were used, and long-term recordings are available over distances ranging from well within to far beyond the radio horizon.

Some results of this measurement program are evaluated to provide estimates for power requirements and interference problems concerning broadcasting services in this frequency range.

Kiely, D. G. (1956) Quelques problemes poses par la propagation des ondes de 8 mm et de 3 cm, au dessus de la mer et à travers la pluie, Ann. Telecomm., 11, 233-244 Nov. and 267-279 Dec. (Some problems posed by wave propagation of 8 mm and 3 cm wavelengths over the sea and through rain).

56-3 Abstract: This article describes the results of a large number of experimental investigations of the propagation of centimeter and millimeter waves. The first part, devoted to 8 mm waves, treats three subjects: investigation of the echoes from rain for monostatic and bistatic CW radars; measurements of fading for a very short over-sea path; and measurements of the reflection coefficient of water for various angles of incidence. The second part deals with 3 cm wave propagation measurements of fading on a very short over-sea path. The results of these measurements explain the reduction of range of radars. Next, measurements are described of the characteristics of guided waves propagated along "Goubau" wires; measurements which show the considerable importance of the effects of rain. --HTD

McFadden, J. A. (Dec. 1956) The axis-crossing intervals of random functions, Trans IRE, IT-2, 146-150.

56-4 Abstract: For an arbitrary random process $\xi(t)$ there exists a function x(t) which may be obtained by infinite clipping. The axis crossings of x(t) are identical with those of $\xi(t)$. This paper relates the probability density $P(\tau)$ of axis-crossing intervals to $r(\tau)$, the autocorrelation function of x(t), i.e., the autocorrelation after clipping. It is shown that the expected number of zeros per unit time is proportional to $r'(0+)$, i.e., the right-hand derivative of $r(\tau)$ at $\tau = 0$. Next a theorem is proved, stating that $P(\tau) = 0$ over a finite range $0 \leq \tau < T$ if and only if $r(\tau)$ is linear in $|\tau|$ over the corresponding range of $|\tau|$. If $r(\tau)$ is nearly linear for small τ, then the initial behavior of $P(\tau)$ is like $r''(\tau)$. These results are illustrated by some simple, random square-wave models and by a comparison with Rice's results for Gaussian noise.

Misme, P. (1956) Evanouissements d' intérferences causes par des discontinuités frontales, L'Onde Electrique 36, 43-47. (Destructive interference caused by frontal discontinuities.)

56-5 Abstract: Multipath effects caused by abrupt changes in the gradients of refractive index are described. Particular attention is given to the case of cold weather fronts characterized by the localized abrupt drop in temperature and increase in temperature. Some experimental observations are presented of the resulting destructive and constructive interference effects.—H. T. D.

Rivet, P. (1956) Essais de diversité et étude de l'effect defocalisation sur les liaisons longues en visibilité, L'Onde Electrique 36, 24-31. (A diversity experiment and study of the effect of defocusing on long line-of-sight paths.

56-6 Abstract: Both space and frequency diversity effects are investigated for the fading encountered on long line-of-sight microwave paths. Both multipath and defocusing are considered as the causative mechanism.—H. T. D.

Schmelovsky, Karl-Heinz (Aug. 1956) Partielle Reflektionen in schwachen tropospharischen Wellenleitern, Zeitschrift fur Meteorologie, 10, 239-243 (Partial reflections in weak tropospheric wave-ducts).

56-7 Abstract: This work describes an approximation process for obtaining the propagation constants in weak ducts. A diagram collects the results for some special height relations of the modified refraction index. Transl. of author's abstract (Met. Abs. 8.4-343).

Staras, H. (Aug. 1956) The statistics of combiner diversity, Proc. IRE, 44, 1057-1058.

56-8 Abstract: The distributions are presented for the output signal to noise ratio of an nth order of diversity linear adding combiner for input signal voltages whose S/N ratios are Rayleigh distributed.

Suzuki, M. (1956) Problems concerning the variations of ρ_e (Equivalent reflection coefficient) in microwave propagation over snow-covered terrain, ETJ of Japan 2, 104-107.

56-9 The reflection coefficient of snow covered terrain is evaluated for a variety of angles of incidence and dielectric constants. H. T. D.

Barsis, A. P., and F. M. Capps (1957) Effect of super-refractive layers on tropospheric signal characteristics in the Pacific Coast region, IRE Wescon Conv. Rec. Part 1, 116-132.

57-1 Abstract: Results of tropospheric radio wave propagation measurements over two paths between San Nicholas Island and the California coast near Pt. Mugu are correlated with the characteristics of refractive index profiles determined at the path terminals simultaneously with the radio measurements. The radio paths extend to the vicinity of and slightly beyond the radio horizon. Specifically, it was found that the existence of super-refractive layers (either ground-based or elevated) favors the occurrence of prolonged space-wave fadeouts for the within-the-horizon path, and increases the short-term fading range for the beyond-the-horizon path. It was found that the base and top elevations of a super-refractive layer, and also the magnitude of the refractive index gradient within the layer have a noticeable effect on various characteristics of the received signal for both paths. An example of this is found if the hourly median basic transmission loss for the beyond-the-horizon path is plotted as a function of the layer heights. These results generally agree with earlier observations by Smyth and Trolese.

Beard, C. I., and I. Katz (April, 1957) The dependence of microwave radio signal spectra on ocean roughness and wave spectra, Trans. IRE AP-5, 183-191.

57-2 Abstract: This paper is an extension of previous work on reflection of microwaves from an ocean surface. The present analysis, dealing with spectra, is based on data obtained in a one-way X-band propagation experiment performed across the Golden Gate, San Francisco. Two paths of 9,000 and 15,000 feet were used. To describe the ocean surface, wave gages were mounted on a piling driven into the Golden Gate channel.

Radio-signal spectra are found to be broader than the ocean-wave spectra and the spectral breadth a function of ocean roughness. The important result of this analysis is the establishment of a linear relationship between ocean roughness and the spectral breadth of the radio signals. Ocean roughness is measured by the product of the standard deviation of the wave height and the grazing angle divided by the radio-wave length. Radio spectral breadths are determined by the frequencies at which each spectrum drops to the 0.9-, 0.8-, 0.7-, 0.5-, 0.25-, and 0.1-power points. The breadths are then expressed as ratios of these frequencies to the frequency of the peak in the simultaneous ocean-wave spectrum.

The analysis now enables one to predict the approximate shape of the spectrum of the radio signal received in a one-way transmission path given only a knowledge of the geometry, radio-wave length, ocean-wave height, and the peak frequency in the ocean spectrum.

Bullington, K. (May 1957) Radio propagation fundamentals, BSTJ, 36, 593-626.

57-3 Abstract: The engineering of radio systems requires an estimate of the power loss between the transmitter and the receiver. Such estimates are affected by many factors, including reflections, fading, refraction in the atmosphere, and diffraction over the earth's surface.

In this paper, radio transmission theory and experiment in all frequency bands of current interest are summarized. Ground wave and sky wave transmission are included, and both line of sight and beyond horizon transmission are considered. The principal emphasis is placed on quantitative charts that are useful for engineering purposes.

Gudmandsen, P. and B. F. Larsen (July, 1957) Statistical data for microwave propagation measurements on two oversea paths in Denmark, Trans. IRE, AP-5, 255-259.

57-4 Abstract: Measurements were carried out on 6.4-cm. and 17-cm wavelength on two optical paths, 54-km and 82-km long, stretching over sea nearly East-West and starting at the same point. For the greater part of the measurements, height-spaced receivers were used. The bulk of the statistical data comprises distributions of field strengths for every day of measurement. Curves for single receivers and diversity combinations of two receivers have been worked out. Distributions for every hour of a day as well as distributions of fadurations for a few days with special propagation conditions were obtained. A study of special fading phenomena with almost coinciding fades on the receivers in operation has been made.

The data reveal that the field strength distribution for single receivers on days with a great number of fades generally approximates the Rayleigh distribution irrespective of wavelength path, and antenna height within the range of height considered. The field strength distributions for diversity systems approximate the diversity Rayleigh distribution, which is derived from two uncorrelated Rayleigh distributed signals. Deviations from appropriate Rayleigh distribution towards more serious fading conditions seem to be more frequent and more pronounced for diversity systems than for single receivers. Distributions of fade durations are found to be log-normal. Measurements on three-height-spaced receivers on 17-cm wavelength indicate that the simple two-ray theory is insufficient to describe the fadings on a path over sea.

Millington, G. (Jan. 1957) The concept of the equivalent radius of the earth in tropospheric propagation, Marconi Rev., 20, 79-93.

57-5 Abstract: The concept of the equivalent radius of the earth to take account of a linear variation of refractive index with height in tropospheric refraction is re-examined. It is shown that the transformation is not limited to nearly horizontal rays, but that essentially it reduces the curvature of the earth by that of a ray traveling horizontally and the curvature of the rays by the amount required to straighten them at whatever angle to the horizontal that they may be going. The results obtained geometrically in a previous paper (46-8) for the angle of elevation at the reflection point, the optical path difference between the direct and indirect rays and the divergence factor are derived by simple analysis, affording a useful check on the method.

Montgomery, G. Franklin (Dec. 1957) Intermittent communication with a fluctuating signal, Proc. IRE 45, 1678-1684.

57-6 Abstract: Intermittent transmission is proposed as a method to combat the effects of signal fading. Message error and average transmission rate are functions of operating bandwidth and threshold signal-to-noise ratio. The method is evaluated for Rayleigh-fading signals, using binary frequency modulation and phase modulation. One variable-bandwidth system is examined. The theoretical advantage (power gain > 40 db for a binary error = 10^{-6}) is reduced by practical limitations but should be nearly realized for some systems.

Bremmer, H. (1958) Propagation of electromagnetic waves, Encyclopedia of Physics, XVI, Electric Fields and Waves, Sec. 97,
58-1 596-601 (Handbuch der Physik, Springer-Verlag, Berlin) [Text].

du Castel, F., P. Misme, and J. Voge (March 1958) Reflexion d'une onde electromagnetique par une couche d'atmosphere presentant une variation de l'indice de refraction, Acad. Sc., Comptes Rendus, 246, 1838-1840 (Reflection of an electromagnetic wave from an atmospheric layer with a variable refractive index).

58-2 Abstract: A more general formulation of the reflection coefficient, which may be interpreted as an increasing function of the atmosphere thickness where great stability prevails, is presented. (Met. Abs. 10.1-342)--A.V.

Clarke, K. K., and J. Cohn (May 1958) Carrier-to-noise statistics for various carrier and interference characteristics, Proc. IRE 46, Part I, 889-895.

58-3 Abstract: Techniques are presented for the calculation of the statistical properties of the resultant carrier-to-noise ratios of systems subject to both additive and multiplicative noise. The cases considered are those in which the desired signal is either steady or exhibits Rayleigh fading while the interference consists of receiver noise plus an interfering signal which may be steady, Rayleigh fading, Gaussian fading, or Rayleigh fast fading with slow Gaussian fading of the median of the Rayleigh distribution. The results of the indicated calculations are presented graphically. A simple process is outlined for converting the data presented for use with any other signal strength.

The utility of the data is demonstrated by a sample calculation the results of which are presented graphically. This calculation derives threshold data for the system as a function of desired signal power with the percentage of time that it operates in one of its two possible modes (fading or nonfading) as a parameter.

Attention is called to the technique demonstrated in the Appendix. This result appears quite useful in many joint or combination probability problems, especially those requiring numerical solutions.

