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A Propagation of Ten Meter Radio Waves By Vertical and By Horizontal Dipole Antennas

James William Haddock
Fort Hays Kansas State College

The Propagation of Ten Meter Radio Waves
by Vertical and by Horizontal Dipole Antennas

being

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the requirement for the Degree of Master of Science.

by

James William Haddock, B. S. in Educ.
Kansas State Teachers College of Hays

Approved Harvey A. Zinszer
Major Professor

Date July 28, 1939.

H B Streeter
Acting Chairman of Graduate Council

Acknowledgements

I wish to express deep graditude to Dr. Harvey A. Zinszer, Professor of Physics and of Astronomy of the Fort Hays Kansas State College, for suggesting the problem and for continued interest and assistance during the course of the research; to the hundreds of radio amateur operators through-out the world who co-operated with me in obtaining the necessary data in this research and who furnished much valuable advice; and to Dr. E. F. Carpentar of the Stewart Observatory at the University of Arizona for his valuable advice and criticism of the results obtained.

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HISTORICAL INTRODUCTION

In 1888 Heinrich Hertz conducted experiments which showed his newly discovered rays obeyed the laws developed by Maxwell[1] for electromagnetic waves; that these rays could be reflected[2], refracted[3], and polarized[4] by methods similar to the procedure used in the field of optics. Their wavelengths were measured[5] and found to range from 24 cm to several hundred cm. The velocity of the radiations was measured and found to be near that of light. The practical minded Guglielmo Marconi continued the experiments and astounded the world by proving that messages could be sent between distant points without wires, even across the Atlantic ocean. He was able to transmit over these great distances by employing high power, long radio waves, his newly developed magnetic detector, and the Marconi type antenna.

Five years previous to Hertz's work, Edison discovered his famous effect — a phenomenon taking place inside an incandescent lamp. He observed that an electric current could be made to pass through the space between a heated filament and an

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[1]Maxwell, James Clark. A Dynamical theory of electromagnetic field, Philosophical Transactions, Vol. 155, p.459, 1865.
[2]Hertz, Heinrich. Electric Waves, London, Macmillan & Co. p. 179, 1900.
[3]loc. cit. p. 181.
[4]loc. cit. p. 177.
[5]loc. cit. p. 121.

adjacent cold plate. This discovery was considered of no importance until in 1904 when Flemming, while a student listening to a lecture on the Edison effect, conceived the idea of the electric valve. As a detector the Flemming valve was far superior to anything that had been used before, and it is still used in the modern receiver. In 1906 De Forest introduced the grid as the third element of the radio tube, making the modern superheterodyne receiver possible and producing the triode oscillator that made modern broadcasting practical.

When Marconi sent the first wireless signals across the Atlantic ocean on December 12th. 1901, and proved that radio waves could bend around the earth, scientists began searching for an explanation for the new phenomenon. Working independently and almost simultaneously, the answer had been given by Kennelly and by Heaviside in 1900. Their theory[6] was that layers of ionized gases high up in the earth's atmosphere could reflect radio waves back down to the earth's surface. The parts of the atmosphere reflecting these radiations has become known as the ionosphere. Within the last few years considerable attention has been given this region of the atmosphere and now the Government broadcasts[7] ionospheric data over WWV every Wednesday. It is hoped that knowledge gained in this field may soon be applied to weather forecasting over long periods of time.

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[6]Conklin, E. H., New Ionosphere broadcasts. Radio, Oct. 1937. p. 26 - 29.
[7]loc. cit. p. 26.

For a quarter of a century after the first trans-Atlantic radio signals, radio engineers thought that reliable long distance radio communication depended upon the use of longer waves and more power. These engineers began to realize that they had overlooked something when, in 1923, radio amateurs began to work across the Atlantic on 110 meters. Allured by this success, new transmitters were built to work on higher frequencies and soon the amateurs of the United States began to work New Zealand, Australia, and South Africa. All this was done on 40 meters, and using a hundred watts or so of power. By 1924 the commerical companies, realizing the importance of these new developments, began the construction of many new transmitters to operate in the 100-meter region on frequencies hereforeto considered worthless. Soon the amateurs were experimenting with 20-meter waves, and now they have just opened up the 10-meter region and are employing rotary beam antennas. This year (1939) they hope to establish new 5-meter records. There are amateurs who believe that a better knowledge of the ionosphere will make such records possible, and long distant communication not unusual.

THEORY

Radio communication is made possible by means of energy that travels through space from the transmitter to the receiver in the form of electromagnetic waves. These waves move with the velocity of light and differ from visible light only in wave length or frequency. This radiant energy consists of a magnetic field and of an electrostatic field, at right angles to each other and also at right angles to the direction of propagation. The relation of radio waves to the remainder of the electromagnetic spectrum is shown in the table[8] below —

Radio waves - - - -	$2x10^{4}$ to .1 meter
Infra-red or heat waves - - -	$1x10^{-5}$,,
Light waves - - - - -	$5x10^{-7}$,,
Ultra-violet waves - - -	$3x10^{-8}$,,
X-Rays - - - - - - -	$1x10^{-10}$,,
Gamma rays - - - - -	$1x10^{-12}$,,
Cosmic rays - - - - -	$1x10^{-14}$,,

Radio waves are divided into five classes[9]. Low frequency waves over 3,000 meters long having low attenuation at all

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[8]Terman, Frederick E., Fundamentals of Radio. New York, McGraw-Hill Book Company, 1933. p. 1.
[9]loc. cit., p. 3.

times of day and of year; medium frequency waves with lengths from 3,000 down to 200 meters with attenuation low at night and high in the daytime and greater in summer than in winter; medium high frequency wave with lengths from 50 - 200 meters having low attenunation at night and moderate loses in the daytime; high frequency from 10 - 50 meters whose transmission depends solely upon the ionosphere and so varies greatly with the time of day and with the season; and the very high frequencies below 10 meters that travel in straight lines and are not reflected by the ionosphere.

