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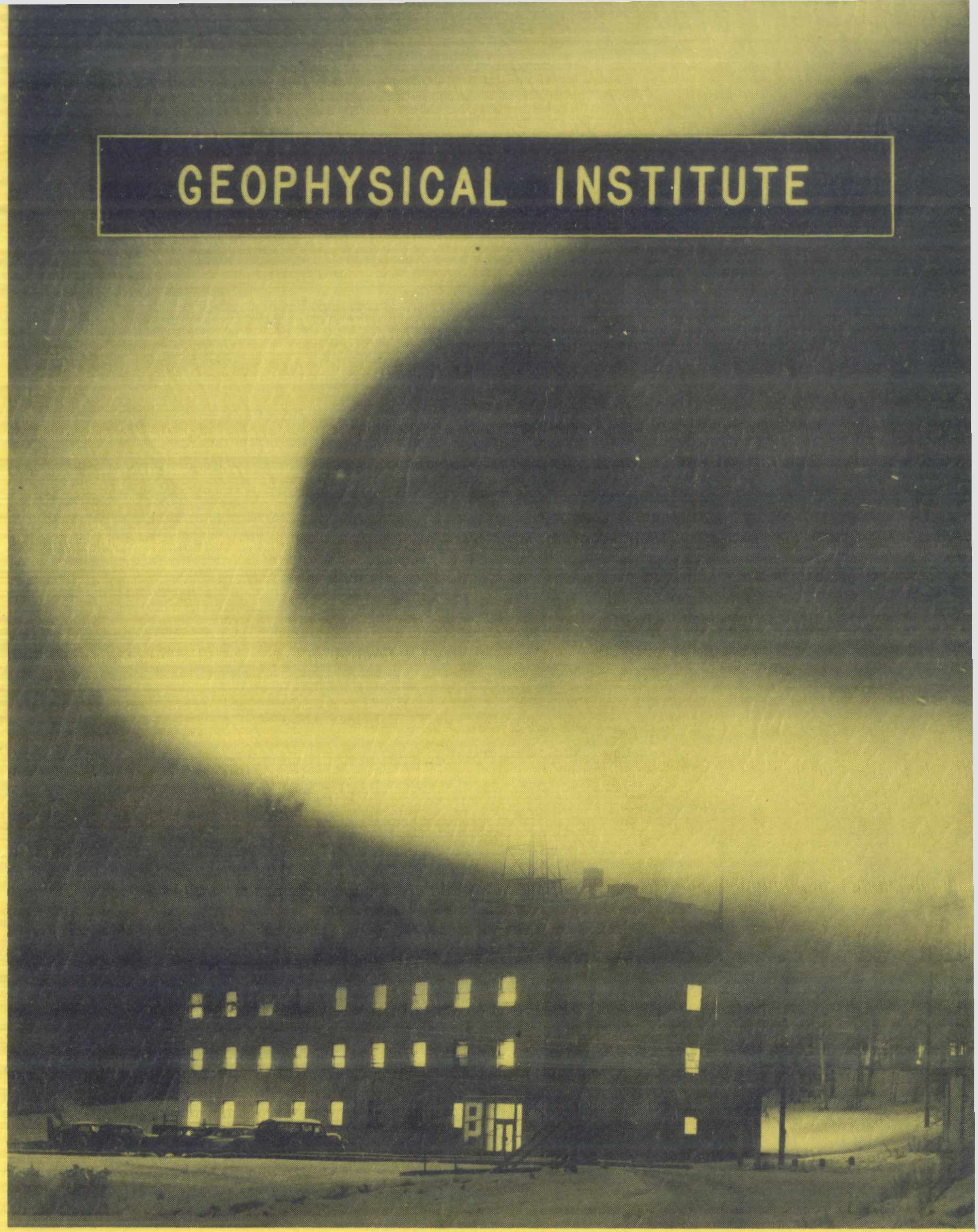

UNIVERSITY
OF ALASKA

COLLEGE
ALASKA

STUDIES OF GROUND CONDUCTIVITY
IN THE
TERRITORY OF ALASKA

Interim Scientific Report No. 1

1 December 1955 - 31 October 1958

Navy Contract No. NObsr 72528
Dept. of the Navy Index NE 120308
Subtask No. 6

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This report covers work done during the period
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GEOPHYSICAL INSTITUTE
UNIVERSITY OF ALASKA
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Navy Department Bureau of Ships
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Approved by:

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Director

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ABSTRACT

The effective ground conductivity of Alaska has been determined by a comparison of experimental and theoretical field strengths. The experimental field strengths have been obtained by use of an airborne receiver, flown along radial paths from a large number of CAA radio ranges and beacons. The surface wave attenuation factor was computed for both a plane and a curved, homogeneous earth by methods presented by Norton. The experimentally determined relative field strengths were plotted as a function of distance and were compared with a family of curves for assumed values of conductivity and dielectric constant. From this comparison, that value of conductivity that best fits the experimental data is taken as the effective conductivity over the path.

An investigation of the effect at dielectric constant on the transmitted signal shows that, within the frequency range used, a change of dielectric constant from 1 to 20 has but little effect on the attenuation of the transmitted signal for values of conductivity between 1 and 5 mmho/m. The experimental results indicate that for most sections of Alaska, the effective conductivity falls within this range.

In some cases the earth was not homogeneous over the entire flight path as evidenced by changes in the slope of the field strength vs distance curves. In such cases, the data were replotted with an initial point at the discontinuity and new theoretical curves were drawn for each section of the field strength vs distance curves.

Investigation of the variation of effective conductivity with change of frequency and at different seasons was made.

In addition, wave tilt methods of determining the conductivity were used. A 'Ground Constants Measuring Set' was obtained from the Signal Corps and measurements were made in selected areas in Alaska.

Attempts were made to use 'height-gain' and 'mutual coupling of loops' techniques but these were not successful.

An investigation of anomolous propagation in the vicinity of Point Barrow was made. It was determined that this anomolous propagation appears to be the result of a layered earth. In addition to the anomolous propagation in the vicinity of Point Barrow, there appears to be similar anomolies in the vicinity of Kotzebue, Galena, Bethel and Port Heiden.

From the above investigations a map showing the effective conductivity of Alaska as determined by the attenuation method is presented.

PART I

A. PURPOSE

The purpose of this contract is to conduct studies of the electrical characteristics of the ground in the Territory of Alaska. A considerable amount of preliminary work in this field has been done by the Geophysical Institute under previous contracts (administered by the Signal Corps). These contracts were numbered: Signal Corps Contract No. DA 36-039-SC5512, Dept. of the Navy Index 120308 and Signal Corps Contract No. DA 36-039-SC56715, Dept. of the Navy NE 120308. During the course of the previous contracts, a method of determining the effective ground conductivity at low radio frequencies by air-borne means was devised and measurements were made over wide sections of the Territory of Alaska. During the present contract, the emphasis has been on the completion of the ground conductivity survey of the Territory.

B. GENERAL FACTUAL DATA

1. Identification of Technicians

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2. Patents

Not applicable

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C. DETAIL FACTUAL DATA

1. General

During the past several years the Geophysical Institute at the University of Alaska has been engaged in a research project that has had as its final object the preparation of a map showing the electrical conductivity of the ground of Alaska. Of primary interest was the determination of the electrical conductivity of the ground at low and medium radio frequencies. The results of the work previous to this contract have been reported both in technical reports and in papers presented at scientific meetings (1,2,3,4). As a paper presented at the VLF Symposium (4) was not published in the symposium record it is reproduced in the appendix of this report.

Briefly, the work during the periods previous to the period covered by this report has included the determination of a feasible method of measuring the conductivity of the Territory of Alaska and a conductivity survey of selected areas.

Although several methods of determining the conductivity were tried, a comparison of measured and theoretical field strengths was found to be the most satisfactory method of obtaining the conductivity over a large area of the Territory. Measurement of the forward "tilt" of a vertically polarized surface wave, the mutual coupling of loops laying on the surface of the ground and the determination of the electrical constants of selected samples of soil were also tried but of these, only the "wave tilt" method seems feasible for use, and that for very restricted areas.

During the period covered by this report more sensitive receiving equipment was developed and air-borne field strength measurements were made over a considerably larger portion of the Territory. As many of the flight runs were for distances of two to three hundred miles in length, it was necessary to make curved earth corrections on the theoretical field strength curves. The methods described by Norton were used throughout.(5,6) A further investigation of the anomolous propagation at 236 kc near Point Barrow was made. In particular, layered earth propagation was assumed to be the cause of the anomolous results and an analysis based on this assumption, following the theoretical developments by Wait was made.(8,9,10)

An attempt was made to utilize the mutual coupling of loops laying on the surface of the ground to determine the effective conductivity. The theoretical aspects of this method are also discussed by Wait.(14)

During the period of the contract, arrangements were made to use the Ground Constants Measuring Set developed by the Kollsman Instrument Corporation for the US Signal Corps under Contract No. DA 36-039-SC-47029 to Radio Communications Branch, Coles Signal Laboratory, Red Bank, New Jersey. Measurements were made using this equipment in two areas.