Although this paper stemmed from work on line-of-sight microwave links, the results may be useful in other applications in the hf, vhf, and uhf regions.

Gough, M. W. (May 1958) Microwave line-of-sight propagation, Elec. Eng. 30, 237-247.

58-4 Abstract: After sketching the historical and physical background of the subject, this article surveys some fundamental investigations into microwave line-of-sight propagation made, mainly since 1939, in Europe and the U.S.A. Theoretical work, based principally on classical optical concepts, is reviewed in conjunction with related experimental investigations. statistical processes important in the research and engineering aspects of the subject are also discussed.

McFadden, J. A. (March 1958) The axis-crossing intervals of random functions—II, Trans. IRE, IT-4, 14-24.

58-5 Abstract: This paper considers the intervals between axis crossings of a random function $\xi(t)$. Following a previous paper, continued use is made of the statistical properties of the function x(t) and the output after $\xi(t)$ is infinitely clipped. Under the assumption that a given axis-crossing interval is independent of the sum of the previous (2m + 2) intervals, where m takes on all values, $m = 0, 1, 2, \cdots$, an integral equation is derived for the probability density $P_o(\tau)$ of axis-crossing intervals. This equation is solved numerically for several examples of Gaussian noise. The results of this calculation compare favorably with experiment when the high-frequency cutoff is not extremely sharp. Assuming that the successive axis-crossing intervals form a Markoff chain in the wide sense, infinite integrals are found which yield the variance $\sigma^2(\tau)$ and the correlation coefficient k between the lengths of two successive axis-crossing intervals. These parameters are obtained numerically for several examples of Gaussian noise. For bandwidths at least as small as the mean frequency, k is large. For los-pass spectra, k is small, yet the statistical dependence between successive intervals may be strong even when the correlation k is nearly zero.

Morita, Kazuo and Kiyoshi Kakita (Sept. 1958) Fading in microwave relays, Reports of ECL, Japan 6, 352-370.

58-6 Abstract: A statistical description is presented for the fading encountered on microwave line-of-sight paths. The theoretical distributions are compared with experimentally observed distributions to provide empirical expressions for percent occurance of severe fades as a functional path length; standard deviation of hourly mean signal levels as a function of path length; etc. A statistical description is also provided for signal-to-noise ratios due to fading.

Omori, Takeo and Rihachi Sato (Jan. 1958) Multipath propagation of microwaves, Tech. J. of ECL, Japan, 6, 1-11.

58-7 Abstract: The distortion experienced for multichannel FM transmission over five line-of-sight microwave paths (3.85 to 9.41 Gc/s) is described. The effects of multipath and of ducting conditions are considered.

Rice, S. O. (May 1958) Distribution of the duration of fades in radio transmission: Gaussian noise model, Bell Sys. Tech. J. 37, 581-635.

58-8 Abstract: The fluctuations of a received radio signal due to fading are assumed to behave like the envelope of narrow-band Gaussian noise. Estimates of the distribution of the fade lengths for various depths of fades are given, and relations which may be useful in analyzing fading data are derived. A similar problem involving the separation of the intercepts of the noise current itself, instead of its envelope, is also discussed.

Suzuki, M. (1958) Experimental analysis of equivalent reflection coefficient of various reflecting rough surfaces in microwave propagation, ETJ of Japan, 4, 3-6.

58-9 Abstract: The reflection coefficient is evaluated for various angles of incidence and types of surfaces and terrain with crop cover.—H.T.D.

Wong, Ming S. (Sept. 1958) Refraction anomalies in airborne propagation, Proc. IRE, 46, 1628-1638.

58-10 Abstract: Propagation at 250-10,000 mc often encounters: 1) dense fadings where the radio signal fluctuates spatially with large amplitudes and small spacings from maxima to minima, e.g. amplitudes of up to 40 db and spacings at 3000 mc of 1 mile; 2) radio holes, where the signal falls spatially to a level often 15 db or more below the levels outside; 3) antiholes, where the signal fluctuates spatially with large amplitudes and irregular spacings; 4) radio ducting, including cases where the transmitter or receiver is far above a ducting layer in the air.

The anomalies (1-4) are portrayed by ray tracings using a differential analyzer which solves a simplified ray equation.

Anderson, W. L., N. J. Beyers and B. M. Fannin (July, 1959) Comparison of computed with observed atmospheric refraction, Trans. IRE, AP-7, 258-260.

59-1 Abstract: Ray tracing methods have been applied in the computation of atmospheric refraction for a path at White Sands Missile Range, N. Mex., with a range of about 48 miles and an elevation angle of 14.5 milliradians. The atmosphere was assumed to be horizontally stratified. Refractive index profiles were derived from meteorological data obtained from surface observations, wiresondes, radiosondes, and airborne refractometer soundings. The profiles were classified "A", "B", or "C", in descending order of reliability, prior to radar refraction computations. The classification system considered the variety of data available, the time lag between radar and weather observations, and the proximity of the sounding to the propagation path. A good correlation between observed and computed angles resulted and the correlation was directly related to the classification.

Radar observations were made in the X-band and instrumental precision maintained to within 0.25 milliradian. Total bending ranged between 0.56 and 2.23 milliradians, with standard deviation 0.38 milliradian.

The rms deviation of computed from observed angles ranges from 0.19 to 0.41 milliradian for Class A and Class C data, respectively. The correlation coefficient ranges from 0.81 to 0.13. It is concluded that within the limits of this experiment: a) ray tracing methods are justified, b) horizontal stratification may be assumed and c) the accuracy of bending predictions is increased by improving the meteorological data.

Bachynski, M. P. (June 1959) Microwave propagation over rough surfaces, RCA Review 20, 308-335.

59-2 Abstract: The field of propagation of short radio waves over rough surfaces is surveyed. The results of available experimental measurements are summarized and theories which are readily amenable to calculation are discussed. The experimental findings may serve as an indication of typical values to be expected in practical situations. The effects of both irregular terrain and sea surfaces are considered. The limitations of various theoretical approaches are outlined and aspects requiring further study are indicated. An extensive bibliography is also included.

Bean, Bradford R. (1959) Climatology of ground-based radio ducts, NBS J. Res., 63D, 29-34.

59-3 Abstract: An atmospheric duct is defined as occurring when geometrical optics indicate that a radio ray leaving the transmitter and passing upwards through the atmosphere is sufficiently refracted that it is traveling parallel to the earth's surface. Maximum observed incidence of ducts was determined as 13 percent in the tropics, 10 percent in the arctic and 5 percent in the temperate zone by analysis of 3 to 5 years of radiosonde data for a tropical, temperate, and arctic location. Annual maximums are observed in the winter for the arctic and summer for the tropics. The arctic ducts arise from ground-based temperature inversions with the ground temperature less than -25° C while the tropical ducts are observed to occur with slight temperature and humidity lapse when the surface temperature is 30° C and greater.

Bean, B. R., and G. D. Thayer (May 1959) Models of the atmospheric radio refractive index, Proc. IRE, 47, 740-755.

59-4 Abstract: Evaluation of atmospheric refraction effects on UHF-VHF radio propagation has long been accomplished with the convenient four-thirds earth concept of Schelling, Burrows, and Ferrell. This method has proven particularly useful in evaluating performance of point-to-point radio communications systems. However, relatively new long-range applications have demanded a model of atmospheric radio refractive index more representative of observed refractive index profiles than the simple linear decay inherent in the four-thirds earth approach.

This paper introduces two models of atmospheric radio refractive index which can be used to predict refraction effects from the value of the refractive index at the transmitting point. Both models offer considerable improvement over the four-thirds earth model, particularly for applications at long distances and high elevations in the atmosphere. Further, both models may be adjusted to represent mean conditions at different times of year and in different geographical locations. A new method of predicting radio-ray refraction at very low initial elevation angles is introduced which utilizes both the initial value and the initial height-gradient of the refractive index over roughly the first 100 meters above the earth's surface. This method, which is dependent only upon the first two radiosonde reporting levels or simple tower measurements of the common meteorological elements, results in a considerable improvement of the values of ray-refraction predicted by the model.

Bean, B. R., and B. A. Cahoon (Nov-Dec. 1959) Effect of atmospheric horizontal inhomogeneity upon ray tracing, NBS J. Res., 63D, 287-292.

59-5 Abstract: The tracing of radio rays is normally carried out under the assumption that the refractive index varies only in the vertical direction. Although this assumption appears to be quite reasonable in the average or climatic sense, it is seldom satisfied under actual conditions and is strongly violated by horizontal airmass changes occurring near frontal and land-sea interfaces. This latter case is investigated by tracing rays through two instances of observed marked horizontal variation of the refractive index. The bending for these ray paths was then compared with values obtained under the normal assumption of horizontal homogeneity.

Although at 1 kilometer and above these horizontal changes appear to have little effect, rays emitted at low elevation angles are sensitive to extreme horizontal variations of the atmosphere near the surface, such as those associated with ducting conditions. However, since it appears that such conditions occur less than 15 percent of the time at most locations, the majority of ray-path calculations may be carried out under the normal assumption of horizontal stratification of the refractive index.

Bean, B. R., and J. D. Horn (Nov.-Dec. 1959) Radio-refractive-index climate near the ground, NBS J. Res., 63D, 259-271.

59-6 Abstract: The radio refractive index of air is a function of atmospheric pressure, temperature, and humidity and is found to vary in a systematic fashion with climate. It was found that the surface value of the refractive index may be estimated four to five times more accurately from charts of reduced-to-sea-level values than from similar sized charts of surface index. Worldwide maps of 5-year means of this reduced value are presented for the months of February and August, for the minimum monthly mean value of the year and for the range of monthly mean values. Year-to-year variation of monthly means is also considered. Applications of these data to the prediction of radio field strengths indicate a possible 30-decibel difference in median level of identically equipped tropospheric communications systems due to climate alone.

Braude, S. Ya. (1959) The Fresnel coefficients for a rough surface,
59-7 (in Russian), Izv. Vyssh. Zav. Radiofiz. 2, 691-696.

Braude, S. Ya., N. N. Komarov, and I. E. Ostrovsky (1959) On the statistical character of the scattering of centimeter radio waves by the rough surface of the sea, (in Russian), Radiotekhnika i.
59-8 Elektr., 3, 172-179.

Brennan, D. G. (June, 1959) Linear diversity combining techniques, Proc. IRE 47, 1075-1102.

59-9 Abstract: This paper provides analyses of three types of diversity combining systems in practical use. These are: selection diversity, maximal-ratio diversity, and equal-gain diversity systems. Quantitative measures of the relative performance (under realistic conditions) of the three systems are provided. The effects of various departures from ideal conditions, such as non-Rayleigh fading and partially coherent signal or noise voltages, are considered. Some discussion is also included of the relative merits of predetection and post-detection combining and of the problems in determining and using long-term distributions. The principal results are given in graphs and tables, useful in system design. It is seen that the simplest possible combiner, the equal-gain system, will generally yield performance essentially equivalent to the maximum obtainable from any quasi-linear system. The principal application of the results is to diversity communication systems and the discussion is set in that context, but many of the results are also applicable to certain radar and navigation systems.

Hathaway, S. D. and H. W. Evans (Jan. 1959) Radio attenuation of 11 kmc and some implications affecting relay system engineering, Bell Sys. Tech. J. 38, 73-89.

59-10 Abstract: Radio waves at 11 kmc are attenuated by rain. In order to derive rules for engineering radio relay systems at 11 kmc, a one-year experiment was conducted in a region of frequent heavy rainfall. The attenuation of paths 27 and 12 miles long was measured, together with rainfall at two-mile intervals along the paths. The instrumentation and the test results are described, and some implications related to systems engineering are pointed out.