The ionosphere, the upper part of the earth's atmosphere, is thought to consist of at least four separate layers[10] of ionized gases. Of the first two layers closest to the earth very little is known. The third layer called the E layer is about sixty miles above the earth and reflects radio broadcast signals back to the earth. The fourth layer or F region divides into two layers known as F_1 and F_2, the former being lower than the latter. The higher F_2 is more heavily ionized than either the E or the F_1 layer, and as a result it is the most important layer in high frequency transmission since signals of high enough frequency to penetrate the less ionized E and F_1 layers may still be returned to the earth by the heavily ionized F_2 layer. At certain times of the year and of the day the E layer may become heavily ionized and reflect five meter waves

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[10] Selvidge, Harner., Characteristics of sky-wave transmission. QST vol. 22, Oct. 1938. p. 32-35.

back to the earth[11]. This has made it possible for amateurs to span the Atlantic ocean, and for the east coast to work the west coast.

A straight wire one-half wave-length long receiving its energy in the center through an untuned transmission line, is known as a half-wave dipole antenna[12]. Such an antenna when placed vertically with respect to the surface of the earth, transmits vertically polarized radio waves in every direction. When mounted horizontally, the waves are horizontally polarized in any horizontal direction perpendicular to the antenna, while it is vertically polarized in the direction of the wire. In any intermediate direction the waves will have both vertically and horizontally polarized components, a state called elliptical polarization.

When a light ray which is a form of electromagnetic radiation strikes a smooth surface at a large angle of incidence, the reflected ray is found to be polarized. Short-wave radio communication at distances far beyond the horizon is made possible by reflection of radio waves by ionized layers within the ionosphere. The angle of incidence at which these radio waves strike the reflecting layers of ionized gases is large — a condition necessary for the polarization of electromagnetic radiations. If such a condition would produce polarization of radio waves, the amount of reflected energy would depend upon the angle of polarization of the

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[11] Selvidge, Harner., Characteristics of sky-wave transmission. QST vol. 22, Oct. 1938. p. 92.

[12] Henney, Keith., The Radio engineering handbook. McGraw-Hill Book Company, New York. 1935. p. 768.

incident wave. Therefore, the following questions arise —

1. Is there a relation between the amount of reflected radio energy and the angle of polarization.

2. If so, which form of radio wave will be reflected to a greater degree.

3. Is there any relation between the angle of polarization of the transmitted signal, and the received signal strength at various distances.

4. Is there any relation between the angle of polarization of the transmitted signal, and the received signal strength at various times of the day.

5. Is there any relation between the angle of polarization of the transmitted signal, and the received signal strength at different seasons of the year.

The answers to these questions have been found with the aid of hundreds of radio amateurs on four continents who, having adequate signal-strength measuring equipment, have furnished the quantitative data used in this research.

The frequencies to be used, the ionized layer or layers that will return the waves to the earth, and the type of antenna to be used are the main factors involved in this problem. As the frequency of radio radiation is increased, the strength of the received signal depends more and more upon the ionized layers until a certain critical frequency is reached. Beyond this frequency the waves do not return to the earth. The fre-

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quencies used were 28,707 kc and 29,200 kc. These frequencies, between the high frequency and the very high frequency region of the radio portion of the electromagnetic spectrum, are about as high as can be used and still have the waves return to the earth. The ionized layers[13] returning these frequencies are the F_2, and in case of the transmissions under 1000 miles, the E layer. After a carefull study of antenna theory, dipole half-wave antennas were chosen as the most appropriate[14] radiators for this investigation.

There has been little work done in this field. What has been done is the work of radio engineers employed by the large communication companies. Radio amateurs are continually discussing these questions but have done little in a scientific and in a quantitative way of finding their solutions. Trevor and Carter[15] have made a study of horizontally and of vertically polarized radio wave propagation over sea water a few feet above the surface. They found the propagation of horizontally polarized waves was extremely poor as compared with vertically polarized waves. In another case[16] when the antennas were located at a considerable height on the sides of two mountains, it was found that there was no marked differ-

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[13]Pierce, J. A., Interpreting 1938's 56-Megacycle DX. QST Vol. 22, Sept. 1938. p. 23-24.

[14]Smith, W. W., Choosing an antenna. The Radio antenna handbook, 2nd. Ed. Los Angeles, Radio, Ltd. 1938. p. 14-84.

[15]Trevor and Carter., Notes on propagation of waves below ten meter in length, Proc. I. R. E. March 1933.

[16]Beverage, Peterson and Hansell., Application of frequencies above 30,000 kilocycles to communicatio problems, Proc. I. R. E. August 1931.

ence between horizontally polarized and vertically polarized waves, even though the transmission path was mostly over sea water and the distance greater than the optical path. Engstrom and Burrill[17] have reported no advantage in one polarization over the other, but that there was slightly less noise on horizontally polarized antennas. Handel and Pfister[18] have shown that the penetration of very high frequency waves beyond the horizon is maimly due to both diffraction and to refraction. The refraction field shows strong variations and produces an effect similar to fading in short wave reception, whereas, the field intensities in the diffraction zone are very stable.

Ross Hull[19] has made studies of the refraction field and has shown that there is excellent correlation between signal intensity and temperature inversion. That is, when warm air masses exist above colder air masses near the ground the signals are refracted down to earth beyond the horizon by the warm air. Observations on 91,800 kc were made by B. Trevor and R. W. George[20]. The antenna was a simple half-wave dipole on the roof of the Continental Bank Building, New York City, 600 feet above the street level. The antenna was readily adjusted to radiate horizontal or vertical waves.

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[17] Engstrom and Burrill., Application of frequencies above 40 mc for television, RCA Review, Jan. 1937. p. 88-93.

[18] Paul V. Handel and Wolfgang Pfister., Ultra short-wave propagation along the curved Earth's surface. Hochfrequenztechnik Und Electroakustik, Vol. 47, No. 6, June 1936.

[19] Ross Hull, Air-mass conditions and the bending of ultra-high frequency waves, QST. June 1935. p. 13.