2. Attenuation Method

During the previous contracts field strength measurements were made using an AN/PRM 1 Stoddart Field Intensity Meter. The sensitivity of this equipment and a trailing wire antenna when mounted in a light aircraft was such that flight runs of 50 to 100 miles could be made using the signal from the low frequency radio ranges and beacons in the Territory of Alaska. As these ranges and beacons were separated by several hundred miles in some cases, large areas between them could not be surveyed with this equipment. Although this equipment gave useful service for short range measurements, it was felt that more satisfactory service could be obtained by modifying a surplus BC 453 receiver (which tunes from 190 to 550 kc rather than from 150 kc to 25 Mc.) The modification of this equipment was made and included the installation of an attenuator network, a preamplifier, a metering circuit, and a regulated power supply. All of the modifications on the BC 453 were of a routine nature and no new or unique circuity was involved. A power driven antenna reel and a 12 volt dc to 115 volt ac converter were procured to complete the field intensity measuring equipment. The completed equipment was capable of making field strength measurements up to 250 miles under optimum conditions.

Experience indicated that the type of aircraft used previously had a limited range and speed which seriously reduced the amount of data that could be obtained. Further, as it was anticipated that much of the data would be obtained in the coastal regions and along the Arctic Slope where the weather was a serious factor, it was decided that an aircraft which was more fully instrumented would give a safer operation. A contract was negotiated between Interior Enterprises of Fairbanks, Alaska and the Geophysical Institute for flying services in connection with the project. A Cessna 180 4-place aircraft was chosen as most suitable for our use and arrangements were made for approximately 400 hours of flying time during the year.

As it was reported that the Dewline sites along the Arctic Slope would have operating radio beacons in the low frequency range covered by the field intensity measuring equipment, negotiations were started with Western Electric to use their sites and beacons to make a complete survey of the entire area north of the Brooks Mountain Range which extends from East to West across the northern quarter of the Alaskan mainland. Although a great deal of advance planning was made (including obtaining security clearance for the personnel of the contract for entrance into the areas) permission, though once granted, was withdrawn by Western Electric officials. It was again granted in July and a party made measurements in the area in August and September. However, the beacons were not operative with suitable antennas and it was possible only to use the stations at Umiat and Point Barrow as sources of radio signals in that region. The station at Point Barrow was operated jointly by Western Electric and by Wien Alaska Airlines and the station at Umiat was operated by Wien Alaska Airlines. Logistic support for operations in this area was provided by Arctic Research Laboratory.

Field strength measurements were taken from 17 May 1956 through 1 October 1956 and included 171 flight runs from 14 stations. Most of the flight runs were markedly longer than those made during the previous contracts. As in previous years, it was found that approximately one half of the total flying time produced useful data, the other half being spent in moving from station to station, aborted flight runs, standby time (because of inclement weather) and training of observing personnel.

Fig. 1 shows the locations of the radio ranges and beacons from which flight runs were made during the period of the investigations (including previous contracts). Fig. 2 shows the actual flight runs for the same period.

As all of the flight paths were along radii from the transmitting antenna, no corrections were necessary for assymetrical transmitting and receiving antennas. In addition, relative field strengths were used throughout the computations of ground conductivity and no attempt was made to calibrate the receiving equipment in terms of absolute field strength.

The output of the receiving equipment was recorded on a 0 - 1 ma spring-wound Esterline-Angus Recorder operated at 3/4 inches/minute. The recorder was equipped with side pens so that additional information could be added to the chart by means of push buttons operated by the observer.

The measurement procedure for each flight run is outlined below:

1. A radial course, chosen by map reconnaissance, was plotted on a 1:250,000 USGS topographical contour map. In each case an attempt was made to choose a course that would have as many check points as possible identifiable both on the ground and on the map.

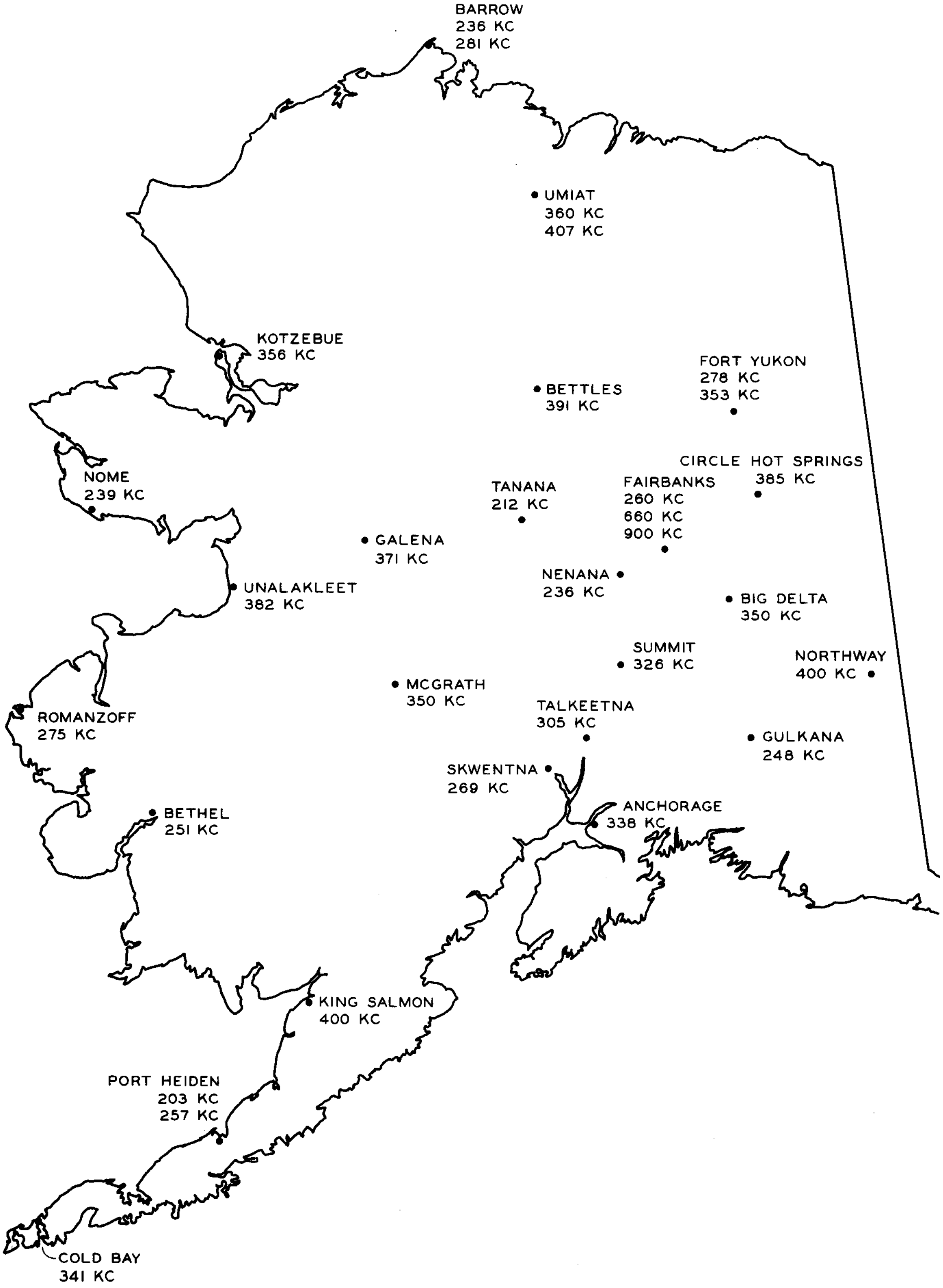


Fig. 1. CAA Ranges and Beacons used for Signal Sources.