Ikegami, F. (July, 1959) Influence of an atmospheric duct on microwave fading, Trans. IRE, AP-7, 252-257.

59-11 Abstract: The results of continuous observation of a duct carried out utilizing a tower 312 meters high are presented together with those of measurements of microwave fading conducted simultaneously.

The variation of duct height with time, as well as the influence of the duct on fading for a horizontal and an oblique propagation path, are investigated in detail.

A ray-theoretical analysis is given, indicating that fading may be attributed to the divergence or the convergence of radio waves and to the interference of two or more rays, caused by existence of a duct, or, more generally, of nonlinear M-profile.

A comparison of calculation with experimental results shows that many of the characteristics of microwave fading are well explained by means of this interpretation.

Johler, J. Ralph and Lillie C. Walters (May, 1959) Mean absolute value and standard deviation of the phase of a constant vector plus a Rayleigh-distributed vector, NBS J. Res. 62, 183-186.

59-12 Abstract: The mean absolute value of the phase and the standard deviation of the phase of a constant vector plus a Rayleigh-distributed vector are determined by an evaluation of the first and second moment integrals of the probability distribution for various values of average relative intensity of the random Rayleigh-distributed component. The results of a quadrature evaluation of the integrals are tabulated over a wide range of values of average relative intensity (k^2 = 0.010 to 1,000).

Kawazu, Sukemoto, Shusuke Kato, and Kazuo Morita (June 1959) Over-sea-propagation of microwave and anti-reflected-wave antenna, Reports of E. C. L., Japan, 7, 171-191.

59-13 Abstract: The fading mechanism encountered for microwave over-sea, line-of-sight paths are described and compared with experimental observations. Distributions are given for the sum of a direct wave, a specularly reflected wave and a diffusely reflected wave for uniformly distributed relative phases. An anti-reflected wave antenna is described which consists of a vertical array spaced so as to provide an antenna pattern null in the direction of the reflection point. The theoretical and experimental performances of the antennas are compared.—H. T. D.

McGavin, Raymond E., and Leo J. Maloney (1959) Study at 1, 046 megacycles per second of the reflection coefficient of irregular terrain at grazing angles, NBS J. Res., 63D, 235-248.

59-14 Abstract: An experimental determination of the reflection coefficient over rough terrain is reported. The reflected signal received over rough terrain is considered to be made up of two components, one that is a specular component and the other a Rayleigh-distributed component. Where one terminal is low, the Rayleigh component is considered to be small with respect to the specular component but increases in relative magnitude as the height of the lower terminal increases. A terminal height is reached where the specular component is no longer significant, and the reflected energy is essentially Rayleigh-distributed. A terminal height is quickly reached above which the mean value of the reflected energy is relatively constant, of a low value, and independent of the grazing angle.

Men', A. V., S. Ya. Braude, and V. I. Gorback (1959) Fluctuations of the phase front in the propagation of decimeter waves over the surface of the sea, (in Russian), Dokl. Akad. Nauk SSSR, 125,
59-15 1019-1022.

Men', A. V., S. Ya. Braude, and V. I. Gorbach (June 1959) Experimental investigation of phase fluctuations of centimeter waves propagated over the sea surface (in Russian), Izvestia Vysshikh Uchebnykh Zavedenii, Radiofizika, 2, 848-857.

59-16 Abstract: Report on results of experimental measurement of the fluctuations of phase fronts during the propagation of vertically polarized radio waves over the sea surface. The frequency employed was 3000 Mc/s and the experiments were carried out under various meteorological conditions during July-Sept. and Oct.-Dec., over a fixed sea route having a length of 33 km. The differential method of measurement was employed, in which the fluctuations of the phase differences of the signals received by spaced antennas were employed to determine the intensity and the decorrelation of the phase fluctuations at various points of the wave front. Fixed transmitting and receiving antennas were used. In order to reduce the effect of the shore refraction, the receiving systems were situated at 15 to 20 meters from the shore with distances of 2, 5, 10, 30, and 100 meters separating them from the first (reference) antenna. The error in the measurement of the phase difference fluctuations was less than ± 1°, even when the amplitude of the received signals varied as much as 60 db. Results of measurements are shown in 11 figures. -- R.M. (W N Bibliog. 64-6).

Men', A. V., V. I. Gorbach, and S. Ya. Braude (March 1959) Effect of an interface on the fluctuations of radio waves propagated in an inhomogeneous medium (in Russian), Izv. Vyss. Ucheb. Zav., Radiofizika, 2, 388-394.

59-17 Abstract: The authors obtain approximate expressions for determining amplitude and phase fluctuations in the line of sight and beyond the horizon in connection with propagation in an inhomogeneous medium over a plane interface. It is shown that there is substantially no dependence of the intensity of fluctuations on distance, wave length, and altitude in comparison with the free space case. Computed values are compared with experimental data. -- Transl. of authors' abstract. - R.M. (WN Bibliog. 64-6).

Norton, K. A. (June 1959) Transmission loss in radio propagation, Pt. 2, NBS Tech. Note No. 12, App. I-III.

59-18 Abstract: In an earlier report with this title (53-10) the concept of transmission loss was defined and its advantages explained. In this report a survey will be made of the transmission losses expected for a wide range of conditions, i.e., for distances from 10 to 10,000 statute miles; for radio frequencies from 10 kc to 100,000 Mc; for vertical or horizontal polarization; for ground waves, ionospheric waves, and tropospheric waves; over sea water or over land which may be either rough or smooth; and for various geographical and climatological regions.

Oxehufwud, A. (1959) Tests conducted over highly reflective terrain at 4,000, 6,000, and 11,000 Mc, Trans. Amer. IEE, Part I 78, 265-270.

59-19 The author considers the problem of choosing the optimum heights of antennas so as to avoid more than one reflecting surface. Some effects of the variation of atmospheric refraction are also considered. --HTD.

Semenov, A. A., and G. A. Karpeiev (Feb. 1959) Investigation of rapid fading of radio signals at medium distances along the Earth's surface, Rad. Eng. and Elec., 4, 43-54.

59-20 Abstract: The results of investigations on the fading of 3 cm band signals reflected from standard reflectors with surface propagation in the zone of direct visibility are given. A result of the investigation is a preliminary estimate of the effect of the surface on the formation of reflected radio signal amplitude fluctuations. The result of the work may be useful for passive retranslation, as well as in radiolocation of ground level targets.

Thompson, M. C., Jr., and H. B. Janes (July-Aug. 1959) Measurements of phase stability over a low-level tropospheric path, NBS J. Res., 63D, 45-51.

59-21 Abstract: A knowledge of the statistics of atmosphere-induced variations in the phase of the received signal (i.e., variations in electrical path length) is essential in evaluating the reliability of any system using radio waves for measuring distance and/or velocity. This paper describes an analysis of phase variations measured at 9,400 megacycles per second over a 9.4- mile path near Boulder, Colorado, during a 40-hour period in September 1958. The power spectral density of these variations is shown to be approximately proportional to $f^{-2.8}$ over a wide range of frequencies throughout the period of recording. The long-term phase variations are closely correlated with atmospheric refractivity measurements made at the path terminals.

Tomlinson, H. T., and A. W. Straiton (Oct. 1959) Analysis of 3-cm radio height-gain curves taken over rough terrain, Trans. IRE AP-7, 405-413.

59-22 Abstract: This report describes the effect of terrain and meteorological conditions on the height-gain pattern of 3.2-cm radio waves over various short transmission paths. Equivalent reflection coefficients are obtained and potential reflection areas are investigated. A study of the time variations in the height of nulls in the signal strength pattern is made and the relationship between movement of the nulls and the corresponding refractive index distribution is considered.

Ugai, Shigetaka (Aug. 1959) Statistical consideration of the structure of atmospheric refractive index, Reports of ECL, Japan, 7, 253-289.

59-23 Abstract: A 300 meter tower is employed to obtain 12 level samplings of the refractive index gradient on an hourly basis over a two month period. These are compared with radiosonde data obtained twice a day for the same period. The resulting distribution of vertical refractive index gradient was found to be approximately normal. The analysis is then extended to determine the resulting mean and standard deviations from radiosonde data between 900 and 1000 mb levels on a monthly basis and for 8 geographical locations.—H. T. D.

Bean, B. R., G. D. Thayer and B. A. Cahoon (1960) Methods of predicting the atmospheric bending of radio rays, NBS J. Res., 64D, 487-492.

60-1 Abstract: Three methods for predicting the bending of radio rays when the refractive index profile above the surface layer is unknown have been developed recently by the authors. These methods are: a statistical technique for refraction at high initial elevation angles, estimation of bending from an expoential model of atmospheric refractive index, and a modification of the exponential model to account for the heavily weighted effects of anomalous initial refractive index gradients at small initial elevation angles. Each model is dependent upon the value of the refractive index at ground level or, in the case of superrefraction, the additional knowledge of the refractive index gradient next to the earth's surface. Each method works best in a particular range of initial elevation angles or meteorological conditions. The height and angular ranges of application of each method are checked by comparison with values obtained from 77 diverse refractive index profiles representative of wide climatic variation. It is found that the use of the best of the three methods will always result in a prediction of the total atmospheric bending within 10 percent for initial elevation angles from zero to 10 milliradians and to within 4 percent for initial elevation angles greater than 17 milliradians (~ 1 deg).

Bean, B. R., and E. J. Dutton (May-June, 1960) On the calculation of the departures of radio wave bending from normal, NBS J. Res., 64D, 259-263.

60-2 Abstract: The calculation of nonnormal tropospheric bending of radio waves is treated in terms of a reduced-to-sea-level value of the refractive index. This method emphasizes departures of bending from the average bending for the United States and consists of visualizing ray bending as consisting of two parts; an "average" component and a "departure-from-average" component. The "average" component comprises most of the bending and is obtained accurately from refraction tabulations while the component due to departures is easily obtained by graphical means.

Bean, B. R., J. D. Horn and A. M. Ozanich, Jr. (Nov. 1960) Climatic charts and data of the radio refractive index for the United States and the World, NBS Monograph 22, 178 pp. (Supt. of Doc., U. S. Govt. Print. Off., Washington, D. C.)

60-3 Abstract: The radio refractive index of air, $n = 1 + N \times 10^{-6}$ is a function of atmospheric pressure, temperature, and humidity and varies in a systematic fashion with climate.

Included in this Monograph is a compilation of refractive index data. Data listings made up of observations from 45 U. S. surface weather stations for 2-hour intervals over an 8-year period are given. Mean values, maxima, minima, and standard deviations of the refractive index have been calculated and tabulated for these observations. Additionally, mean vertical profiles of the refractive index have been prepared for 43 U. S. upper air sounding stations from long-term means of pressure, temperature, and humidity.

Earlier studies of refractive index climate are assimilated and put into perspective. One such study is an extensive analysis and mapping of the refractive index climate of the United States. A worldwide radio refractive index climatology is developed based upon monthly mean observations of pressure, temperature and humidity.

An important finding of these climatological investigations is the strong correlation of N with height. A reduced-to-sea-level value of the index, termed N_o, is used to eliminate this systematic height dependence. The surface value of N, N_s, may be estimated four to five times more accurately from charts of N_o than from similar-sized charts of N_s itself.

From climatic charts of N_o, N_s may be estimated at any given location in the United States throughout the day during every season. In addition detailed annual and diurnal cycles, as well as 8-year cumulative probability distributions, are given for 12 representative U. S. stations.