[20] Beverage, H. H., Some notes on ultra-high frequency propagation, RCA Review, Jan. 1937. p. 82.

There was apparently no consistent difference between the transmission characteristics of horizontally polarized waves and of vertically polarized waves over land. The paths of these waves were affected by diffraction and by refraction, but not by reflection from the ionosphere. In this problem, the questions were in regard to the amount of radio wave energy reflected by ionized layers within the ionosphere when the angle of polarization of the incidental wave was changed.

APPARATUS

The apparatus used in this problem may be divided into four divisions: First, the transmitter; Second, the antenna system; Third, electrically controlled antenna switch; and, Fourth, receivers equipped with R-meters. Each of the first three had to be so well made and so stable that no adjustments whatsoever would be necessary through-out the course of the research.

A transmitter to be operated on ten meters and licensed by the Federal Communication Commission must be possess stable frequency control, free of spurious radiations, and operated by a properly authorized person. The transmitter used (Fig. 1) was constructed for operation on 5, 10, 20 and 40 meters, crystal controlled, and plate modulated. The power input to the final class-C stage was 800 watts. The frequency and the modulation were monitored. The tube line-up in the radio frequency section was: 6A6 oscillator and doubler, RK49 doubler, a pair of T55's as drivers, and a pair of T125's in the final. The tube line-up in the modulator was; a 57 preamplifier, a 56 to a 56 to a 2A5 to a pair of 2A3's acting as class-A drivers to a pair of 203HD's operating class-B. The microphones used were a Uniplex crystal and an Americam dynamic microphone. The transmitter was located in the Science Department, room 20, of the Nogales High School, Nogales Arizona. The transmitter operated under the assigned call letters, W6KSO.

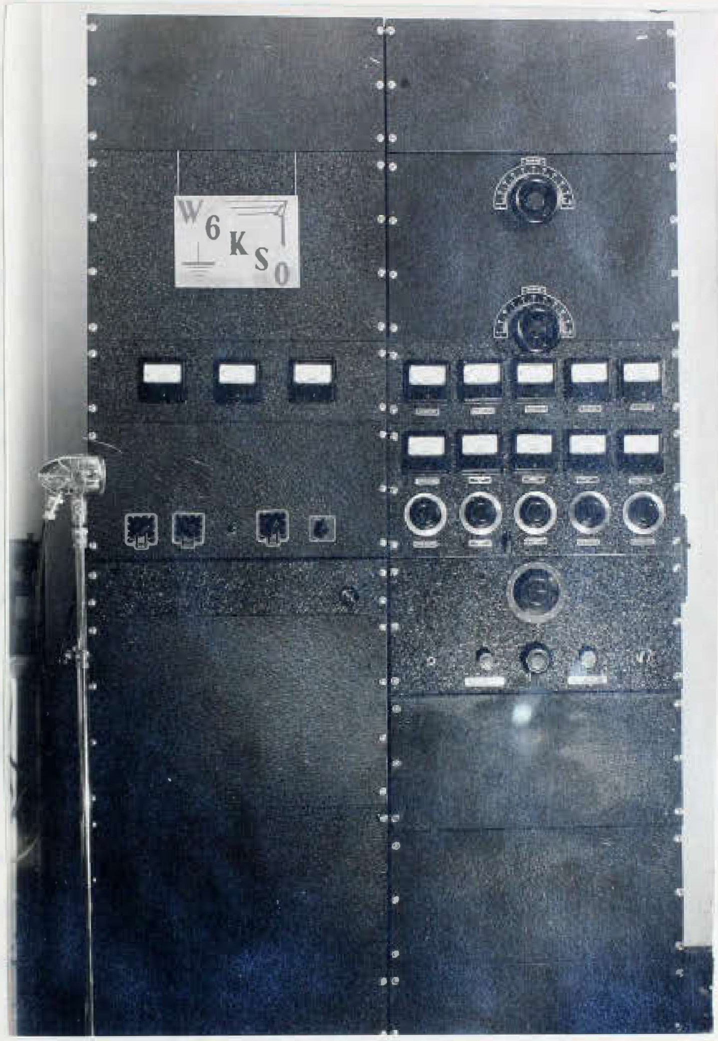

Figure 1. The complete transmitter used at W6KSO, Nogales, Arizona. The transmitter was specially built for operation on very high frequencies. The input to the final was 800 watts. The radio frequency amplifier is in the right hand section, and the speech amplifier and the modulator are in the left hand section.

The five antennas used were located on top of the Nogales High School building; two were dipole verticals, two were dipole horizontals, and one a Marconi type. The tops of the wooden towers were about 75 feet above the street, (Fig. 2) and 140 feet apart. To support the antennas two ropes were stretched parallel from tower to tower. The top rope supported the tops of the vertical antennas and the Marconi antenna. The second rope located about ten feet below (Fig. 3) the first, supported the horizontal antennas and the transmission lines to the vertical antennas. The bottom ends of the vertical antennas were fastened to the roof by short ropes.

The transmitter was located on the top floor near the center of the building, and in the Chemistry supply-room. An EO-1 cable connected the variable link of the Coto-Coil in the final tank coil to a double-pole double-throw relay on the roof. Two EO-1 cables connect the relay to a horizontal and to a vertical antenna. A switch on the control panel of the transmitter operates the relay switching from one antenna to the other so rapidly that the ear cannot tell that the carrier has been off the air. For receiving, a similar arrangement was used except that the relay was omitted and the switching was done by means of a double-pole double-throw switch located on the receiver. Part of the time two receivers were used, one receiver was connected to a vertical antenna (Fig. 4) and the other was connected to a horizontal antenna. The Marconi antenna was used for checking and for testing.

Figure 2. Towers and antennas used at W6KSO. Metallic objects were avoided as much as possible by using 40 foot wooden towers and ropes for suspending the antennas. The building faces the east.