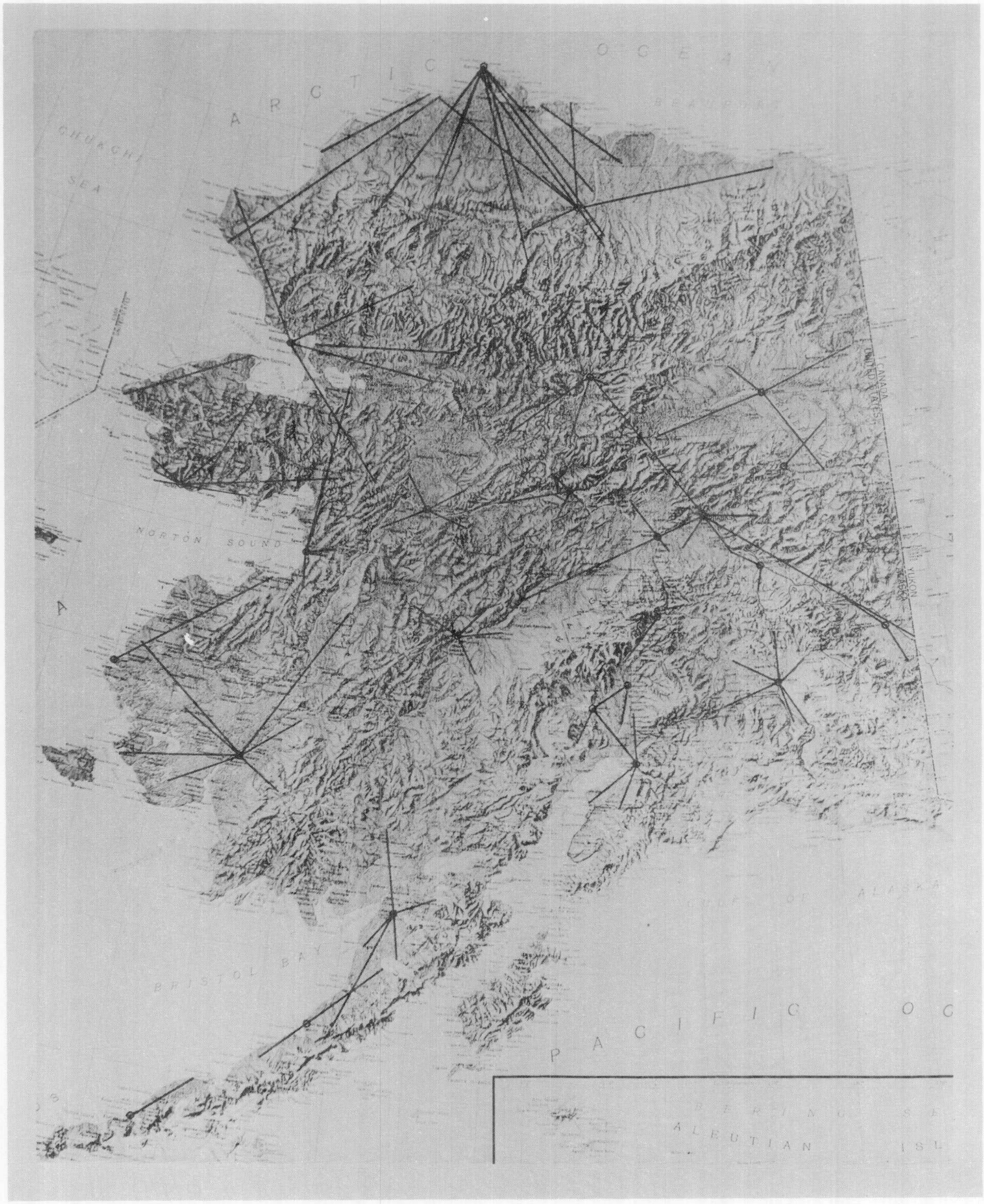


Fig. 2. Flight Runs 1953 - 1956.

2. A flight plan was filed with local CAA or airline personnel.
3. The equipment was turned on and allowed to warm up from 5 to 10 minutes before the start of the flight run.
4. As soon as the aircraft was air-borne, the antennas was extended and attached to the equipment.
5. As the aircraft passed over the transmitting antenna or the first identifiable point on the ground along the proposed flight path a mark was placed on the EA chart paper with the right side pen. At the same time the attenuator setting and the check point number was marked with the left side pen. Both the check point number and the attenuator setting were in a simple code devised for this purpose.
6. Each successive check point, check point number, and attenuator setting was marked on the chart with the side pens.
7. A description of the check point, the altitude, and the air speed was recorded on a log sheet kept by the observer. In addition, the check point was marked on the map.
8. Each flight run was continued until terrain, weather, lack of fuel or lack of signal necessitated its termination. In many cases 50 to 80 check points were used along a single flight path.
9. At the end of each flight run the flight plan was cancelled.
10. At the end of each days measurements, each chart was identified with time, date, flight name, azimuth from transmitting antenna, station and frequency. In addition, check points were numbered and any corrections to the side pen markings were made on the chart.

Fig. 3 is an example of a typical EA chart obtained at 1100 17 July 1954 at Bethel, Alaska for 251 kc. The major pen swings on the chart are for the period when the plate and the filament voltages were being checked. The chart has been cut in the middle for purposes of reproduction.

The method of obtaining the ground conductivity from the attenuation of the ground wave signal has been discussed in detail in previous reports and in the literature (1,2,3,5,6,8,9,11,12,13). No new methods were used during the period. However, as the length of many of the flight runs exceeded the distance allowable under plane earth assumptions, it was necessary to correct the theoretical calculations of the relative field strength to allow for a curved earth. The methods described by Norton were used throughout.(6)

A brief résumé of the method of determining the conductivity for a homogeneous earth is given in Appendix I, page 1, 2, 3 and 4, (equations 1 through 5). If the ground is homogeneous over the entire path and if enough points along the path are taken, the experimental relative field strength will appear as a series of points falling along one or between two of the theoretical curves. Fig. 4 is an example of data obtained over a homogeneous earth. The vertical lines represent the spread of four runs over the same path and the circles represent the average values. Although the spread shown in Fig. 3 is small, larger spreads were sometimes obtained. These larger spreads were generally caused by turbulent air, poor check points, or proximity to hills or mountains.

In the event that the earth is not homogeneous over the entire path, it is necessary to use two or more initial points. Each section of the path with the same rate of attenuation is considered separately. Fig. 5 is an example of such a case. The rate of attenuation changed at 34 wavelengths and the conductivity changed from 5 mmho/m to 1 mmho/m at that point.

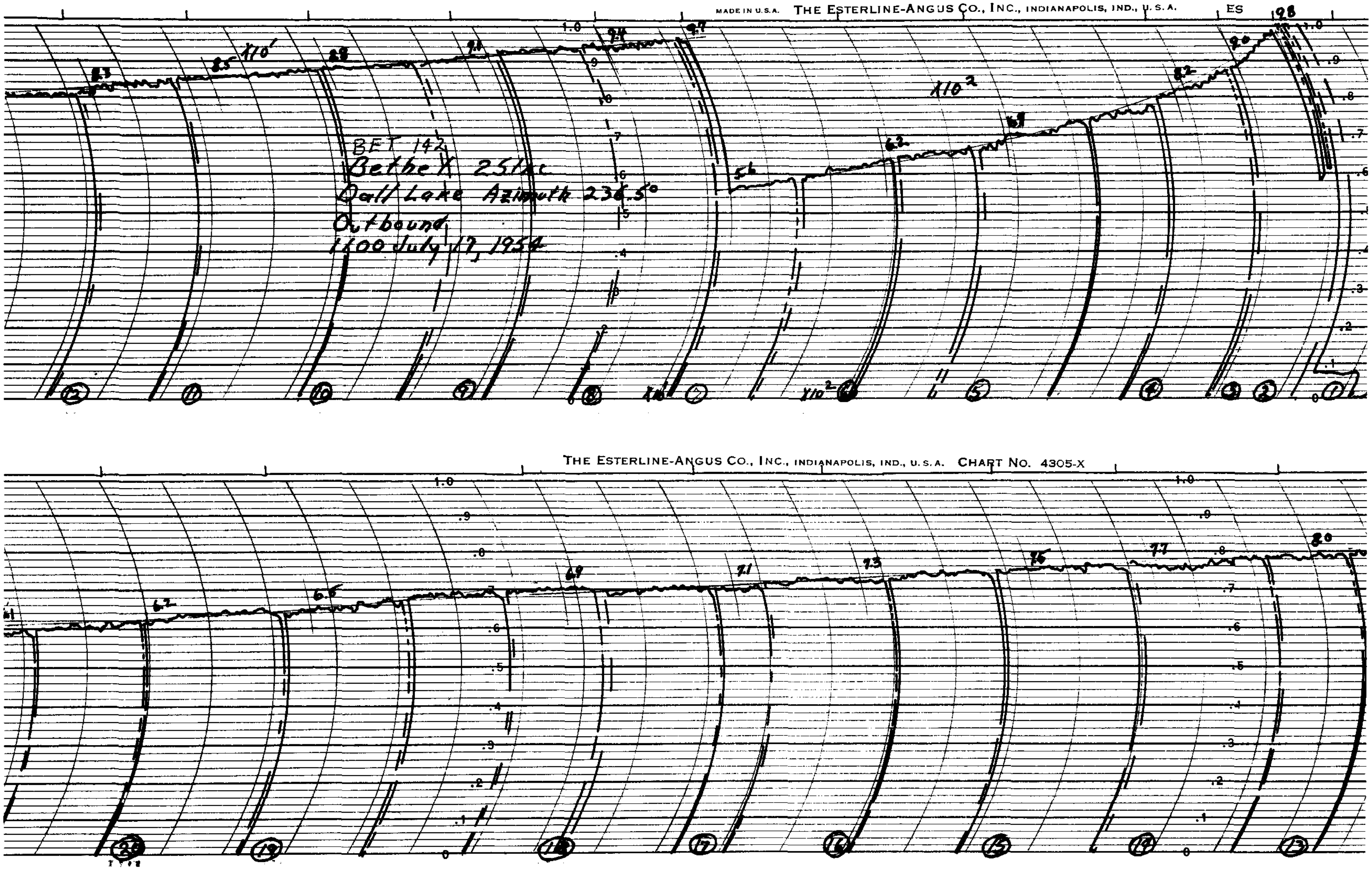


Fig. 3. Example of record for one flight run.