On a worldwide basis, charts of mean N_o are presented for both summer and winter season.

Brekhovskikh, L. W. (1960) Waves in layered media, Academic Press,
60-4 New York and London [Text] .

Brilliant, Martin (Sept. 1960) Fading loss in diversity systems, Trans. IRE, CS-8, 173-176.

60-5 Abstract: In a communication system using optimum diversity combining, the mean signal-to-noise ratio of the combined signal is the sum of the mean signal-to-noise ratios of the separate signals. However, the effective signal-to-noise ratio of the combined signal is less than this. The ratio of the mean to effective signal-to-noise ratios of the combined signal is called the fading loss.

The effective signal-to-noise ratio, and hence the fading loss, depends upon the measure of effectiveness used, which in turn depends upon the form of information conveyed by the signal. In a high-quality speech system, the fading loss is shown to depend principally upon the order of diversity (the number of signals combined). In a binary communication system, the fading loss is shown to depend principally upon the mean signal-to-noise ratio of the separate signals. The system design considerations in these two cases are therefore different.

Flock, W. L., R. C. Mackey and W. D. Hershberger (May, 1960) Propagation at 36,000 Mc in the Los Angeles basin, Trans. IRE, AP-8, 235-241.

60-6 Abstract: Fading characteristics at 36 kmc over a line-of-sight path in the Los Angeles basin have been shown to be closely correlated with meteorological conditions, particularly with the relatively persistent, low-level temperature inversion of the area. No positive evidence of the influence of atmospheric pollutants has been found, but it has been shown that suitably located microwave paths can be of value for locating and monitoring temperature inversions when they are accompanied by sufficient variation in water-vapor content. The relation of diurnal variations in propagation characteristics to diurnal variations in the temperature inversion and in atmospheric turbulence indicate that the refraction mechanism is the predominant one in causing the observed large fading amplitudes. The view is further strengthened by the relatively noncritical relation of fading to the proximity of the inversion layer.

Kühn, U. (Oct. 1960) Space-diversity measurements on a broadcast link with optical range (in German) Nachrichtentechnik, 10, 430-434.

60-7 Abstract: Measurements of received levels are reported for a period of 21 months, using a 1.3 Gc/s system, an 82 km path and two aerials with 250 λ vertical spacing. Marked reductions of long and short term variation effects are shown. Measurements of input signals versus aerial height indicate a small reflection coefficient and show bad agreement with theoretically predicted values. (EE Abstract 4221, July 1961 -- AR).

Oguchi, Tomohiro (Sept. 1960) Attenuation of electromagnetic wave due to rain with distorted raindrops, J. Radio Res. Labs. (Tokyo) 7, 467-485.

60-8 Abstract: The total cross-section of a spheroidal particle of any material with small eccentricity is derived by the solution of scattered field which is expressed as the first-order approximation of drop deformation. Then, by the use of the theoretical value of eccentricity of raindrops falling at terminal velocity, the total cross-sections of distorted raindrops for vertically and horizontally polarized plane waves are computed at 8.6 mm wave-length, and the relation between the attenuation and the rate of precipitation is obtained. From these curves, greater attenuation is expected theoretically in case of horizontal polarization.

Pierce, J. N., and S. Stein (Jan. 1960) Multiple diversity with nonindependent fading, Proc. IEE 48, 89-104 App. III.

60-9 Abstract: Previous analyses of diversity techniques are extended to include the performance of an optimum (maximal-ratio) combiner in the case of nonindependent signal fading fluctuations, for an arbitrary number of diversity branches. The analysis includes the general possibility of correlations among the quadrature components of the various signals. Some computational simplifications for certain cases of physical interest are given, as well as a specific application to two problems in digital communications.

Saxton, J. A. (1960) Propagation à travers la troposphere, L'Onde Electrique 40, 505-514. (Propagation through the troposphere).

60-10 Abstract: A brief histofy of experimental investigations of tropospheric propagation is presented. The conclusions to date and the major problems remaining are described.—H. T. D.

Thompson, M. C., Jr., H. B. Janes, and A. W. Kirkpatrick (Jan. 1960) An analysis of time variations in tropospheric refractive index and apparent radio path length, J. Geophys. Res., 65, 193-201.

60-11 Abstract: The National Bureau of Standards has been conducting a series of measurements for a study of the characteristics of the turbulent lower atmosphere and its effect on the accuracy of radio direction-finding, guidance, and geodetic measurement systems. The results of three experiments are presented, one consisting of recordings of refractive index and apparent path length variations at 9400 Mc/s over a 15.5-mile path on Maui, Hawaii and the other two consisting of similar measurements made over a 9.5-mile path near Boulder, Colorado. The correlation of refractive index and apparent path length fluctuations is discussed as well as the power (variance) density spectra of both variables.

Thompson, Moody C., Jr., Harris B. Janes, and Frank E. Freethey (Feb. 1960) Atmospheric limitations on electronic distance-measuring equipment, J. Geophys. Res., 65, 389-393.

60-12 Abstract: In recent years various instruments and techniques have been developed for measuring distances electronically. The accuracy of such measurements depends on the accuracy with which time and the velocity of propagation of radio waves can be determined.

The National Bureau of Standards, under the sponsorship of the Air Force Ballistic Missile Division, has been studying the effects of atmospheric turbulence on the performance of radio distance- and/or velocity-measuring systems. Many of the data collected in this study are applicable to the problem of determining the accuracy of radio surveying methods, Long-term variations in the apparent length of a 15.5-mile path in Hawaii are shown, along with the effects of correcting for the atmospheric refractive index observed at 2 to 5 points along the path.

Troitskii, V. N. (Dec. 1960) The propagation of centimetre waves on long-distance mountain routes, Rad. Eng. and Elec., 5, 61-69.

60-13 Abstract: This article is concerned with the fading of centimetre and decimetre waves on long-distance mountain routes. Experimental data on the fading on three mountain routes in Central Asia are given. Conclusions are made concerning the nature of the fading on mountain routes using the long-distance tropopheric propagation of ultra-short waves.

Barsis, A. P., and M. E. Johnson (Feb. 1961) Prolonged spacewave fadeouts in tropospheric propagation, NBS Tech. Note No. 88.

61-1 Abstract: This paper contains the results of studies performed during the last several years on the short-term variability of tropospheric signals received over within-the-horizon paths. Signal variations of this type have been termed "prolonged space-wave fadeouts," as they are mainly characterized by reductions in signal level to many decibels below presumably constant values determined from geometrical optics methods. The data described here were obtained from measurements over propagation paths in the Pacific Coast region of Southern California, and the continental region of Eastern Colorado. Fadeouts are analyzed as a function of carrier frequency, path characteristics, and meteorological parameters. The study also includes an evaluation of fadeouts observed over a path using a mountain peak as a diffracting knife-edge like obstacle between transmitter and receiver.

Beard, C. I. (1961) Coherent and incoherent scattering of microwaves from the ocean, Trans. IRE AP-9, 470-483.

61-2 Abstract: This report, the third in a series, summarizes experimental studies of microwave over-ocean propagation on line-of-sight paths. Measurements at 5.3, 3.2, and 0.86 cm wavelength in 1955, in the Gulf of Mexico, between two oil drilling platforms one mile apart are compared with the results of the phenomenological model developed earlier. The total field was measured at maxima, and minima of the interference patterns using a sequence of receiver beam widths. The scattered field alone was measured by means of a narrow beam. The 1955, Gulf of Mexico data, are consistent with the previous 1953, Golden Gate data, in regions of overlap of certain parameters, and provide extended coverage for other values under different conditions.

Braude, S. Ya., I. E. Ostrovskii, and F. S. Sanin (Jan. 1961) Use of the concept of negative equivalent Earth radius for estimating strong refraction of radio waves (in Russian), Izvest. Vyssh. Ucheb. Zaved. Radiofizika, 4, 67-73.

61-3 Abstract: The concept of the negative equivalent earth's radius is introduced in the well known rays alignment method to be applied to the case of the positive refraction: $dn/dh - 1,57.10^{-7} m^{-1}$ (n being the refractive index, h - height above earth's surface). The earth's sfericity is taken into account and Frenels formulas are used for the field calculations. The problem comes to the plane boundary one by the introduction of the corresponding reduced heights. Formulas and curves are given for the heights of the interference maximums versus the values of the negative equivalent radius at the given distance from the source of radiation. All calculations are carried out with the assumption that there exists a constant gradient of the refractive index in a sufficiently thick atmospheric layer. (WN Bibliog. 64-6).

Dawson, G. (1961) A space aerial diversity reception technique for microwave radio relay systems, Proc. Microwave Seminar, Tokyo, I, Doc. No. 4, 86-101.

61-4 Abstract: Experience with space diversity reception systems is recounted. The specification of a dynamic space diversity system in terms of antenna spacing and combiner operation is described for microwave paths subject to fading due to multipath or atmospheric ducts. -- HTD.

Dutton, E. J. (June 1961) On the climatology of ground-based radio ducts and associated fading regions, NBS Tech. Note 96, 38 pp., (Office of Tech. Serv., U. S. Dept. of Commerce, Washington, D. C.)

61-5 Abstract: An atmospheric duct is defined as occurring when geometrical optics indicates that a radio ray passing upwards through the atmosphere is sufficiently refracted that it travels parallel to the earth's surface. Maximum observed incidence of ducts was determined to be 13%, 10%, and 5% by analysis of three to five years of radiosonde data for a tropical, temperate, and arctic location, respectively. Annual maxima are observed in the winter for the arctic and summer for the tropics. Arctic ducts arise from ground based temperature inversions with the ground temperature less than -25° C; temperate zone ducts arise from radiation inversions and accompanying humidity lapse; while tropical ducts occur with slight temperature and humidity lapses when the surface temperature is 30° C and greater. The mean initial elevation angle of a radio ray trapped by these ducts is found to be about 3 mr, with the maximum value about 5.8 mr. The steepest gradient of N observed is -420 N units/km. Observed ducts trap radio-waves of frequency ≥ 1 kMc at all locations for at least 50% of the time.

Fading regions arising from abnormal defocussing of radio-rays passing from an elevated antenna down through the duct to a ground-based receiver are analyzed. The horizontal extent of these regions is determined for the same arctic, tropic, and temperate conditions given above.

Dutton, E. J., and G. D. Thayer (Oct. 1961) Techniques for computing refraction of radio waves in the troposphere, NBS Tech. Note No. 97.

61-6 Abstract: Eight methods of computing atmospheric refraction of radio rays are discussed with appropriate theoretical background. These methods are:

(1) The high-angle, or astronomical, refraction case
(2) The statistical method
(3) The low-angle, or terrestrial, refraction case (Schulkin's method)
(4) The four-thirds earth model
(5) The exponential model
(6) The initial gradient correction method
(7) The departures-from-normal method
(8) A graphical method (Weisbrod's and Anderson's method).

Sample computations are included for each of the above methods.

Ikegami, F. (1961) Estimation of short interruption due to fading in microwave relay system, Proc. Microwave Seminar, Tokyo I, Doc. No. 8, 59-71.

61-7 Abstract: An empirical method is presented for estimating the duration of deep fades for microwave line of sight paths. -HTD

Jasik, H. (1961) Antenna Engineering Handbook, McGraw-Hill, New York
61-8 [Text] .

Kakita, K. (1961) Space diversity reception in microwave relay systems, Proc. Microwave Seminar, Tokyo I, Doc. No. 9, 102-120.