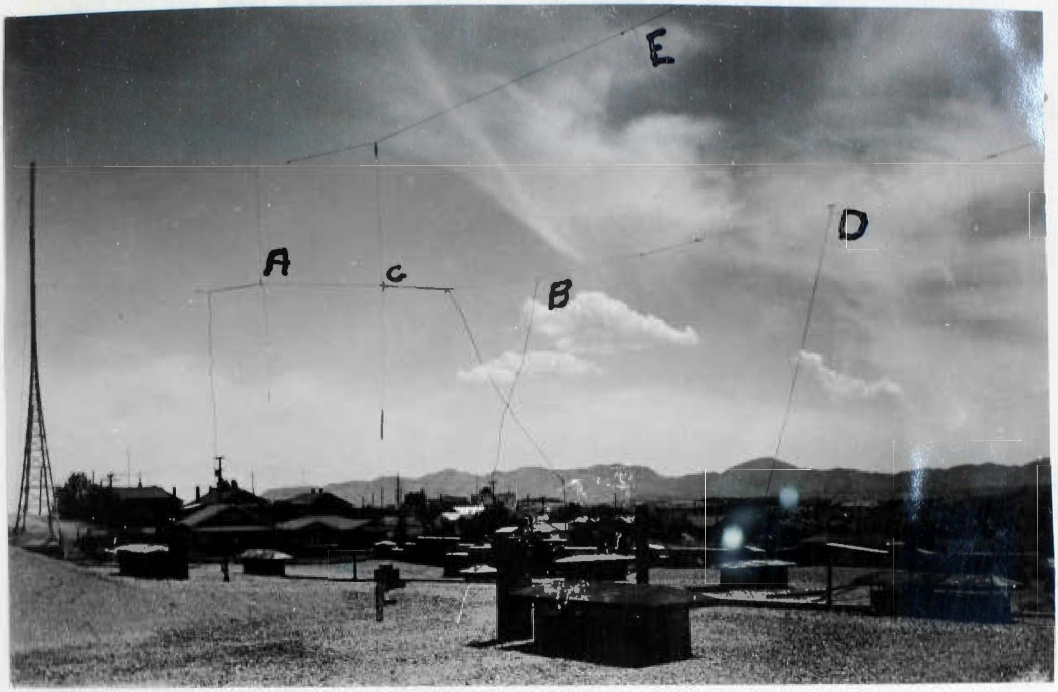

Figure 3. Antenna system on top of the high school building. The antennas were suspended between two ropes. (a) Transmitting vertical. (b) Transmitting horizontal. (c) Receiving vertical. (d) Receiving horizontal. (e) Marconi antenna. (f) Relay in ,,dog house''. The photograph was taken facing the north-east.

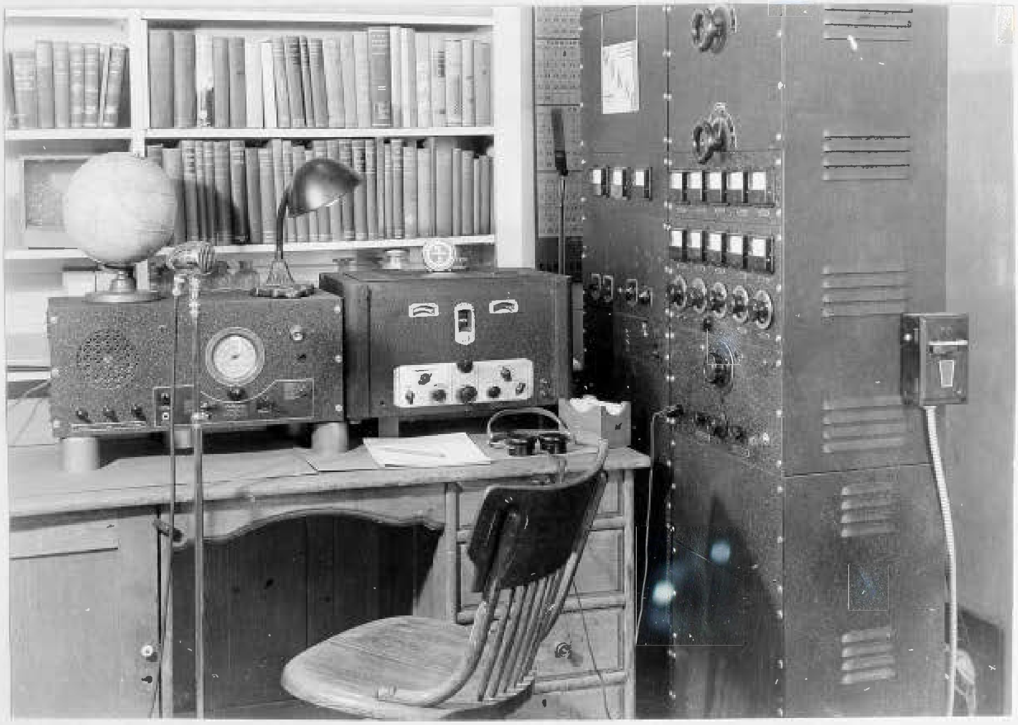

Figure 4. The receiving and the transmitting equipement used at W6KSO. The receiver on the right (Patterson PR-16) was connected to a vertical antenna and the one on the left was connected to the horizontal antenna. The control panel on the transmitter is at the right of the small card filing box.

The success of this problem depended upon the co-operation of the many amateurs who checked my signals and who gave me the three hundred seventy-five reports used in this research. Also, the fact that they possessed receivers equipped with signal-strength measuring meters, indicates the fine quality of apparatus found in many amateur radio stations.

A receiver to be used in quantitative work must be of the superhetrodyne class and equipped with a signal strength measuring device. Such a device (Fig. 5) is generally referred to as an R-meter, since it is calibrated in R's. Some receiver (Fig. 6) are also calibrated in decibels or db's. The meaning of the R-designations[21] are as follows —

R1 Faint signals, just audible.

R2 Weak signals, barely audible.

R3 Weak signals copiable. (in absence of any difficulty)

R4 Fair signals, readable.

R5 Moderately strong signals.