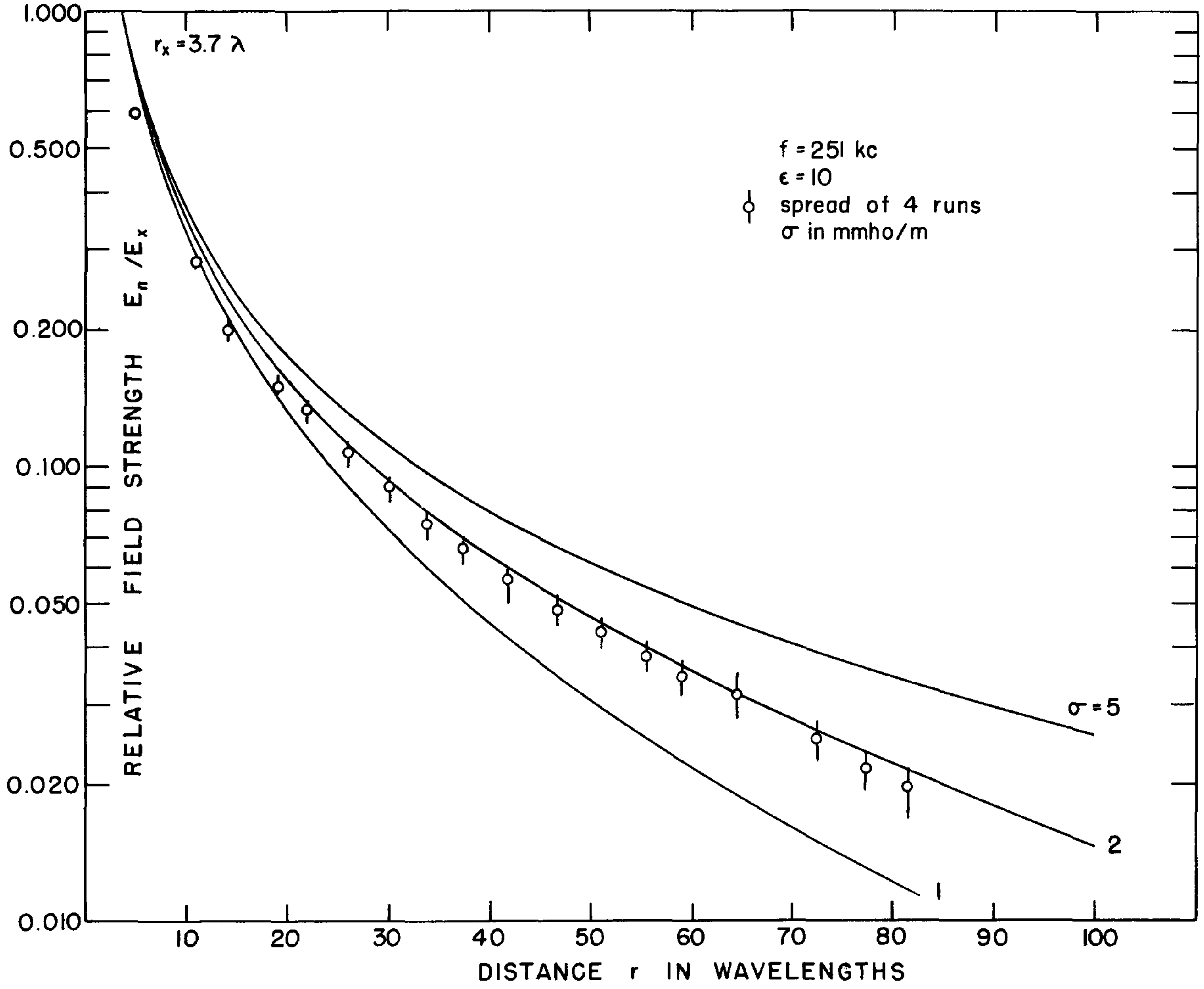


Fig. 4. Comparison of theoretical and experimental relative field strengths over a homogeneous path.