61-9 Abstract: A brief explanation is presented of the equipment and principles involved for a space diversity system. Phase combining is employed, requiring both phase detection and phase shifting circuits. - HTD

Kirby, R. S., P. L. Rice, and L. J. Maloney (Oct. 1961) Characteristics of point-to-point tropospheric propagation and siting considerations, NBS Tech. Note 95, 102 pp. (U.S. Dept. of Commerce, Off. of Tech. Serv., Washington, D. C. 20234).

61-10 Abstract: This Technical Note presents the fundamental characteristics of tropospheric propagation, with particular application to point-to-point telecommunications.

The concept of service probability is introduced, and its application to the planning of tropospheric circuits is discussed.

This concept provides an objective means for taking into account the variables and uncertainties connected with a planned circuit so that a reasonable balance can be made between the cost of installation and operation, and the probability of success. Principles of siting based on taking advantage of favorable technical characteristics of the sites, and on associated considerations such as radiation hazards, are discussed.

Simple methods of making preliminary estimates of performance adequate for field use are presented.

Kitchen, F. A., W. R. R. Joy, and E. G. Richards (May, 1961) Some factors influencing 3 cm radiowave propagation oversea within and beyond the radio horizon, Proc. IEE, Part B, 108, 257-263.

61-11 Abstract: The results of a number of short term oversea measurements of the variation of received signal level with range from a 10 Gc/s transmitter are presented. It is shown that the variation of signal level within the horizon was rarely that expected for propagation through an atmosphere having a uniform refractive index gradient. Signal losses of from 5 to 30 db frequently occurred well within the horizon, these losses being recovered when the range between transmitter and receiver was sufficiently reduced. A well defined interference pattern usually occurred in the region of reduced signal level. Some data on the variation of refractive index with height up to about 700 ft. above sea level were gathered using a radio sonde and a captive balloon, but the detail was not sufficiently fine to enable a direct relationship to be established between signal losses within the horizon and the occurrence of irregularities in the refractive index profile at low elevations.

A direct relationship was found to exist between the signal level within the horizon and that propagated well beyond the horizon into the extra diffraction region.

LaGrone, A. H., and C. W. Chapman (Sept. 1961) Some propagation characteristics of high UHF signals in the immediate vicinity of trees, Trans. IRE, AP-9, 487-491.

61-12 Abstract: Results are reported of measurements made at very low angles of 2880-Mc vertically-polarized signals over wooded areas, with the elevation angle to the transmitter the principal variable. The effects of one tree and of many trees on the apparent location of a signal source, as determined with a narrow-beam antenna, are reported. A hypothetical direction-finding system is assumed and its pointing characteristics determined.

Men', A. V. (Oct. 1961) Time (spectral) characteristics of phase-difference fluctuations occurring in the propagation of radio waves in the troposphere, Rad. Eng. and Electronic Physics, 6, No. 10, 1451-1459.

61-13 Abstract: Average "statistical" spectral characteristics of phase- difference fluctuations, obtained from experimental measurements over sea water, of fluctuations on a wavelength $\lambda = 10$ cm and on a fixed path 33 km long, are given for a wide frequency interval.

The data obtained pertain to the case of "transverse" correlation with different distances between receiving antennas (bases) b, ranging from 2 to 100 m, corresponding to different ratios $d/\iota \gtrless 1$ (ι - characteristic correlation scale). The measurements were carried out at the illuminated region as well as in the penumbral and shadow regions.

Norton, K. A., J. W. Herbstreit, H. B. Janes, K. O. Hornberg, C. F. Peterson, A. F. Barghausen, W. E. Johnson, P. I. Wells, M. C. Thompson, Jr., M. J. Vetter, and A. W. Kirkpatrick (Nov. 1961) An experimental study of phase variations in line-of-sight microwave transmissions, NBS Monograph 33, 90 pp, (Supt. of Doc. U. S. Gov't. Print. Off. Washington, D. C.)

61-14 Abstract: During 1956 an experiment was conducted at Maui, Hawaii, to study the time variations in the phase of arrival of microwave signals propagated over a 15-mile line-of-sight path and the time variations in the phase difference of signals originating at a common antenna and received at two points on a horizontal baseline normal to the propagation path. These time variations are analyzed in terms of their serial correlation functions and power density spectra for different times of day, and for several baseline lengths ranging from 2.2 to 4,800 feet. The slope of the power spectra and the total variance of phase difference variations are shown to be dependent upon baseline length. In some instances there was evidence of a diurnal cycle in total variance of both phase and refractive index, with larger variances during the day time, but in other instances this diurnal effect was not detectable. The slope of the phase spectra appeared to be independent of time of day or meteorological conditions. The long-term variations in single-path phase were well correlated with variations in the mean value of refractive index measured at 5 points along the path.

Turin, George L. (July 1961) On optimal diversity reception, Trans. IRE IT-7, 154-166.

61-15 Abstract: The ideal probability-computing M-ary receiver is derived for a fading, noisy, multidiversity channel, in which the link fadings may be mutually correlated, as may the link noises. The results are interpreted in terms of block diagrams involving various filtering operations. Two special cases, those of very fast and very slow fading, are considered in detail.

Ugai, S. (1961) Studies on microwave propagation within line-of-sight distance, Proc. Microwave Seminar, Tokyo, I, Doc. No. 6, 30-43.

61-16 Abstract: The fading mechanisms for microwave line of sight paths are classified as k-type and duct type fading. The characteristics of each type are described in terms of the path geometry and transmission frequency. - HTD

Ugai, S. (May-June 1961) Characteristics of fading due to ducts and quantitative estimation of fading, Rev. of ECL, Japan, 9, p.319-

61-17 Abstract: As a result of long-term propagation tests carried out on four frequencies simultaneously, it has been clarified that microwave fading due to the irregular distribution of the refractive index of the air has two modes of variation - long-period variation and short-period variation. The characteristics of each have been described.

The quantitative relation between these two variations was found experimentally. It has been brought to light after considerations by geometrical optics and experimental analysis that the long-period variation is closely related to the statistics of the distribution of the refractive index of the air, which can be obtained by radiosonde data for the method of estimating the fading ranges in UHF and SHF bands for all seasons and various places is described.

Anastassiades, M. A., L. N. Karapiperis, N. K. Kariambas, and P. G. Paraskevopoulous (May 1962) Prediction of the field strength fading forms by means of weather situations, Geofisica Pura e Applicata, 52, 143-152.

62-1 Abstract: In this study the different forms of the electromagnetic field strength recordings at the Thera-Vrete microwave link are examined, in comparison with the corresponding weather situations prevailing over that area. According to the amplitude of fluctuations, the different forms of recordings have been classified in three basic types A, B, C and the annual frequency of the appearance of these types has been observed. Finally, the influence of weather situations on radio wave propagation was examined and it has been found that in most cases a close relationship exists between weather situations and the different fading forms of the electromagnetic field so that a prediction of the fading form may become possible by means of the weather forcast.

Arsen'ian, T. I., and A. A. Semenov (Oct. 1962) Comparison of statistical characteristics of fluctuations in direct and reflected fields of microwave signals in the troposphere, Rad. Eng. and Elec. Phys., 7, 1573-1576.

62-2 Abstract: The report presents the experimental results of comparison of the statistical characteristics of fluctuations in the direct and reflected fields of microwave signals under identical or similar propagation conditions. It is shown that the time autocorrelation functions of fluctuations in the direct and reflected signals coincide. The space autocorrelation functions (transverse) undergo oscillations which are similar in nature in the direct and reflected signals. The experimental results are compared with the theoretical behavior of the space correlation for the special case of the correlation function for fluctuations in the refractive index of the medium in the form of a Gaussian curve.

Barsis, Albrecht P. and Mary Ellen Johnson (1962) Prolonged space-wave fadeouts in tropospheric propagation, NBS J. Res., 66D, 681-694.

62-3 Abstract: This paper contains the results of studies performed during the last several years on the short-term variability of tropospheric signals received over within-the-horizon paths in Colorado and California. Signal variations of the type observed over such paths have been termed "prolonged space-wave fadeouts." They are analyzed as a function of carrier frequency, path characteristics, and meteorological parameters. The study also includes an evaluation of fadeouts observed over a path using a mountain peak as a diffracting knife-edge obstacle between transmitter and receiver.

Principal results show a stronger diurnal trend of fadeout incidence in continental climates than in maritime climates. A significant dependence of the fadeout characteristics on the refractive index structure has been observed in maritime climates.

In general, fadeouts tend to be more frequent but of shorter duration for higher frequencies. There are also indications that the occurrence of fadeout is well correlated on vertically spaced antennas. Thus conventional space diversity techniques may not be effective to increase the reliability of systems operating over within-the-horizon paths.

Bean, Bradford R. (1962) The radio refractive index of air, Proc. IRE 50, 260-273.

62-4 Abstract: This is a tutorial paper. The derivation of the classical Debye expression for the radio refractive index is reviewed. Recent determinations of the constants in this expression are reviewed and the conclusion reached that differences between constants are small compared with the error in using standard meteorological data in the formula. The various transformations of refractive index data are discussed as a natural result of the model assumed for its height distribution. The effect of the use of the various units is illustrated by examples drawn from radio climatology and the refraction of radio waves.

Beckmann, Petr (1962) Statistical distribution of the amplitude and phase of a multiply scattered field, NBS J. Res., 66D, 231-240.

62-5 Abstract: The probability distribution of the amplitude and phase of the sum of a large number of random two-dimensional vectors is derived under the following general conditions: Both the amplitudes and the phases of the component vectors are random, the distributions being arbitrary within the validity of the Central Limit Theorem; in particular, the distributions of the individual vectors need not be identical, the amplitude and phase of each component vector need not be independent and the distributions need not be symmetrical. The distributions formerly derived by Rayleigh, Rice, Hoyt, and Beckmann are shown to be special cases of this distribution.

Fukushima, M., H. Iriye, and K. Akita (Sept. 1962) Spatial distribution characteristics of atmospheric refractive index from helicopter and kytoon observations, J. Rad. Res. Lab. (Japan), 9, 369-383.

62-6 Abstract: Atmospheric refractivity profiles, elevated inversion layer characteristics and turbulence spectra were observed at elevations up to 2,000 m MSL by the use of a helicopter and a kytoon, during August, 1960, July to August and November, 1961. It was found that the value of k of the earth's effective radius ka varied 1.52 (August, 1960), 1.59 (July-August, 1961), to 1.30 (November, 1961). Large-scale elevated inversion layer characteristics were obtained with the extraordinarily intense and stable signals in UHF beyond-the-horizon propagation. The turbulence spectra nearly approach a -2 power law at high wave numbers.

Funakawa, Kenji and Joji Kato (Sept 1962) Experimental studies of propagational characters of 8.6 mm wave on the 24 km path, J. Radio Res. Labs. 9, 351-367.

62-7 Abstract: The propagational experiments of 8.6 mm wave on the 24 km path have been carried out nearly all the year round. From the results of the rain attenuation measurement, an empirical method was developed for the estimation of the long-term distribution of rain attenuation. During no-rainfall period, the fading range is large in the morning and about midnight in summer. The estimated value of absorption by water vapor is somewhat larger than the value measured by Texas University.

There is fairly noticeable correlation between the fading range and the appearance of temperature inversion in the atmosphere.

Gossard, E. E. (May 1962) The reflection of microwaves by a refractive layer perturbed by waves, Trans. IRE, AP-10, 317-325.