R6 Strong signals.

R7 Good strong signals.

R8 Very strong signals.

R9 Extremely strong signals.

The difference between one R and the next R is about 6 db's (Fig. 7) or a power gain of four.

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[21]Publication No. 7 of the American Radio Relay League, Fifth Ed. The American Radio Relay League, Inc., West Hartford, Conn.

Figure. 5. An R-meter. This meter was used by the Radio Mfg. Engineers, Inc., on their popular RME-69 model receiver. Above the R scale may be seen the decibel or db scale used as a standard in this investigation.

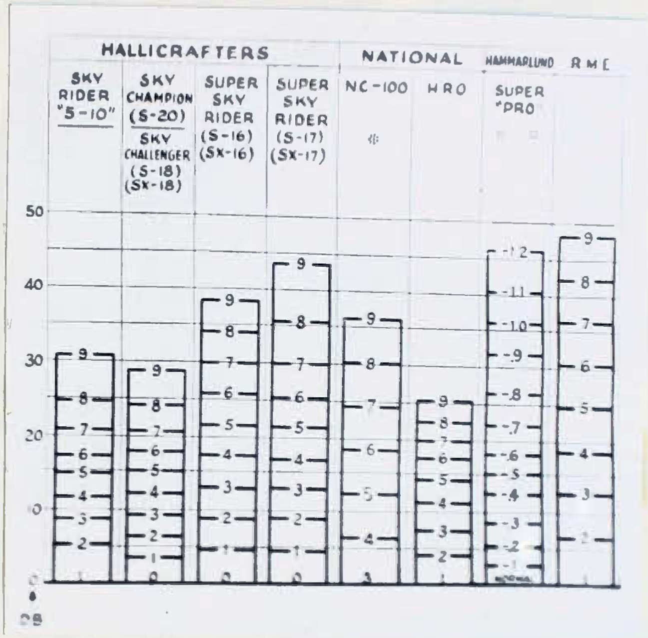

Figure 6. R-meter calibrations in terms of db's. The relation between R's and db's vary between different makes of receivers. The relation between these units used by the RME receivers was used in this investigation.

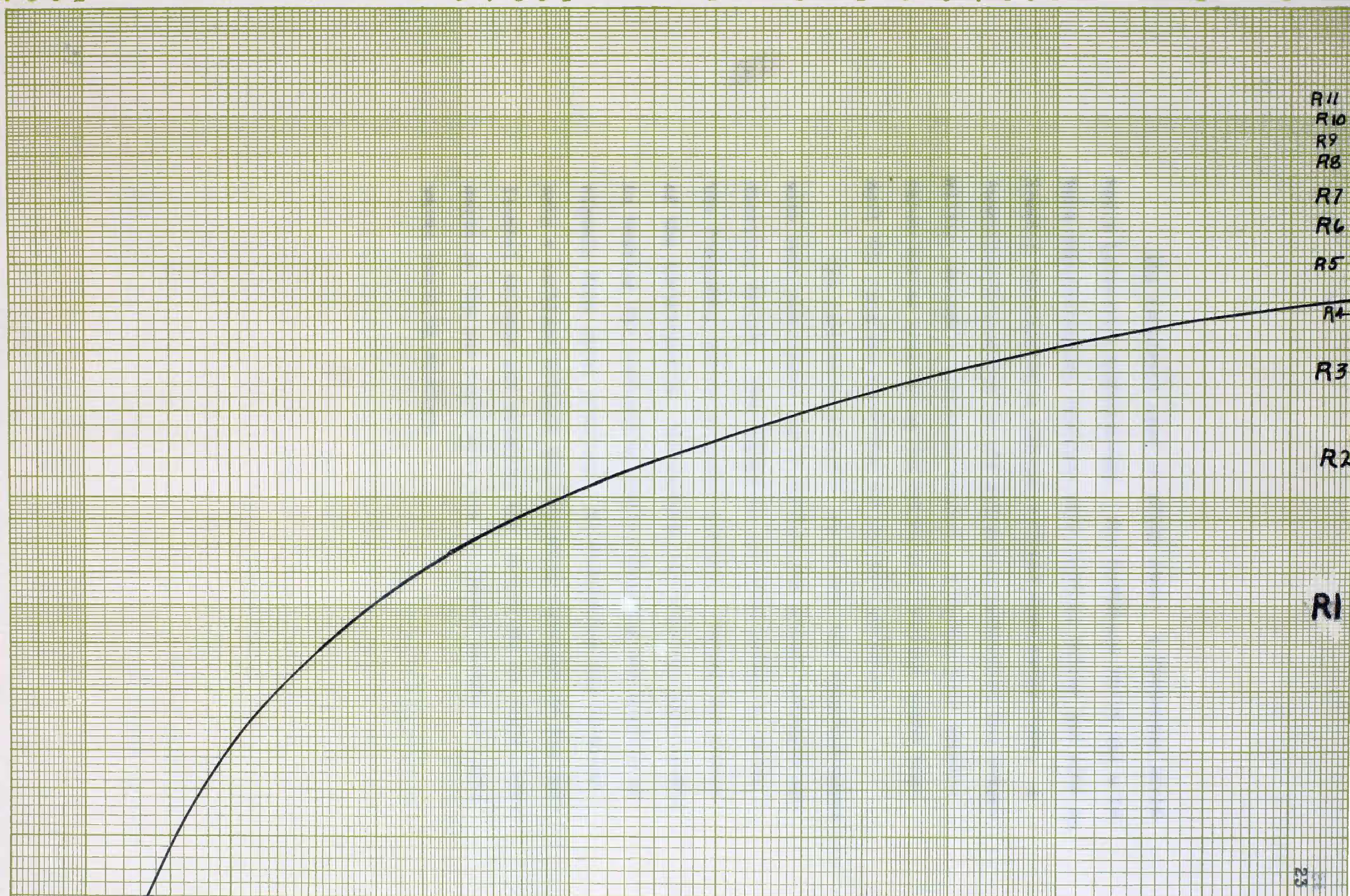

Figure 7. Ratio of Power Gain

The receivers used at W6KSO were; a Patterson PR-16 and a Lafayette Professional. The Patterson PR-16 was a 16 tube superhetrodyne equipped with crystal filter and with an R-meter operated by a special voltage amplifying tube. A communication switch on the Patterson controlled the transmitter through a system of relays. A double-pole double-throw switch mounted on the Patterson receiver would connect the receiver to either of the two antennas.