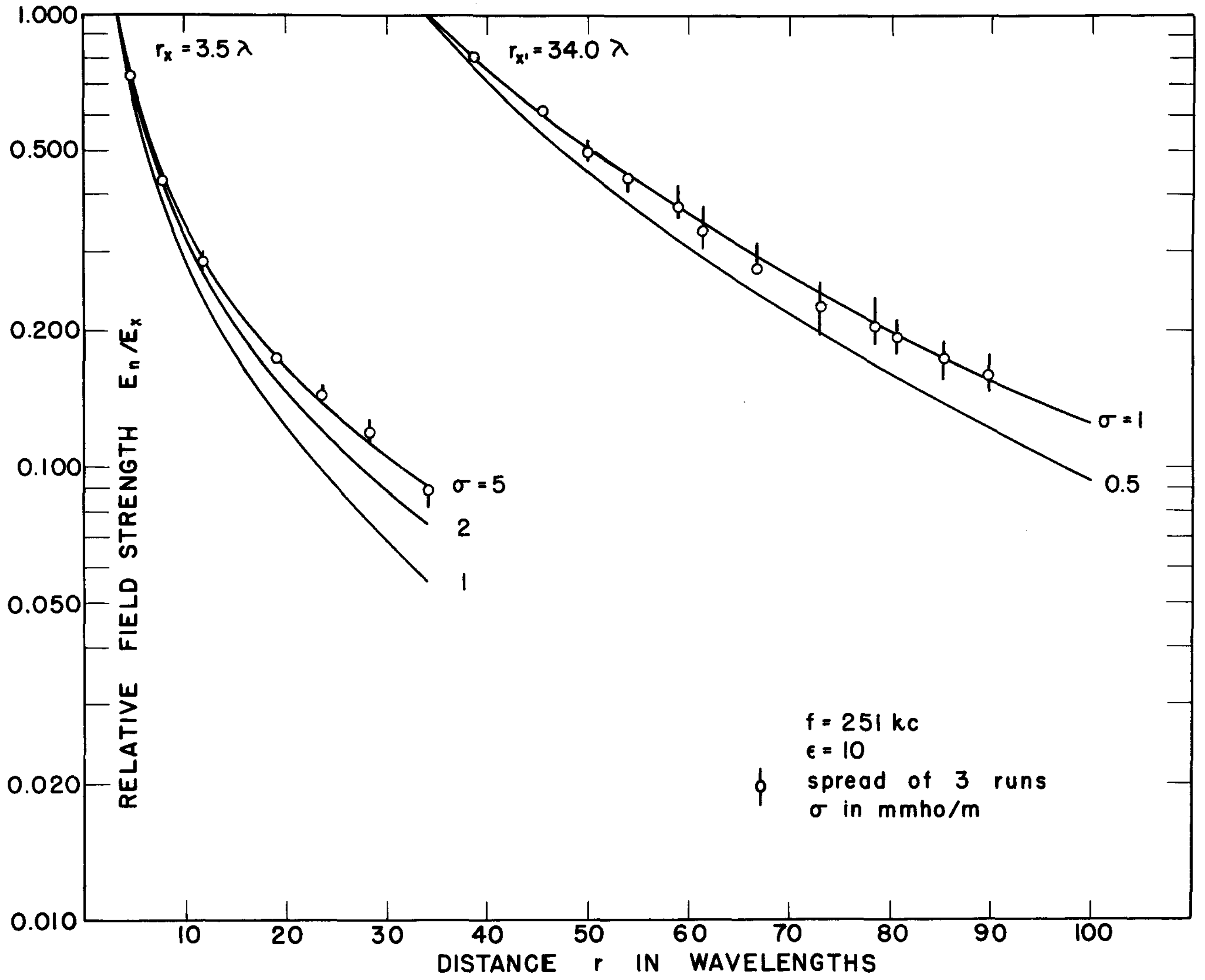


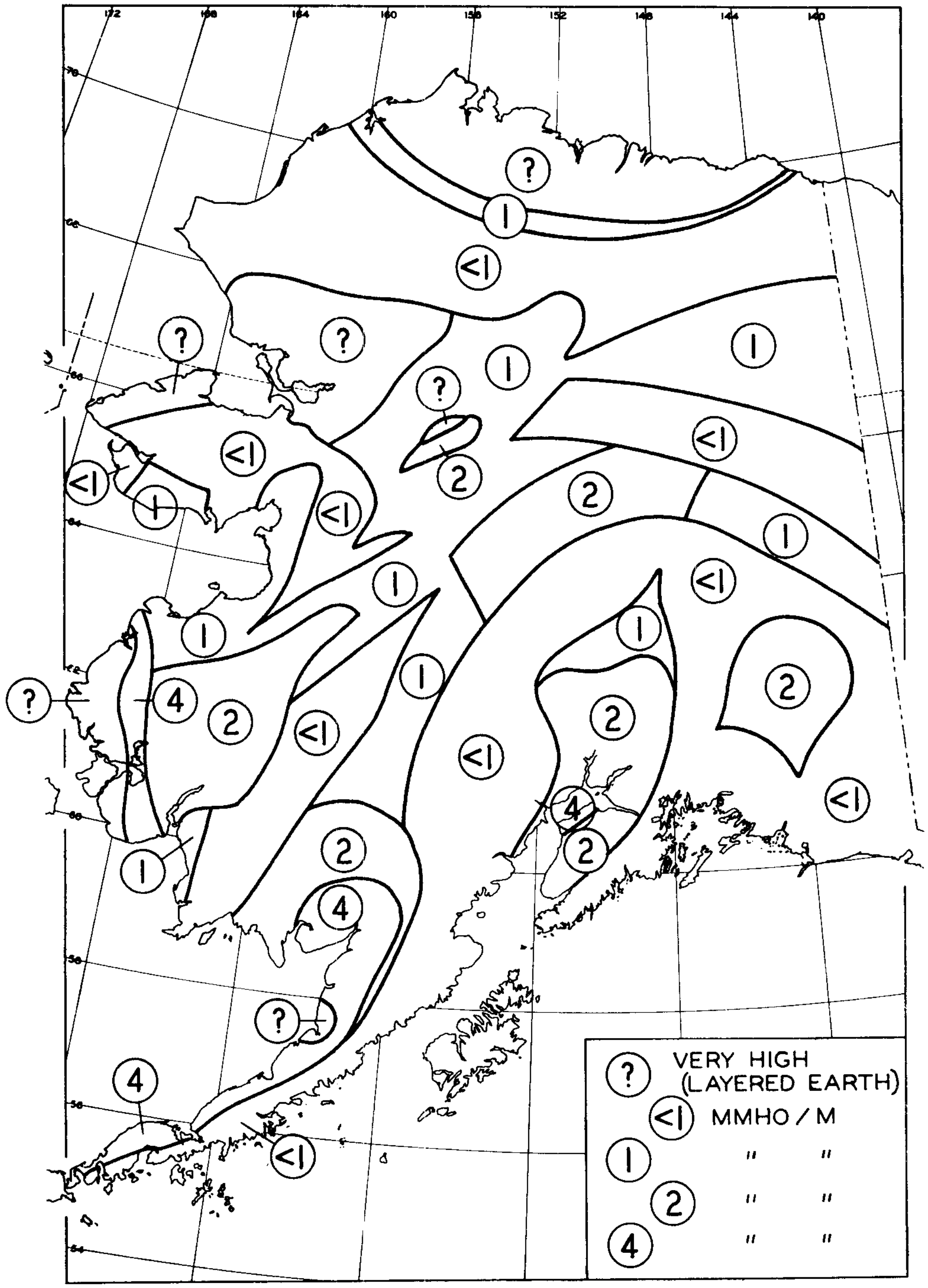
Fig. 5. Comparison of theoretical and experimental relative field strengths over an inhomogeneous path.

The ground conductivity obtained by the methods just discussed must be regarded as an effective ground conductivity. As the depth of penetration of the radio waves at these frequencies may amount to several tens of meters and as the earth is seldon homogeneous to these depths, the ground conductivity thus obtained may be frequency dependent. The limit of extrapolation was not determined during the course of these investigations. No appreciable change in the apparent ground conductivity was noted between the frequencies of 391 kc and 260 kc over a flight path between Fairbanks and Bettles. It would appear, then, that the effective ground conductivity obtained by use of frequencies of from 200 to 400 kc might well be valid in some cases for frequencies of from 150 to 500 kc. Theoretically it is possible to determine the effects of an n-layered earth and thus obtain the ground conductivity, however the geology of Alaska is not well enough known to compute the theoretical attenuation of a signal except for very special cases. Appendix I discusses in detail the procedure necessary to determine the effects of two-layered earth at 236 kc. An example of layered earth propagation is given. The procedure outlined in Appendix I appears to be valid in the frequency region where the displacement currents in the air are small compared to the sum of the combined displacement and conduction currents in the ground.

During the course of the contract, the theoretical attenuation of the surface wave was computed for 15 frequencies between 200 and 400 kc. For each frequency, the attenuation was computed for at least three values of conductivity and for distances of from one to two hundred miles from the transmitting antenna. These theoretical values were then compared with the experimental values obtained on the flight runs to obtain the effective conductivity over the flight path. It should be noted that there were difficulties with the calibration of the equipment. It was necessary to rescale the data and to recompute the ration E_n/E_x for all flight runs. A second analysis of the data was then made.

Using all the data collected, including that from previous contracts, a conductivity map of Alaska, Fig. 6, was prepared. The areas marked less than 0.5 mmho/m are mountainous. In all cases there is practically no soil on these area surfaces, therefore, the conductivity should be that of rock. Verification of low conductivity in these areas was not possible.

The areas in the vicinity of Kotzebue, Cape Romanzof, Port Heiden and the Arctic Slope showed evidence of anomalous propagation. It is probable, but not certain, that layered earth propagation is the cause of this anomalous propagation. In some cases it might be possible to determine the effective conductivity but, for the most part, the anomalous propagation was not continuous over the flight path and the resulting record of field strength does not lend itself to analysis. Fig. 7 is an example of such a record. Of particular interest in Fig. 7 is the signal strength in the region between check points 1 and 27 (on sheet 1). Although the distance to the transmitting antenna at check point 27 is 54 miles less than it is at check point 1, the signal strength is considerably less at check point 27 than at check point 1. Further, this increase of signal strength with increasing distance from the transmitting antenna is repeatable. Although only two flight runs were made over this path and both on the same day, the same type of phenomena was observed on other flight paths over periods of several weeks. In some cases, typical interference



VERY HIGH (LAYERED EARTH)
<1 MMHO / M
1 " "
2 " "
4 " "
172
168
164
160
156
152
148
144
140

Fig. 6.

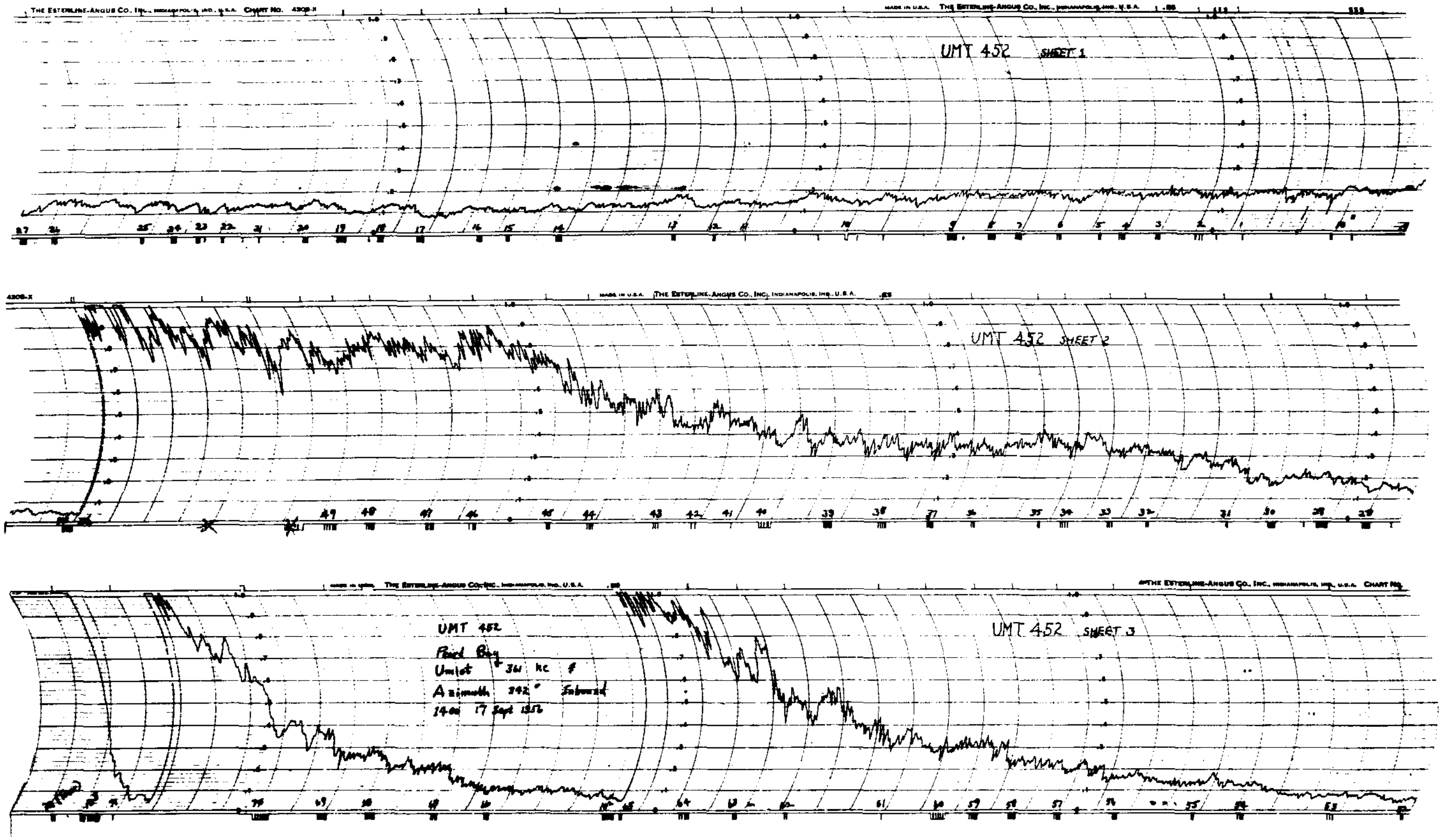


Fig. 7. Flight run UMT 452 showing increase of signal with distance between check points 27 and 1.

phenomena has been observed. Fig. 8 is an example of interference of this type. It is assumed that sky wave propagation is responsible for this pattern. It should be noted that this flight was made at 2045. The previous flight made at 1915 shows only small amounts of interference pattern, while flights made near 1200 show no evidence of sky wave propagation.