62-8 Abstract: The power spectra of amplitude and slope for several cases of internal waves on a radio refractive layer are shown and the implication of these waves for radio and radar coverage is discussed. The angular reflection patterns are derived for rough layers and the beamwidths in elevation and azimuth are obtained. The amplitude, frequency, wavelength and velocity of atmospheric waves are described, and the possibility of such waves acting as very rapidly moving reflectors is discussed. It is concluded on the basis of present observations of wavelength, amplitude, and phase velocity of atmospheric internal waves that they are not likely to be a source of very rapidly moving reflections such as were observed by Waterman at microwave frequencies.

Gough, M. W. (July 1962) Propagation influences in microwave link operation, Brit. J. IRE, 24, 53-72.

62-9 Abstract: Basic characteristics of ground-to-ground propagation in the frequency band 50 - 10 000 Mc/s are discussed, with emphasis on the operation of point-to-point radio links. Practical applications of such knowledge are illustrated by appraisals of the use of flat radio mirrors for circumventing mountain obstructions on microwave radio links, and of the capabilities of large-aperture aerials and space-diversity systems in reducing fading. Ground reflections are shown to be a key factor in the performance of very short wave radio links and the influence of inhomogeneities in the lower atmosphere is also stressed. It is pointed out how statistical analysis of temporal and spatial signal strength variations can often reveal the nature of the propagation mechanism at work, while at the same time pointing the way to improvements in circuit reliability.

Kahn, L. R. (1962) A time diversity technique for speech transmission over rapidly fading channels (Echoplex), IRE Int. Conv. Rec., 10, Part 8, 157-160.

62-10 Abstract: The Echoplex system is restricted to systems having a high degree of frequency repetition, such as voice or music. The speech spectrum is split up by bandpass filters and a progressive time delay is applied to each portion of the spectrum before being modulated on to the carrier. At the receiving end decoding equipment delays the various speech segments by such amounts as to make the time delay for all equal. The signals are then fed to a combiner, which may be a ratio squarer or linear combiner. Advantages are: (1) effective anti-fade characteristics; (2) peak-to-average ratio of the Echoplex encoded wave is considerably smaller than a normal speech wave, giving 6 dB improvement in s/n ratio; and (3) privacy. (--C. Van der N., EE Abstract 3320, March 1963).

Lewin, L. (July 1962) Diversity reception and automatic phase correction, Proc. IEE Part B, 109, 295-304.

62-11 Abstract: The interference between the direct ray and a ground-reflected ray gives rise at the receiver of a communication link to a sinusoidal field pattern in the vertical plane consisting of nodes and maxima. The position and pattern wavelength of this field depend on the receiver and transmitter heights and spacing and on propagation conditions in an effective curvature parameter, C. This parameter varies in time and is the cause of most fading at a single antenna. Its upper limit, which may be as high as 2.5 for a small percentage of the time, determines minimum antenna heights for line-of-sight transmission under extreme conditions. C is normally about 3/4. Its range of variation determines the optimum spacing of a pair of diversity antennae, and suitable design formulae are given. Experiments using a pair of mirrors, a varying transmitter frequency, and photographs of oscillograph traces indicate an extreme lower value of C over water of -1.5. A moving-film display shows that conditions can vary rapidly from minute to minute, although at other times the display is steady for hours at a time.

An automatic phasing junction has been designed for insertion in the feed from two diversity antennae, the drive for the phasing element being taken from the receiver. A combined signal nowhere smaller than the greater of the received signals is obtained from the combining element, and when the diversity spacing is chosen with regard to the extreme values of curvature obtained on the path, an excellent overall response is ensured. Some preliminary figures are given for the performance of an improved combining network and phase-control apparatus operating in conjunction with a height-diversity microwave system over a 69-mile overwater path.

Marukawa, T. (Aug. 1962) Surface roughness and effective reflection coefficients of the sea in 9 Gc/s-band wave propagation, (in Japanese), J. Inst. Elec. Comm. Engrs. (Japan), 45, 1071-1075.

62-12 Abstract: A report of measurements of the surface roughness and the effective reflection coefficient of the sea for 9 Gc/s-band transmissions over a 5.75 km path at the entrance to Tokyo Bay. The values of ρ_e, the reflection coefficient, were obtained by the aerial height gain pattern method. The measurements of the sea waves were made about 500 m from the reflection point of the radio waves. The results obtained show that the bigger the sea waves are, the smaller is the value of ρ_e, and the range of variation of the ρ_e values increases with the height of the waves. Short-period fading may also result from sea-wave height variation.

McGavin, R. E. (May 1962) A survey of the techniques for measuring the radio refractive index, NBS Tech. Note 99, 37 pp. (Supt. of Doc. U. S. Gov't. Print. Off., Washington, D. C.)

62-13 Abstract: The radio refractive index can be measured either directly or indirectly. The former method is utilized by radio frequency refractometers; the latter method involves measurement of temperature, pressure and humidity and conversion to refractive index. In terms of convenience and accuracy the direct method is superior; however, lack of universal use of refractometers requires the use of weather service type of data for the bulk of refractive index structures. Meteorological sensing is limited mainly by the inaccuracy in measuring humidity which under ideal conditions appears to limit the accuracy to ± 1.0 N. Gradient measurements utilizing radiosondes reflects an accuracy no better than ± 3 N units. Radio frequency refractometers are capable of accuracies as much as an order of magnitude better than that achieved by meteorological sensors. Lightweight refractometers have been devised for balloon-borne and dropsonde measurements reflecting accuracies inferior to the conventional refractometer but superior to the radiosonde.

Men', A. V. (Feb. 1962) The correlation of amplitude and phase fluctuations of radio waves propagating in the troposphere, (in Russian), Radiotekhnika i Elektronika (USSR), 7, 232-238.

62-14 Abstract: The correlation between fluctuations in amplitude and phase at one and the same point in space in the propagation of radio waves in an inhomogeneous turbulent medium is investigated. It is shown that the theoretical conclusions concerning the decorrelation of these fluctuations in the distant region, obtained by Chernov [Dokl. Akad. Nauk, SSSR, Vol. 98, No. 6, 953 (1954)], assuming an unbounded medium, are correct. The results of experimental measurements of the correlation of amplitude and phase fluctuations for propagation in the lower regions of the troposphere both in the irradiated region and in the region hidden by the earth's curvature are given. (RCG - EE Abstract 1038, Jan. 1963).

Norton, K. A., E. C. Barrows, M. C. Thompson, Jr., and H. B. Janes (Dec. 1962) Variance of radio frequency caused by atmospheric turbulence in line-of-sight transmissions, Trans. IRE I-11, 153-155.

62-15 Abstract: The frequency stability of a radio signal propagated over a line-of-sight path is reduced by time variations in phase velocity along the path. This instability caused by the atmosphere will produce errors in frequency measurements made by averaging a standard frequency transmission over a period of time T and also in time interval measurements made by counting the number of cycles of the standard frequency received during a period of time T. Recent measurements of the variations in phase of a received signal at microwave frequencies permit estimation of both types of error as a function of T.

These atmosphere-induced errors are compared to the errors inherent in the best currently available crystal oscillators and it appears that the latter source of error is dominant for line-of-sight paths through the atmosphere.

The level and slope of the frequency spectra have been observed to vary over wide ranges with time and geographical location. The spectral form $W(f) \sim f^{-2/3}$ expected on the basis of the Obukhov-Kolmogorov theory of atmospheric turbulence has a slope which lies well within the range of observed slopes for the range of fluctuation frequencies from 1 cycle/day to 1 cps.

Siddiqui, M. M. (March-April 1962) Some problems connected with Rayleigh distributions, NBS J. of Res., 66D, 167-174.

62-16 Abstract: This is an expository paper presenting the following: (1) the origin, and (2) the properties of the Rayleigh distribution; (3) the most efficient estimators of its parameters; (4) a test of the hypothesis that a set of observations is from a Rayleigh distribution; (5) the distribution of the ratio of two independent Rayleigh variates; and (6) the Rayleigh process derived from a normal process.

Turin, G. L. (March 1962) On optimal diversity reception, II, Trans. IRE CS-10, 22-31.

62-17 Abstract: In a previous paper the structure of the optimal multi-diversity receiver for a fading, noisy diversity channel was determined under the assumption that the memory of the receiver does not extend beyond the time interval of the signal currently being received. The probability of error for such a receiver is determined herein under the following assumptions: the channel is binary and symmetric; the (Gaussian) noises in the various diversity links are white and independent; and the fadings in the various links are Rayleigh distributed and slow, but not necessarily independent. Detailed curves of this probability of error are given for various orders of diversity in the two cases of independent fadings and "exponentially correlated" fadings.

Since the optimal receiver may be difficult to implement, a more easily implemented "square-law combining" receiver is also considered, and it is shown that for all practical purposes this simpler receiver behaves optimally. Finally the effect of the assumption that the receiver has a short memory is considered by comparing its performance with that of a longer-memory receiver studied by Pierce and Stein.

Weihrauch, H. (1962) The determination of the location of transmitters for UHF and microwave communication with the aid of a relief-map model (in German), Wiss. Z. Hochsch. Elektrotech., 8, 65-74.

62-18 Abstract: The optimum position of UHF transmitters can be determined on a relief-map model of the receiving area by using a miniature light source as "transmitter" and photographing the shadowy and illuminated areas. Measurements proved that there is a good correlation between illuminated areas and areas of high field strength whereas the actual field strength can be still considerable in the shadowy parts. It is proved that the use of a light source as transmitter is justified and the sources of errors are mathematically analysed. The effects of the obstacles and the curvature of the Earth is taken into consideration and the correction factors are presented in diagrams. Radiation patterns of aerials can be simulated by a mask on the light source. A brief survey of other methods of determining the position of UHF transmitters is given. (LGS - EE Abstract 979, Jan. 1963).

Wilkerson, R. E. (1962) Defocusing of radio rays by the troposphere, NBS J. Res., 66D, 479-485.

62-19 Abstract: When radio rays pass through the atmosphere, they are defocused due to its presence. This effect is measured by the divergence coefficient and general formulas are derived for D_1, the divergence coefficient of the direct ray, and D_2, the divergence coefficient of the reflected ray—assuming a smooth spherical earth. As examples, D_1 and D_2 are shown for some typical cases with an "exponential" atmosphere (troposphere).

Anderson, E. W. (Feb. 1963) The S.H.F. radio link comes of age, Point-to-Point Telecomm. (GB), 7, 4-15.

63-1 Abstract: The history of the development of S.H.F. (3000 to 30,000 Mc/s) microwave communication links is traced from the early experiments up to the present day. The present situation is briefly reviewed and some of the factors which will influence future developments are discussed.

Barrow, Bruce B. (March 1963) Diversity combination of fading signals with unequal mean strengths, Trans. IRE, CS-11, 73-78.

63-2 Abstract: The paper compares several techniques of diversity combination without placing the usual restriction requiring the mean signal-to-noise ratios on the various diversity branches to be equal.

The probability distribution of the postcombination SNR is calculated for various cases, and it is shown that the shape of this distribution curve is not greatly affected either by the choice of diversity technique or by reasonable unbalance in the mean SNR's on the various diversity branches. Various diversity techniques are compared by calculating the number of decibels by which transmitter power would have to be increased to achieve performance equivalent to that of the maximal-ratio combiner, which is the optimum. The same comparison is shown to hold, at the low SNR's that are of greatest practical interest, for a number of different types of fading, including Rayleigh fading of unequal mean strengths on the various branches, correlated Rayleigh fading, and certain non-Rayleigh types.