The Lafayette receiver was a ten tube superhetrodyne with beat oscillator and a cathode ray signal strength indicating device. The Lafayette was used mainly to check the frequency and as an audio monitor. During the course of the investigation, the cathode ray tube was very useful in testing the transmitter and in checking the quality of signals from other stations. By connecting one receiver onto a vertical antenna and the other receiver on the horizontal antenna and watching the variations in signal strength on the two receivers, the ellipical nature of radio waves could be studied.

Method of Procedure

When the transmitter had been assembled and tested, antennas connected and relays in working order, receivers connected, the collecting of the necessary data was started. The receiver would be switched on and while the filaments were warming up the power switch to the transmitter closed, transmitter filament switch closed, line voltage checked and Variac auto-transformer adjusted until the filament voltage was correct, key placed into the relay lock, and then attention would be turned back to the receiver which should be warmed up by this time. The communication switch on the receiver would be turned to reception and the setting of the bandspread dial adjusted against a local broadcasting station, then the receiver switched to the ten meter band and a check made of the conditions on the band. If a few signals were coming in, the lower frequency 28,707 kc would be used; if the F_2 layer was heavily ionized and many stations were on the band, the higher frequency 29,200 kc would be chosen. With the closing of the key in the relay lock and the opening of the log book, the rig was ready to go on the air. With the turning of the communication switch on the receiver from reception to transmission and a glance at the meters, W6KSO (Fig. 8) was on the air.

While checking the band a station sending out a strong general call (CQ) would be located, and a call made to this

Figure 8. W6KSO — On the air.

station. In a few minutes communication would be established, signal reports and a brief discription of equipment exchanged. If the receiver, at the station with whom communication had been estiblished, was equipped with an R-meter a statement was made to the affect that his co-operation would be appreciated in checking the signal strength of two different antennas being used. After receiving an OK signal, tests would be run something like this, ''I am now using antenna No. 1. I will now switch to antenna No. 2. I am now no No. 2, now using No. 2. I wonder if you noticed any difference in signal strength or in the rapidity or in the depth of fading. Now I will go back to antenna No. 1, now I am using No.1, Was any difference notice?'' This procedure would be repeated several time, and then his report would be recorded in the log book. While listening to his reply, the receiver would be switched from one antenna to the other and the results recorded.

The results from these tests soon gave the cue to the answer to the first question. A change in receiver set-up was made. Two receivers were used, one connected to the vertical antenna and one connected to the horizontal antenna. The same signal was tuned in on both receivers (Fig. 4) and watching the signal strength vary simultaneously on the two antennas , the nature of the polarization of radio waves was revealed.

Now the nature of the problem had changed and the question of paramount importance was, why the difference between

the two antennas and why did the results vary as they did. The results varied minute to minute and from day to day. Any conclusions to be of value must be based upon hundreds of observations. The transmitter was on the air whenever school work or the conditions of the ionosphere would permit. No adjustment were necessary on the transmitter. One rectifier (866) in the buffer stage was replaced. One microphone was returned to the manufactor for replacement. Before the tests were started the Patterson receiver had been returned to the manufactor for a complete overhauling, and accurate adjustments made for the tests that were being made.

Nearly a thousand contacts were made with amateurs of four continents; three hundred seventy five reports were received and the data used in this study. The shortest distance worked was five hundred miles and the longest distances, over eight thousand miles. The mode of frequency of calls made (Fig. 14) was about seventeen hundred miles and the average distance worked was about two thousand miles. The time of contact varied from eight o'clocked in the morning until after midnight. The test began on december 30th. 1938, and were concluded on june 3rd. 1939.

The time of the contacts was recorded using the 24 hour system, and was that of the Rocky Mountain states. The signal strength was first recorded in R's and later changed to difference in decibels. The direction of the station worked was given in degrees east of north.

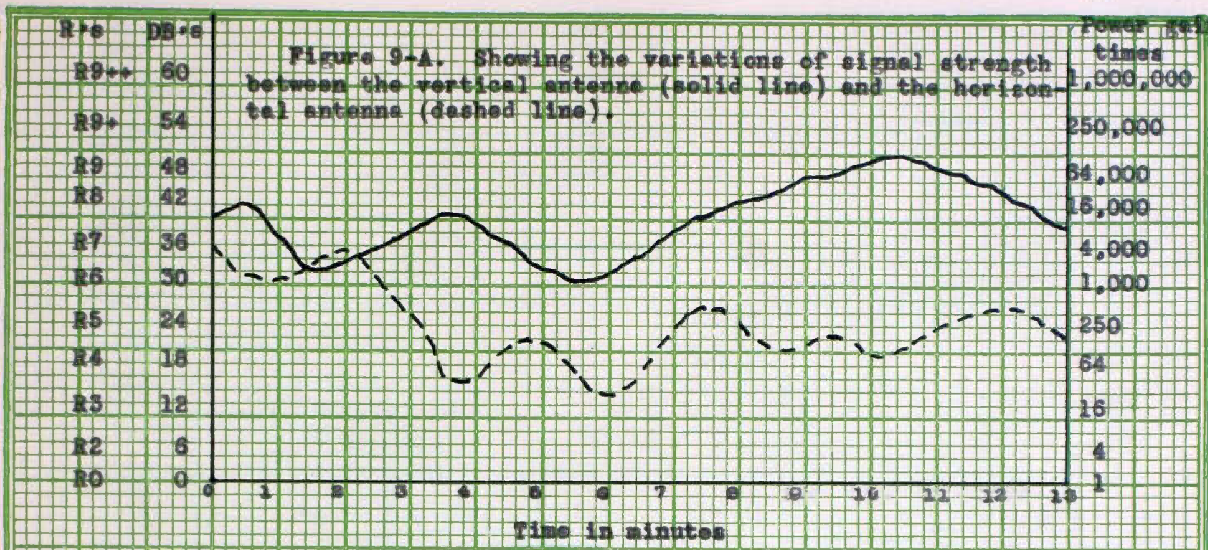

Figure 9-A. Showing the variations of signal strength between the vertical antenna (solid line) and the horizontal antenna (dashed line).