No serious attempt has been made to investigate either of the above observations. The first of them does not appear to lend itself to analysis by a two-layered earth theory. Although the magnitude of the surface wave attenuation factor may be greater than unity, it does not appear to increase at such a rate as to allow for an increase in the magnitude of the surface wave. An increase in the postulated number of layers might allow for an increase of signal strength with distance but such a solution appears to be greatly contrived and was not attempted. In the case of the apparent sky wave interference, no attempt was made to compute the height or nature of the layer contributing to the interference as such an investigation appeared to be outside the scope ot the contract.

In addition to the above observations, the data also contain information concerning the signal strength as a function of distance and elevation above a discontinuity on the surface of the ground. These discontinuities may be either large or small with respect to a wavelength. There is also information inherent in the data concerning the effect of rough or smooth terrain on the surface wave.

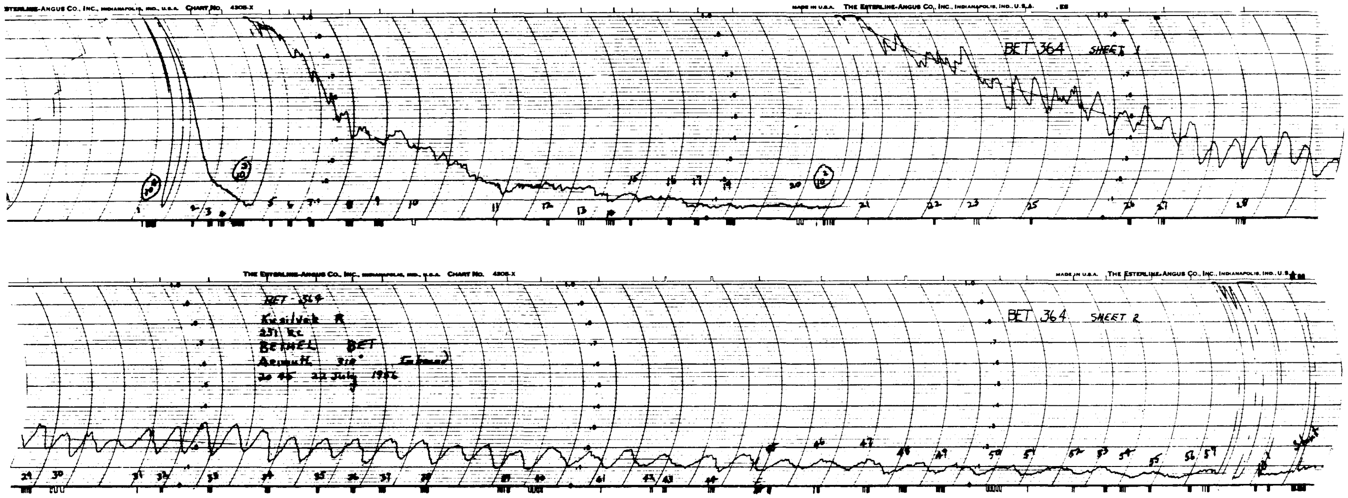
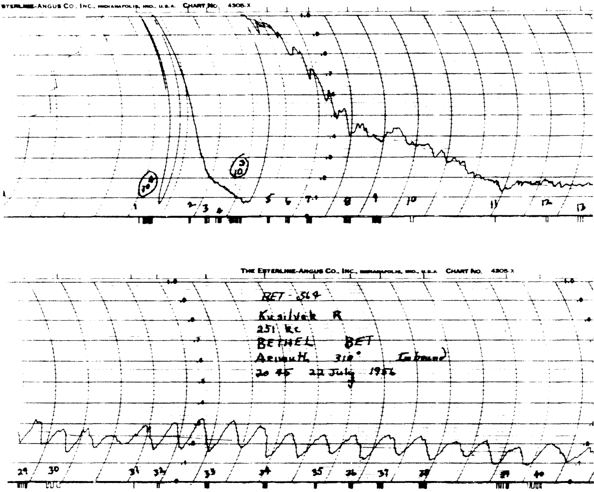


Fig. 8. Flight run BET 364 showing sky wave interference.



BET - 364
Kusilvak R
251 kc
BETHEL BET
Azimuth 310° Inbound
20 45 22 July 1956

Fig. 8. Flight run BET

3. Wave Tilt Method

During previous contracts, several unsuccessful attempts were made to use the 'Wave Tilt' method of determining the ground conductivity in this frequency region. In general, the wave tilt method depends on determining the forward tilt of the vertically polarized surface wave. More exactly, the wave tilt may be defined as the ratio of the horizontal component to the vertical component of the surface wave in the air and at the ground. A measure of this ratio may be determined by measurement of the apparent forward tilt of this wave in the plane of propagation, a ratio of the minimum to maximum signal in the plane of propagation, or by the ratio of the horizontal to the vertical component(5,8,9,11). It is thought that instrumentation was the main source of difficulty in our previous attempts to measure the tilt angle. These difficulties led us to abandon the wave tilt method as a means of determining the effective conductivity of Alaska.

A device, the "Ground Constants Measuring Set", has been developed by the Kollsman Instrument Corporation of Elmhurst, New York, (under Signal Corps Contract No. DA-36-039-SC-42709). This device is designed to determine the ground conductivity and dielectric constant in the region from 100 kc to 30 Mc. Details of construction of this instrument are given in the Final Technical Report, Ground Constants Measuring Set, October 30, 1954, File No. 13331-PH-53-91(4106) Contract No. DA-36-039-SC-42709, Kollsman Instrument Corporation, Elmhurst, New York.

Arrangements were made with the Radio Communications Branch, Coles Signal Laboratory, Red Bank, New Jersey to obtain the use of the Ground Constants Measuring Set for the project. Unfortunately, it was not possible to make use of the equipment until rather late in the year. Thus, the number of measurements that it was possible to make with the equipment was limited. The tests were to serve two purposes. The first was to compare the value of effective conductivity obtained with the Ground Constants Measuring Set with that obtained by the Attenuation method. The second was to test the practicality of Ground Constants Measuring Set under field conditions in Alaska.

Nine sites were chosen for the measurements. Four of these were in the vicinity of Bettles and were accessable only by air and boat. The remaining five sites were in the Point Barrow vicinity and accessable by air and tracked vehicles (in this case an Army 'Weasel'). Measurement of the magnitude of the vertical and horizontal components of the vertically polarized wave, the wave tilt, and the magnitude of the maximum and the minimum signal in the plane of propagation were made at each site. As the rotating antenna was mounted on the top of a long column which in turn was mounted on a large ball and socket joint, the column was leveled after each set of readings. Further, the antenna was rotated 180 degrees and readings of theta, the tilt angle, were made in each position, thus, each set of readings may be considered as an independent observation.

It was determined that the accuracy with which the tilt angle could be determined by use of the Ground Constants Measuring Set was of such a nature that no gross errors in determination of the conductivity would result from inherent inaccuracies of the instrument. It was also determined that the column of the instrument was misaligned in the vertical plane. This misalignment resulted in the loss of the data concerning the ratio of the horizontal to the vertical field. However, it was still possible to compute the tilt angle, theta, and the ratio of the maximum to the minimum signal in the plane of propagation so that it was possible to determine the ground conductivity in the vicinty of the sites tested.

The table below shows the values of ground conductivity obtained by the set.

Location		ground conductivity determined by ratio E_{hor}/E_{ver}	ground conductivity determined by tilt angle
Bettles Village	#1	1.5 mmho/m	0.9 mmho/m
Bettles Village	#2	1.5 mmho/m	0.8 mmho/m
Bettles Field	#1	1.7 mmho/m	0.9 mmho/m
Malemute	#1	2.2 mmho/m	0.9 mmho/m
Pt. Barrow	#1	50 mmho/m	9.7 mmho/m
Pt. Barrow	#2A	32 mmho/m	17 mmho/m
Pt. Barrow	#2B	35 mmho/m	17 mmho/m
Pt. Barrow	#3A	27 mmho/m	44 mmho/m
Pt. Barrow	#3B	27 mmho/m	30 mmho/m

It is notable that the first four sets of measurements (in the vicinity of Bettles) are in good agreement with the values obtained in the same region by the attenuation methods. The values obtained in the vicinity of Point Barrow are considerably higher than those obtained near Bettles. It should be noted the sites near Point Barrow are underlain with permafrost to great depths and should not give high values of conductivity. In addition, the results in the vicinity of Point Barrow do not agree as well with those obtained by the attenuation method as do those near Bettles. It is felt that an analysis of these measurements in terms of a layered earth might resolve this problem.