Constant-gain combination, which is a generalization of equal-gain combination, is discussed. It is shown that the gains in the different diversity branches should be adjusted to make the noise powers equal before combination.

Barsis, A. P., A. F. Barghausen and R. S. Kirby (Jan. 1963)
Studies of within-the-horizon propagation at 9300 Mc,
Trans. IEEE AP-11, 24-38.

63-3 Abstract: Propagation characteristics of radio signals in the 9300-Mc frequency range were investigated over a 113-km tropospheric within-the-horizon path in Eastern Colorado. Special attention was given to the short-term fading characteristics of the received carrier envelopes and to the bandwidth capability of the medium in this frequency range, which was studied by the comparison of amplitude variations of two CW carriers separated by 100 Mc in frequency. For this purpose, correlation coefficients between carrier envelopes as well as the distributions of carrier amplitude ratios were analyzed. Although these parameters are related, the amplitude ratio has some advantages as an indicator of selective fading phenomena for within-the-horizon paths.

By sampling the 9250 and 9350 Mc instantaneous carrier amplitudes at the rate of one per second, an over-all value of 0.91 was obtained for their cross-correlation coefficient. The standard deviation of the amplitude ratios expressed in db at 9250 and 9350 Mc averaged 0.76 db, with a maximum hourly value of 1.81 db. These results include the effect of space diversity, as separate antennas were used for transmission and reception of the two carriers, but they support the feasibility of wide-band modulation techniques for within-the-horizon paths if judged by the statistics of amplitude variations at discrete frequencies at the limits of the band considered.

Short-term and long-term fading characteristics at 9300 Mc are similar to the ones previously observed on lower frequencies over this path. An analysis of prolonged space-wave fadeouts in this frequency range resulted in fadeout depths up to 25 db below weekly transmission loss medians, approximately log-normal distributions of fadeout durations, and the expected diurnal variations of fadeout occurrence typical of a continental climate.

Bean, B. R., V. R. Frank, and J. A. Lane (1963) A radiometeorological study, Part II. An analysis of VHF field strength variations and refractive index profiles, NBS J. Res., 67D, 597-604.

63-4 Abstract: This paper discusses the cumulative probability distributions of field strength for four 200 km VHF paths in Illinois in terms of a classification of refractive index profiles. It is shown that extended elevated layers produce signal enhancements of 10 to 25 db above the level observed in unstratified conditions. Assuming the layer characteristics given by radiosonde data, the best agreement between calculated and measured values of field strength is obtained using a layer model with a linear n-profile.

The possible influence of smaller layers is also discussed in relation to the observed results for conditions judged to be unstratified or well mixed on the basis of sonde data.

Beckmann, P., and A. Spizzichino (1963) The scattering of electromagnetic waves from rough surfaces, MacMillan Co., New York
63-5 [Text] .

Franceschetti, Giorgio (Nov. 1963) An approach to tropospheric duct propagation, Proc. IEEE 51, 1481-1486.

63-6 Abstract: A modal solution for the em propagation in a spherical stratified troposphere is derived, via the Marcuvitz-Schwinger formalism. The approximations due to the small curvature of the earth are illustrated. The representation of the sources via the complete set of modal solutions is presented, as well as the excitation factors, computed for the vertical electric or magnetic dipole. The possible use of digital and analog computers is highlighted. Future plans for the work are the computations of a great deal of digital and analog solutions, and also the study of the influence of the random variability of the tropospheric refraction index. In the Appendix, a preliminary case [$f(z) = az$] is presented.

Glasser, W. (April 1963) Present position and development trends of optical-path radio communication systems, (in German), Nachrichtentechnik, 13, 123-127.

63-7 Abstract: An account of present-day practice in the field of optical-path radio communication systems compairing their performance with that of multi-channel cable systems and discussing the factors influencing the choice of operating frequencies, modulation techniques and type of electronic equipment employed at sender and receiver and at relay points. The article concludes with a reference to methods of trans-horizon communication without employing fixed relay station on the earth. (RHB - EE Abstract 12244, Oct. 1963).

Hay, D. R., and F. M. Fanaki (March 1963) Experimental technique for studying reflection coefficients of tropospheric inhomogeneities,
63-8 Canadian J. of Phys., 41, 563-567 [an abstract] .

Hogg, D. C., R. A. Semplak, and D. A. Gray (March 1963) Measurement of microwave interference at 4 Gc due to scatter by rain, Proc. IEEE, 51, p. 500.

63-9 Abstract: An experimental observation is reported of an interference effect caused by rain. The interfering noise signal arrived at the receiving antenna due to scattering of energy by a thunder shower. The observed variation with time is presented for this scatter interference, the associated rainfall rate, and the noise source. - HTD

Janes , H. B. (Nov. 1963) Correlation of the phase of microwave signals on the same line of sight path at different frequencies, Trans. IEEE, AP-11, 716-717.

63-10 Abstract: The phase and phase difference variations and their power spectra are presented for 9.2 and 9.4 Gc/s signals received over a 47 km line of sight propagation path.

LaGrone, A. H., P. E. Martin, and C. W. Chapman (Feb. 1963) Height gain measurements at VHF and UHF behind a grove of trees, Trans. IEEE, BC-9, 37-54.

63-11 Abstract: Results are reported of horizontally polarized signal strength measurements of frequencies of 82, 210, 633, 1280, and 2950 mcps. The measurements were height gain runs made behind a grove of trees in full leaf. The site was selected so that propagation took place over approximately the same path near the receiver terminal at all frequencies. Measurements were repeated at several distances. Theoretical analyses are reported for several assumed cases for comparison with the field measured data. Exceptionally good agreement was found in many cases.

Lane, J. A., and B. R. Bean (1963) A radiometeorological study, Part I. Existing radiometeorological parameters, NBS J. Res., 67D, 589-595.

63-12 Abstract: A survey is made of existing radiometeorological parameters, including those derived from the vertical profile of refractive index, n, and others which involve the concept of thermal stability. Quantitative comparison of radio and meteorological data confirm the value of N, (the surface value of $[n-1]\,10^6$) and ΔN (the difference in value of N_s and N at one kilometer) in a wide variety of conditions. For particular areas, however, it seems desirable to develop improved prediction techniques using a parameter which is related to the size, stability, and intensity of elevated layers in the troposphere.

Martin, F. L., and F. E. Wright (April 1963) Radar ray refraction associated with horizontal variations in the refractivity, J. Geophys. Res., 68, 1861-1869.

63-13 Abstract: The relative bending effects on a radio ray of the horizontal and vertical gradient of refractivity are investigated. With the use of ray-curvature formulae developed by Wong, convenient differential equations governing the three-dimensional ray path are derived. It is also shown that the ratio of "horizontal to vertical" bending effects is a maximum when the ray is propagated in the vertical plane containing the horizontal gradient of refractivity. In a two-dimensional example, computations of path height as a function of horizontal distance are obtained by numerical integration. For this purpose, a regional space-time averaged exponential model drawn from climatological studies of Bean and Thayer is used. Even though this smoothed model and an extreme version of it derived synthetically by increasing the horizontal gradient everywhere by a factor of 10 have comparatively strong horizontal gradients, the "horizontal bending" effect is virtually negligible.

It is not implied, however, that this conclusion is necessarily applicable to an atmosphere exhibiting small-scale fluctuations in the refractivity pattern. The ray paths corresponding to the nonhomogeneous model are significantly different from those in a horizontally uniform atmosphere. The problem of replacing a nonhomogeneous model by an equivalent horizontally uniform one is also investigated. The choice of the best uniform atmosphere depends upon minimizing the r.m.s. height error over a designated horizontal path length, and this in turn requires the specification of several ray-propagation parameters in addition to the distribution of refractivity.

Micheletta, C. (Feb. 1963) Radiowave diffraction on limited areas of ground, Alta Frequenza (Italy), 32, 127-132.

63-14 Abstract: The problem is examined for the purpose of determining the reradiated field by a portion of homogeneous and smooth ground, effectively flooded by both antennas of a line-of-sight link and having a sharply limited contour with respect to the vertical projection of the axis of the same link.

Rigorous methods being excluded, since they are applicable with difficulty even to a flat circular figure, there exists no other possible way but to integrate the field contributions which are produced by the surface elements of a curved ground, considered as Huygens sources.

This procedure is only approximate, since it supposes the diffraction area to be perfectly conductive and neglects the effects at the countour of such area.

However, if its dimensions are very large with regard to the wavelength and if the polarization is horizontal, the obtained results are not far from truth and may be actually useful for applications in particular link situations.

In the study, performed for the above mentioned practical purposes, some questions of a theoretical character have acquired certain prominence, such as the specification of the so called "essential domain of reflection", that is of the portion of ground which mainly contributes to the reflected field and the portion of the half-period zones, respectively, on flat ground (diffraction ellipse) and on curved ground. Confronting the diffracted fields by such zones a possible, new definition of the spherical divergence coefficient of Van der Pol and Bremmer is deduced.

Rainey, R. J., Jr., and D. C. Thorn (July, 1963) A refraction correction technique which includes nonsymmetric index of refraction, Trans. IEEE AP-11, 446-450.

63-15 Abstract: The problem of predicting refraction errors in a nonsymmetric, inhomogeneous atmospheric refractive index distribution is examined, utilizing the basic (vector) differential equation of a ray path. The simplifications made in the basic equation are based on known atmospheric refraction characteristics in conjunction with the limitations inherent in obtaining distributions over a wide region which are valid for a given time. The assumptions made are 1) $n \doteq 1$, 2) total bending is small, and 3) the gradient of n along the ray path is approximately the same as the gradient of n along the straight line in the launch direction. A fourth assumption, not mathematically necessary but useful in analyzing actual situations, is that the gradient of n may be described by regions of constant gradient.

The first three assumptions allow the general three-dimensional ray path to be computed in terms of its two plane-ray projections; the fourth assumption yields a mathematically simple solution for each path.

Siddiqui, M. M. and G. H. Weiss (Nov.-Dec. 1963) Families of distributions for hourly median power and instantaneous power of received radio signals, NBS J. Res. 67D, 753-762.

63-16 Abstract: In this paper the gamma family of probability distributions is studied in connection with the distribution of hourly median received power or transmission loss. By taking a mixture of Rayleigh distributions with gamma distributions as mixing distributions the long-term distributions of instanteous signal power are theoretically derived. These distributions are evaluated in closed form under several hypotheses. The question of estimating the parameters is discussed. Graphs and tables are prepared to facilitate the application of the theory to the data.

Ugai, S., S. Aoyagi, and S. Nakahara (May 1963) Microwave transmission across a mountain by using diffractor gratings, (in Japanese), J. Inst. Elec. Comm. Engrs. (Japan), 46, 653-661.

63-17 Abstract: This is a report on the diffractor grating method, which is found to considerably improve the various characteristics of radio waves propagated over a mountain district. The gain by the diffractor grating, which is usually built over the top of a diffracting mountain, is theoretically treated according to the Fresnel-Kirchhoff theory, to give the basis of actual design for the net or the gratings of diffractor.

Also several experimental results using this diffractor method are presented, which show great improvements as expected in the various characteristics, and suggest a considerable advantage of the use of this method, as compared with the reflector plate method hitherto used. - KF.

Ugai, S., and Y. Kaneda (May 1963) Statistical evaluation of microwave attenuation due to rain cells, Rev. Elec. Comm. Lab., 11, 268-

63-18 Abstract: From statistical investigations of the characteristics of rainfall, the concept of rain cells was obtained. This paper describes a statistical method of estimating the attenuation due to rain in radio relay links on the basis of this concept of rain cells and a method of determining the optimum path length for radio relay spans.