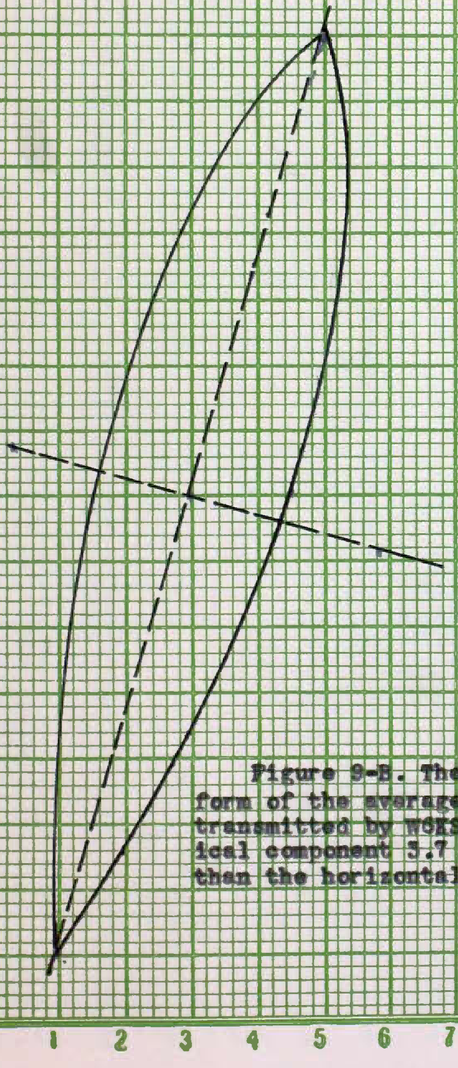

Figure 9-B. The elliptical form of the average radio wave transmitted by W8XSO. The vertical component 3.7 db stronger than the horizontal component.

Figure 9-C.

Vertical component 30 db stronger than the horizontal component.

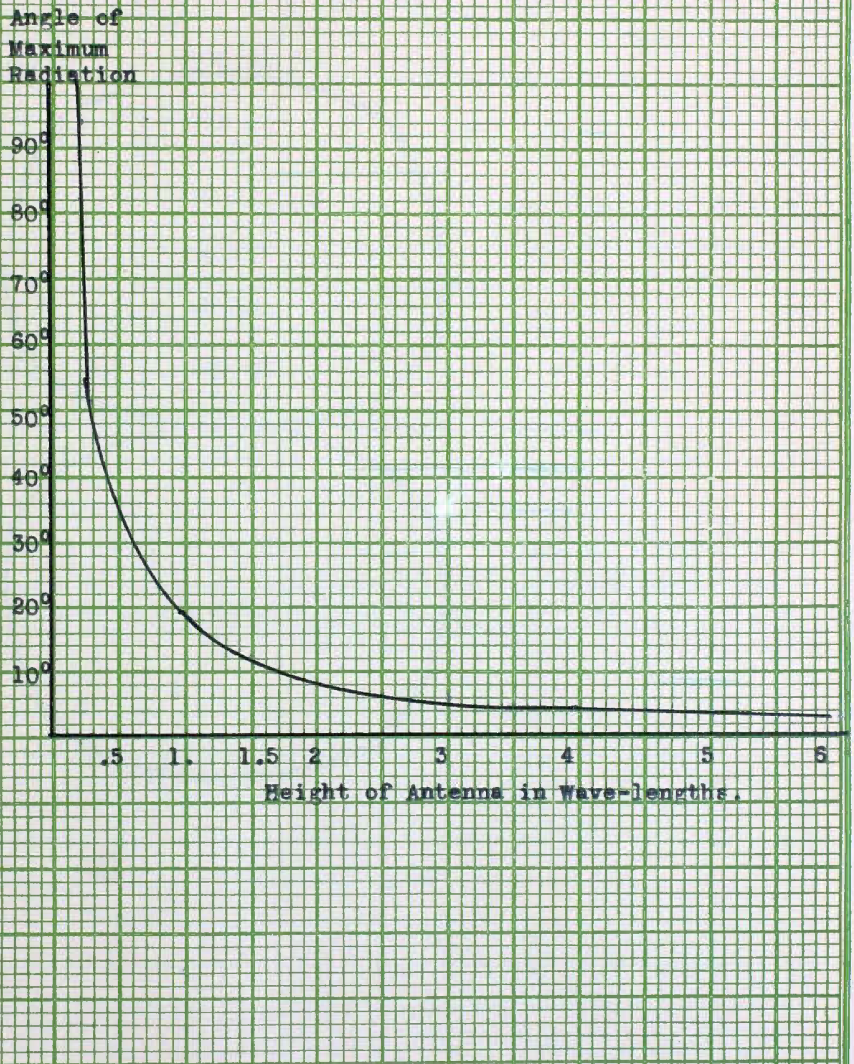

Figure 10. Relation of antenna to the maximum angle of radiation.