In addition to the use of the instrument for the determination of ground conductivity, a purpose of the investigation was to determine the feasibility of the Ground Constants Measuring Set as an instrument for use in remote areas.

The instrument seemed to be well designed. It did not malfunction during our use of it. It is true that the use was limited but the conditions were somewhat severe. The equipment was carried in truck, DC3 aircraft, Alaska riverboat (approx. 30 ft. long), by army jeep and military weasel. The temperatures during our use of the equipment ranged from 10° to 60°F. Also, the equipment was set up on sand, in water, on tundra and in snow. The instrument had been shaken loose from it's mounts in transit to Alaska, however, no damage was found. Batteries were not shipped with the equipment and an attempt to obtain replacements consumed several weeks. In desperation, batteries were mounted externally. With these external batteries, a considerable amount of backlash in the antenna drive mechanism was noted. Without the external batteries, this backlash was very much reduced. The column was difficult to level accurately. It is suggested that the leveling system should have long indexed bubbles and that they be attached directly to the column rather than to the base. It was also noted that the single carrying case with the instrument in it was a difficult load for two men over good terrain and would have been very difficult over rough terrain. It is suggested that it might be possible to design an auxiliary carrying case for the equipment for use over rough terrain. Perhaps the equipment could be broken into two 'one man pack' loads.

Other than the above noted items the equipment seemed to work well and should be very satisfactory for determining the values for which it was designed. It should be noted that it would be necessary to obtain a suitable source of signal in remote areas; a serious problem in Alaska where no suitable signal was available in some regions.

4. Other Methods

Although the primary effort was directed at determining the effective ground conductivity by the attenuation method and an investigation of the Ground Constants Measuring Set, preliminary investigations of two other possible methods of determining the ground conductivity were tried. Neither of these methods showed immediate results and efforts to perfect them for use on this project were abandoned rather quickly.

The first of these methods is the determination of the height-gain function. The height-gain function for a homogeneous earth is discussed by Norton and for a layered earth by Wait.(6, 11) Specifically the height-gain function relates the signal strength of the surface wave to antenna heights. For certain conditions the relationship between a two-layered ground and the field strength above, it is simplified and the height-gain function as measured may be compared to theoretical curves.

Three attempts were made to obtain data from which the height-gain function might be determined. In each case weather difficulties made the results of doubtful value.

A somewhat more extensive program was instigated to attempt to determine the effective conductivity by use of the mutual coupling of loops. A theoretical treatment of the problem by Wait shows that the dielectric constant and the conductivity may be determined by an investigation of the mutual impedance of two loops near the surface of the ground.(14) The mutual impedance is a function of the dielectric constant, the conductivity, the frequency, the separation, and the position of the loops. Two methods of investigation are suggested. The first of these is to measure the induced voltage in one of the loops as a function of the frequency of the driving signal in the other loops for a given loop configuration. The other method is to measure the induced voltage in the second loop as a function of the spacing between the loops for a constant frequency.

The second of these methods was chosen for investigation as it appeared that the loading of the loops might pose a serious problem. Experiments were conducted near 4 Mc and between 200 and 400 kc in the vicinity of Fairbanks. Interpretation of the results of these measurements was not satisfactory, as they did not match the theoretical curves. The experiment was then abandoned.

PART II

A. CONCLUSIONS

1. General

Relative field strength measurements have been made over most of the mainland of Alaska at frequencies of from 200 to 400 kc. These relative field strength measurements have been used to construct a map showing the effective conductivity of Alaska. As it was necessary to extrapolate over rather large region, some inaccuracies will appear in the map. The attenuation method does not allow for determination of the effective conductivity over mountainous terrain nor for short distances. It would appear that the use of auxiliary equipment such as the Ground Constants Measuring Set or similar device would be necessary to make measurements in these areas.

2. Anomalous Propagation

In several instances anomalous propagation was found. It was particularly apparent in the vicinity of mountainous terrain and near the coastal regions. Some of the anomalous propagation, especially that in the Point Barrow area, may be explained in terms of layered earth propagation. The vast majority of instances, however, do not lend themselves to a simple explanation. It is suggested that the data obtained under this project would be suitable for continuing a study to investigate several of the anomalous propagation events.

3. Other Methods of Determining the Conductivity

Over the entire period of the investigation, several methods of determining the conductivity were tried. Among these were testing soil samples in the laboratory, determining the mutual coupling of loops and measurement of the height-gain function. As previously reported, it is felt that the determination of the conductivity of a soil sample in the laboratory does not accurately reflect the conductivity of the ground. The method should have application in determining the effect of frozen ground and of the water content of the ground. The mutual coupling of loops might have application in the determination of the conductivity of a small area. However, a considerable amount of work needs to be done before the technique may be considered practical. The height-gain function would appear to have rather great significance in the determination of the effective conductivity of a layered earth. It is suggested that the investigation of the height-gain function as applied to the anomalous propagation in the vicinity of Point Barrow be extended.

APPENDIX I

LAYERED EARTH PROPAGATION IN THE VICINITY OF POINT BARROW, ALASKA

Glenn M. Stanley

For several years, studies of effective ground conductivities in the Territory of Alaska have been in progress by the Geophysical Institute at the University of Alaska. The project has been carried on under the auspices of Buships US Navy and an Arctic Institute of North America Research Grant. The data used in this paper were gathered under a Buships contract administered by the Signal Corps.

The relative field strength, as a function of distance from the transmitting antenna, was measured along several radials from each of 25 Civil Aeronautics Administration radio ranges and beacons in the Territory of Alaska. These ranges and beacons operate in the frequency range of from 200 kc to 400 kc. The measurements were made from a low-flying aircraft equipped with a sensitive receiver, an Esterline-Angus recorder, and a nearly vertical trailing wire antenna. The effective ground conductivity is obtained by a comparison of the experimental relative field strength values with families of theoretical curves obtained by Norton's method. From this comparison, the value of conductivity that best fits the experimental data is taken as the value of effective conductivity over the path. The method and the results were discussed in a paper presented before the National Convention of The Institute of Radio Engineers in New York in 1955.

Signals were recorded continuously along radii from the transmitting antennas for distances up to 120 miles. Check points along the flight paths were obtained from U.S.G.S. 1:250,000 topographical contour maps. The aircraft used was equipped with a gyrocompass,and constant course checks were made with maps. In most instances, deviations from the radial course were less than a few hundred feet.

As all signals were recorded along radii from the transmitting antenna, no corrections were necessary for assymetrical transmitting and receiving antennas. At a distance of approximately 30 wavelengths, no appreciable change in the signal level was apparent in a 1/2 mile horizontal deviation from the radial flight path. In addition, no appreciable changes in the signal levels were noted for changes of a few hundred feet in elevation at the same distance. The elevation of the receiving antenna, however, was kept to within 400 feet of the local terrain (and in general, was nearer to 200 feet) to reduce the effect of interference between the direct and the reflected signal.

Relative field strengths were used throughout the computations of effective conductivity and no attempt was made to measure absolute field strength.

Measurements made in the vicinity of Point Barrow, Alaska, showed that the signals did not attenuate as rapidly as might have been expected for a region known to be underlain with permafrost to depths of 500 to 1,000 feet. Flight runs were made from Point Barrow in June and again in August. With one exception, the signal strength decreased less rapidly than predicted by the theory of a plane homogeneous earth for an infinitely conducting ground.

To make clear the implications of this anomaly, it is appropriate to review briefly the theory underlying the experimental measurements. The surface wave field strength at short distances is given by the relation

$$E = \frac{2E_o \left|F_e\right|}{\rho}, \qquad (1)$$

where E_o = the free space field strength,

ρ = the distance from the transmitting antenna to the receiving antenna and

$\left|F_e\right|$ = the surface wave attenuation factor;

provided the antennas are very near the ground and that

$$O(2\lambda) < \rho < \frac{50}{f^{1/3}_{mc}} \text{ miles} \qquad (2)$$

The surface wave attenuation factor may be obtained by methods given by Norton.(1)

Taking the ratio of the relative field strengths at two points at distance ρ_n and ρ_x respectively, from the transmitting antenna, where ρ_n is greater than ρ_x, it may be seen that

$$\frac{E_n}{E_x} = \frac{\left|F_e\right|_n \rho_x}{\left|F_e\right|_x \rho_n}. \qquad (3)$$

Using this relation a relative field strength curve may be drawn from any convenient initial point. Each set of values of ground constants will give one such curve. Fig. 1 shows a family of these curves for f = 236 kc, $\epsilon = 5\,\epsilon_o$ and an initial point of 2.3 miles from the transmitting antenna.