Weihrauch, H. (March 1963) Site determination for UHF and microwave link transmitters with the aid of a relief model, II, (in German), Nachrichtentechnik, 13, 111-114.

63-19 Abstract: For Pt. I see Abstract (62-18). This part discusses some practical points in connection with work on the model, including the effect of the surface of the model on the results, and methods for obtaining the correct spatial distribution of light transmitted from the lamp. Various methods for obtaining an estimate of service area from a proposed transmitter are compared and finally some of the applications of the method are pointed out. (E.A.; EE Abstract 6496, 1964, May).

Burns, W. R. (1964) Some statistical parameters related to the Nakagami-Rice probability distribution, NBS J. Res., Radio Science, 68D, 429-434.

64-1 Abstract: Formulas and tables are given for the mean and standard deviation of $R=20 \log_{10} r$ where the random variable r has the Nakagami-Rice distribution. This distribution is of interest in connection with the short-term fading characteristics of some received radio fields. A particularly simple formula for the mean of R is obtained in terms of the well-known exponential integral function $-Ei(-x)$. Additional information concerning the median and interdecile range of R is also given.

Cahoon, B. A., and L. P. Riggs (Sept. 1964) Climatology of elevated superrefractive layers arising from atmospheric subsidence, Proc. 1964 World Conference on Meteorology, Boulder, Colorado.

64-2 Abstract: Some world wide charts are presented of the seasonal variations of height and persistance of elevated ducting layers in tropical and subtropical regions. - HTD

Dougherty, H. T. and L. J. Maloney (Feb. 1964) Application of diffractions by convex surfaces to irregular terrain situations, NBS J. Res., Radio Science 68D, 239-250.

64-3 Abstract: Previous solutions by Rice and by Wait and Conda are combined and extended to provide more readily evaluated formulas for the diffraction of radio waves by the "rounded obstacles" encountered in irregular terrain situations. A comparison with experimental data is also provided.

Gilmer, R. O., R. E. McGavin and B. R. Bean (Sept. 1964)
The response of microwave refractometer cavities to atmospheric variations, Proc. of 1964 World Conference on Meteorology, NBS Boulder Laboratory.

64-4 Abstract: The microwave refractometer has been used extensively in the study of the refractive index structure of the atmosphere. Little work has been done evaluating the sampling cavity of the refractometer as an accurate measuring probe of the short-term variations of the atmosphere. Wind tunnel, water flow tunnel, and free atmospheric tests of the microwave sampling cavities currently in use have yielded information on aspect and velocity sensitivity, and on the spatial resolution of the cavities.

The tests revealed that the air flow through the sampling cavity undergoes a transition from laminar to turbulent type flow at wind velocities in excess of 5 mph. The pressure in the cavity decreases as the wind velocity increases. The indicated error due to the pressure drop at 15° C is as high as 1 N unit at 135 mph for a cavity oriented into the wind. This error appears to be a function of the aspect of the cavity relative to the direction of the wind, becoming a minimum at an angle of 22½°.

Flow tunnel tests gave direct visual indications of the flushing time versus the aspect angle of the sampling cavities. A characteristic flushing length of approximately 2.5 feet for complete flushing was measured at 0° as compared to 5.75 feet at 90°.

These tests revealed the limitations imposed on the measurement of the structure of the index of refraction by the sampling cavities. The results have suggested new possible approaches of construction of the cavity to reduce the errors due to aspect sensitivity and to increasing the spatial resolution of the sampling probe.

Ikegami, F. (May-June 1964) Radiometeorological effects in propagation over the sea and islands, Rev. Electr. Commun. Labor., NTT, 12, 5-6, 312-324.

64-5 Abstract: The studies on meteorological factors and propagation over the sea and islands are reviewed. For various modes of propagation such as line-of-sight, beyond the horizon and mountain-diffraction, special phenomena have been described which are peculiar to oversea propagation.

The differences are discussed between overland and oversea paths, on the refractive index structure of the atmosphere, diurnal and seasonal variations in signal strength, and occurrence of abnormal propagation conditions.

Nupen, Wilhelm (May 1964) Bibliography on propagation of radio waves through the troposphere, NBS Tech. Note No. 304

64-6 Abstract: A bibliography of over a thousand abstracts or titles taken from the literature published between 1902 and 1964. The subject matter is confined to the effects of the earth's atmosphere on radio frequency radiation from 10 c/s to 100,000 Mc/s. -HTD

Oguchi, Tomohiro (Jan. 1964) Attenuation of electromagnetic wave due to rain with distorted raindrops (Part II), J. Radio Res. Labs. (Tokyo) 11, 19-37.

64-7 Abstract: In the preceding paper, the total cross-section of a spheroidal particle of any material with small eccentricity was derived in the first-order approximation of drop deformation, and introducing the theoretical value of eccentricity of raindrops falling at terminal velocity, the total cross-sections of distorted raindrops for horizontally and vertically polarized plane waves were computed at 34.8 Gc/s.

By the use of these cross-sections, the theoretical relation between attenuation and the rate of precipitation for horizontally and vertically polarized plane waves was obtained.

The present paper is a continuation of the preceding one. The total cross-section of a spheroidal particle is derived to the second-order approximation of drop deformation. The numerical computations for the first-order approximation are extended from 4 Gc/s to 100 Gc/s.

Under the condition of constant rainfall rate, it is concluded that the difference of attenuation between horizontally and vertically polarized wave divided by that of vertically polarized one becomes very small as frequency becomes higher, except some frequency range, where the raindrops having major contribution to the attenuation are resonant with the incident field.

Preikschat, F. K. (Aug. 1964) Screening fences for ground reflection reduction, Microwave Journal, 7, 46-50.

64-8 Abstract: This article describes the design of Fresnel diffracting fences which, when placed in the foreground of one antenna, will provide a specified reduction in the ground reflected wave for line of sight paths. - HTD

Saxton, J. A., J. A. Lane, R. W. Meadows, and P. A. Matthews, (Feb. 1964) Layer structure of the troposphere, Proc. IEE, III, 275-283.

64-9 Abstract: A discussion is presented of the manner in which layer-type echoes may arise and be observed using a 10 cm radar at vertical incidence; such echoes are due to variations in the gaseous refractive index and not to water droplets in clouds or precipitation. Specular reflection and scattering processes are compared and the conditions indicated when an echo may be due to one or the other process, although the applicability of the turbulence theories used to relatively thin layers needs to be established.

The results of the analysis are discussed in relation to data obtained from simultaneous soundings of the troposphere by radar and airborne microwave refractometers. Some comments are made regarding further experimental and theoretical investigations of the fine structure of elevated layers.

Vogler, L. E. (July 1964) Calculation of groundwave attenuation in the far diffraction region, Radio Sci. J. Res. NBS/USNC-URSI 68D, 819-826.

64-10 Abstract: This paper presents a graphical method of determining the groundwave attenuation over a spherical homogeneous earth in the far diffraction region. The curves are applicable to either vertical or horizontal polarization and to any combination of effective earth's radius, electromagnetic ground constants, frequency, path distance, and antenna heights. A criterion is given that indicates the method may be used not only for far beyond line-of-sight paths but, in many practical situations, at line-of-sight or even slightly within. Examples illustrating the use of the formulas and curves are included.

Wait, J. R. (July 1964) A note on VHF reflection from a tropospheric layer, Radio Sci. J. Res. NBS/USNC-URSI, 68D, 847-848.

64-11 Abstract: Some remarks concerning reflection from tropospheric layers are made with special reference to a recent paper by Bean, Frank, and Lane on the subject. It is indicated that the finite vertical extent of the layer must be considered in the analysis.

ADDENDUM

Hoyt, R. S. (1947) Probability functions for the modulus and angle of the normal complex variate, BSTJ 26, 318-359.

A 47-1 Abstract: This paper deals mainly with various "distribution functions" and "cumulative distribution functions" pertaining to the modulus and to the angle of the "normal" complex variate, for the case where the mean value of this variate is zero. Also, for auxiliary uses chiefly, the distirbution function pertaining to the reciprical of the modulus is included. For all of these various probability functions the paper derives convenient general formulas, and for four of the functions it supplies comprehensive sets of curves; further, it gives a table of computed values of the cumulative distribution function for the modulus, serving to verify the values computed by a different method in an earlier paper by the same author.

Riblet, H. J. and C. B. Barker (1948) A general divergence formula, J. Appl. Phys. 19, 63-70.

A48-1 Abstract: A divergence expression for the ratio of energy per steradian reflected from a smooth curved surface to that incident on the surface is derived. It generalizes previous results in that the source and point of observation may both be at finite distances from the reflecting surface. No restrictions are placed on the angles of incidence and reflection except that they be equal. The only limitation placed on the analytic accuracy of the geometrical result is that the surface be sufficiently smooth so that the principle radii of curvature are defined at the point of reflection. It is required, of course, that the wave-length of the energy shall be small compared to the principle radii of curvature of the surface, in order that the geometrical result may be interpreted as a divergence formula. All of the previous results on this problem known to the authors are derived as special cases. Application of the result in connection with the spreading of radio waves by the curvature of the earth leads to somewhat simpler formulas than now available.

Bremmer, H. (1949) Terrestrial Radio Waves, Elsevier Pub. Co., New York. (Text).
A49-1

Hartman, W. J. (1960) Limit of Spatial Resolution of Refractometer Cavities, J. of Res. NBS 64D, 65-72.

A60-1 Abstract: Filtor factors that determine an upper limit for the wave numbers for which refractometer measurements can be used to calculate the spectrum of refractivity are derived in this paper based on the assumption that the refractometers measure a weighted average of the refractive index in a volume of air surrounding the center of the refractometer cavity. Two models are used assuming the weighting function has spherical symmetry around the center and one model is used assuming the function has cylindrical symmetry. All models result in a simple mathematical form which should be easy to use in further theoretical developments.

Nakagami, M. (1960) The m-distribution - a general formula of intensity distribution of rapid fading, Statistical Methods in Radio Wave Propagation (ed. W. C. Hoffman), Pergamon
A 60-2 Press, Oxford.

Stratonovich, R. L. (1963) Topics in the theory of random noise, Vol. I, (translated from the Russian by R. A. Silverman),
A 63-1 A Text.

Beckmann, Petr. (Sept. 1964) Rayleigh distribution and its generalizations, Radio Sci. J. Res. NBS 68D, 927-932.

A 64-1 Abstract: The Rayleigh distribution is the distribution of the sum of a large number of coplanar (or time) vectors with random amplitudes and uniformly distributed phases. As such, it is the limiting case of distributions associated with more general vector sums that arise in practical problems. Such cases are the following: (a) The phase distributions of the vector terms are not uniform, e.g. in the case of scattering from rough surfaces; (b) One or more vector terms predominate,

their mean square value not being negligible compared to the mean square value of the sum, e.g. in the case of signals propagated in cities, meteor-scatter, and atmospheric noise; (c) The number of vector terms is small, e.g. in radar returns from several close targets; (d) The number of vector terms is itself random, e.g. in atmospheric turbulence, meteor-scatter and atmospheric noise. The resulting distributions for these cases and their deviations from the Rayleigh distribution will be considered.

Stratonovich, R. L. (1964) Topics in the theory of random noise, Vol. II (translated from the Russian by R. A. Silverman),
A 64-2 Gordon and Breach, New York.

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