The surface wave attenuation factor F_e is given by

$$F_e = 1-i(\pi p_e)^{1/2} e^{-p_e} \operatorname{erfc}(ip_e^{1/2}) , \qquad (4)$$

where p_e is the effective numerical distance and is given by

$$p_e = |p_e| e^{ib} . \qquad (5)$$

Assuming a homogeneous earth, b is negative and $|F_e|$ is less than unity. However, Wait has shown that(for certain conditions of horizontally stratified media) b may be positive and $|F_e|$ greater than unity $^{(2,3,4)}$. Wait presents tables of $|F_e|$ as a function of $|p_e|$ for positive values of b to +75 degrees and for negative values of b to -90 degrees. The negative values were obtained using the results of Norton. $|p_e|$ can be computed in terms of the impedance of the surface of the top layer looking normally downward. The impedance of the top layer is related to the impedance of each succeeding lower layer by a recurrence equation. For a two-layer earth, where $\sigma_2 \gg \sigma_1$, and h_1 is not too small,

$$|p_e| = \frac{\pi \rho \mu \omega}{(120\ )^2 \lambda_o \sigma_1} (A^2 + B^2) ; \qquad (6)$$

$$b = \tan^{-1}\left(\frac{2\ AB}{A^2 - B^2}\right) ; \qquad (7)$$

where

$$A = \frac{\tanh w \sec^2 w}{1 + \tanh^2 w \tan^2 w} \quad ; \qquad (8)$$

$$B = \frac{\tan w \operatorname{sech}^2 w}{1 + \tanh^2 w \tan^2 w} \quad ; \qquad (9)$$

and

$$w = \frac{(\sigma_1 \mu \omega)^{1/2} h_1}{\sqrt{2}} \qquad (10)$$

From these relations the effective numerical distance $|p_e|$, and the phase angle b, may be obtained for a given frequency, a given thickness and conductivity of the upper layer. When $|p_e|$ and b are known, the surface wave attenuation factor $|F_e|$ can be determined. Since $|F_e|$ is the only unknown entering the equation for the relative field strength, curves may then be drawn for different values of the parameters σ_1 and h_1. Fig. 2 shows curves of relative field strength for some values of h_1 taking σ_1 to be constant and equal to 10 mmho/m.

Returning to the experimental values of relative field strength obtained near Point Barrow, an attempt is made to explain the low attenuation of the signals in terms of layered earth propagation.

The existence of highly conducting saline layers or lenses at depths of from 10 to 100 feet in the immediate vicinity of Point Barrow is deduced from test wells driven by the Arctic Contractors during the course of their work on US Navy Petroleum Reserve #4. The extent and exact nature of these layers or lenses is not known. However, relative field strength measurements indicate that the propagation characteristics change markedly at distances of from 60 to 100 miles southward from Point Barrow. In addition, there is visual evidence of an abandoned beach line at about this same location. Mr. Max Brewer, of the Arctic Research Laboratory at Point Barrow reports that the salinity of these layers near Point Barrow is equal to, or greater than that of sea water.

Fig. 3 shows flight runs 93-95 made in June 1954. The vertical lines depict the spread of the three runs while the circles represent average values. Other flight runs in the vicinity have shown similar conditions of anomalous propagation.

Thus, it is reasonable to approximate the ground in the vicinity of Point Barrow by a two layer ground. The conductivity of the lower layer has been assumed to be equal to that of sea water (5000 mmho/m). Several families of relative field strength curves were drawn for different values of the conductivity of the upper layer σ_1, and for different thicknesses of the upper layer h_1. The thickness of the lower layer was assumed to be semi-infinite. Fig. 4 shows the average values obtained from flight runs 89-92 and 202-205 superimposed on the relative field strength curves for σ_1 equal to 10 mmho/m. The comparison of the experimental curve with the theoretical curves suggests that the apparent thickness of the upper layer h_1 is equal to approximately 9 meters.

Flight runs 93-95 and 197-199, which were about 30 degrees to the East, and flight runs 193-196, approximately 30 degrees to the West of those shown in Fig. 2, have similar characteristics. In contrast, flight runs 85-88, show a very high signal level. No combination of ground constants that has been tried will produce a relative field strength curve which matches the experimental curve corresponding to this high signal level.

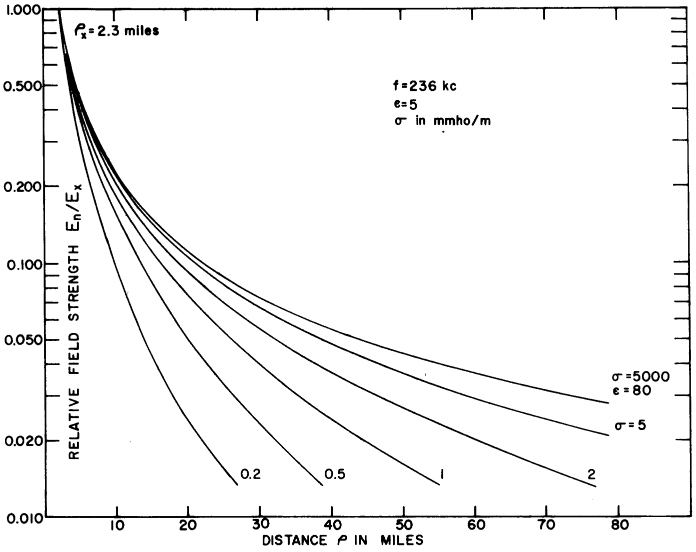


FIG. 1

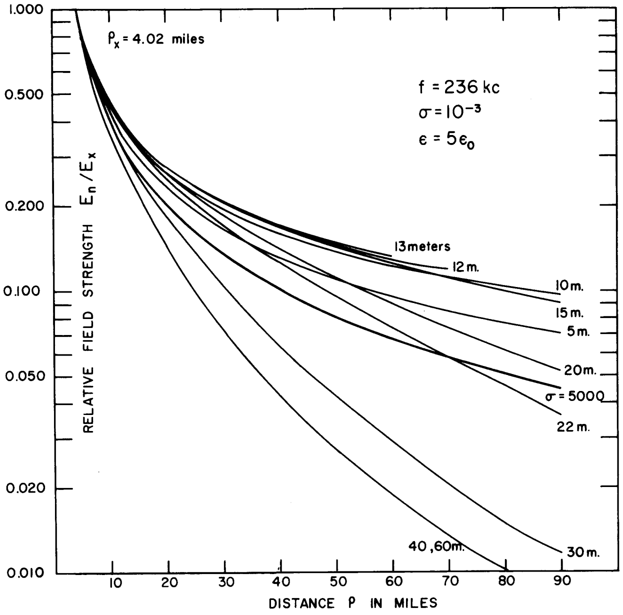


FIG. 2

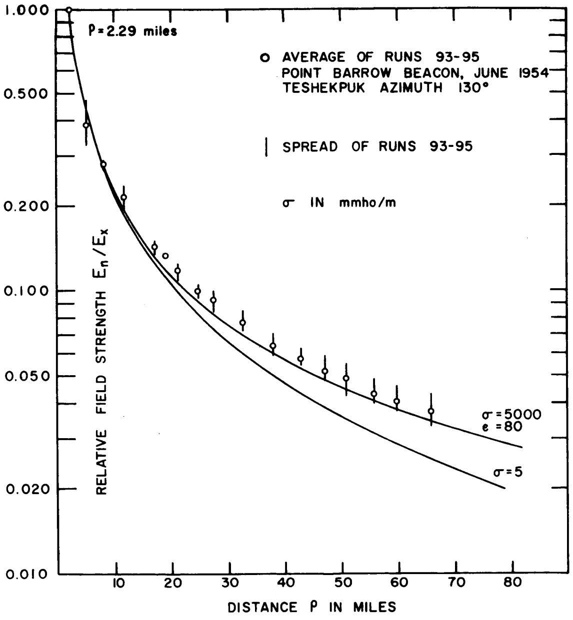


FIG. 3

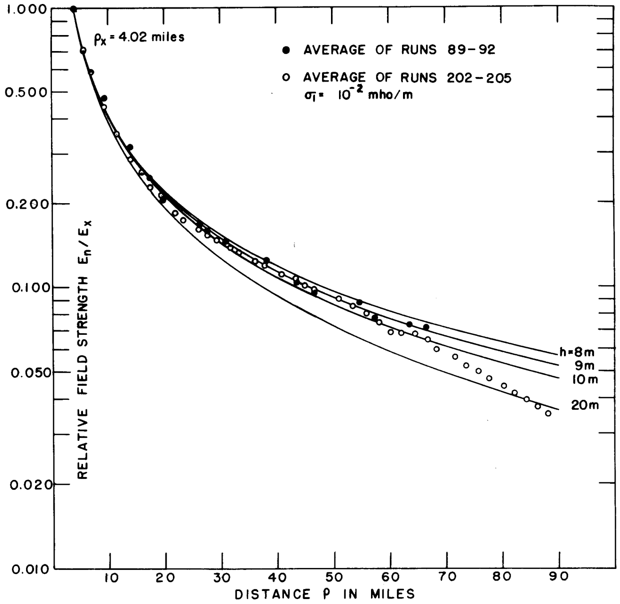


FIG. 4

The analysis of these data indicates, that at a frequency of 236 kc, there is, indeed, layered earth propagation in the vicinity of Point Barrow, Alaska. The analysis further suggests that the ground conductivity of the upper 9 meters is approximately 10 mmho/m, when measured by the method outlined.

The area of measurement which encompasses most of the Arctic Slope is essentially flat and free from man-made interference such as fences, railroads, powerlines, and other sources of disturbance. It therefore appears that this area would provide an excellent test site for various low frequency propagation studies.

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