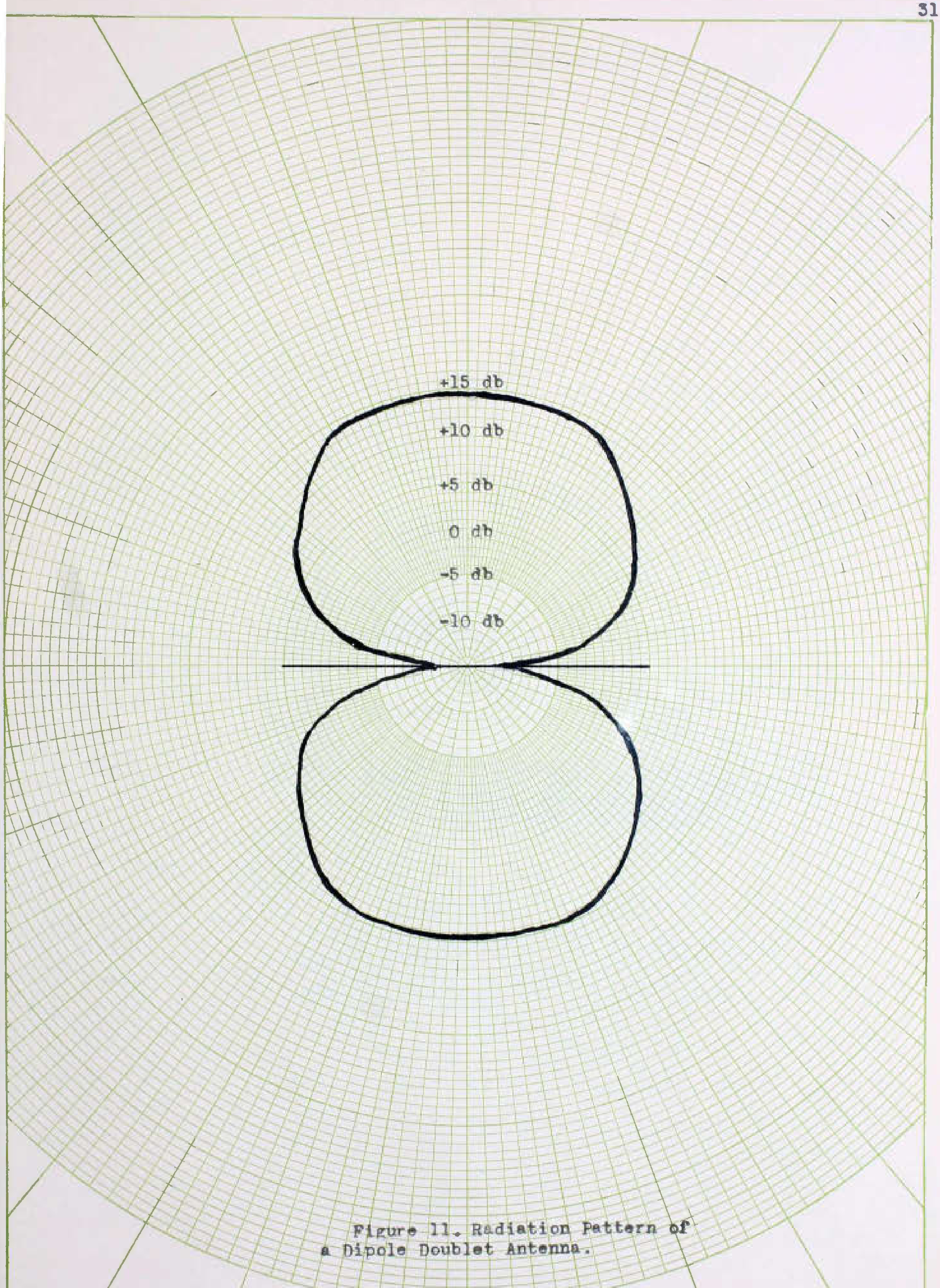

Figure 11. Radiation Pattern of a Dipole Doublet Antenna.

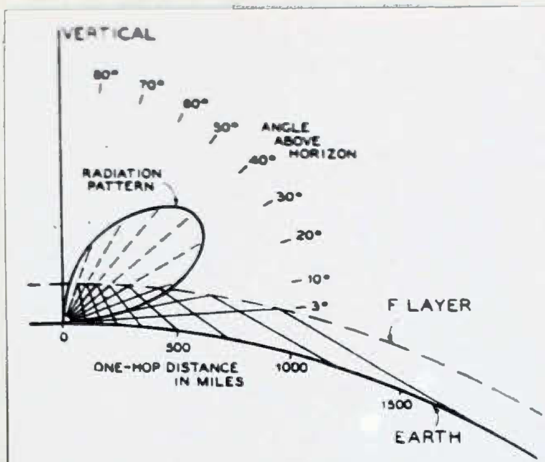

Figure 12. Scale drawing of F layer reflection assuming a 250-km. layer height. A field strength pattern for a horizontal antenna one-half wavelength high is superimposed.

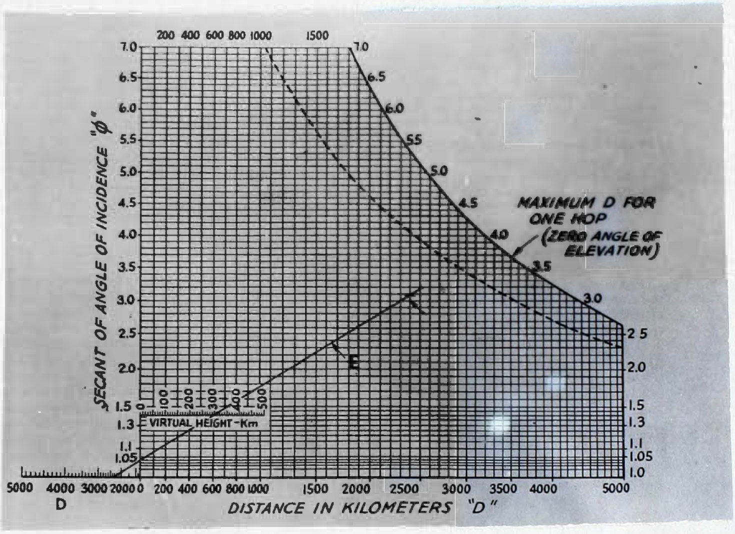

Figure 13. Graph used by the Bureau of Standards in determining the Secant of the Angle of Incidence.

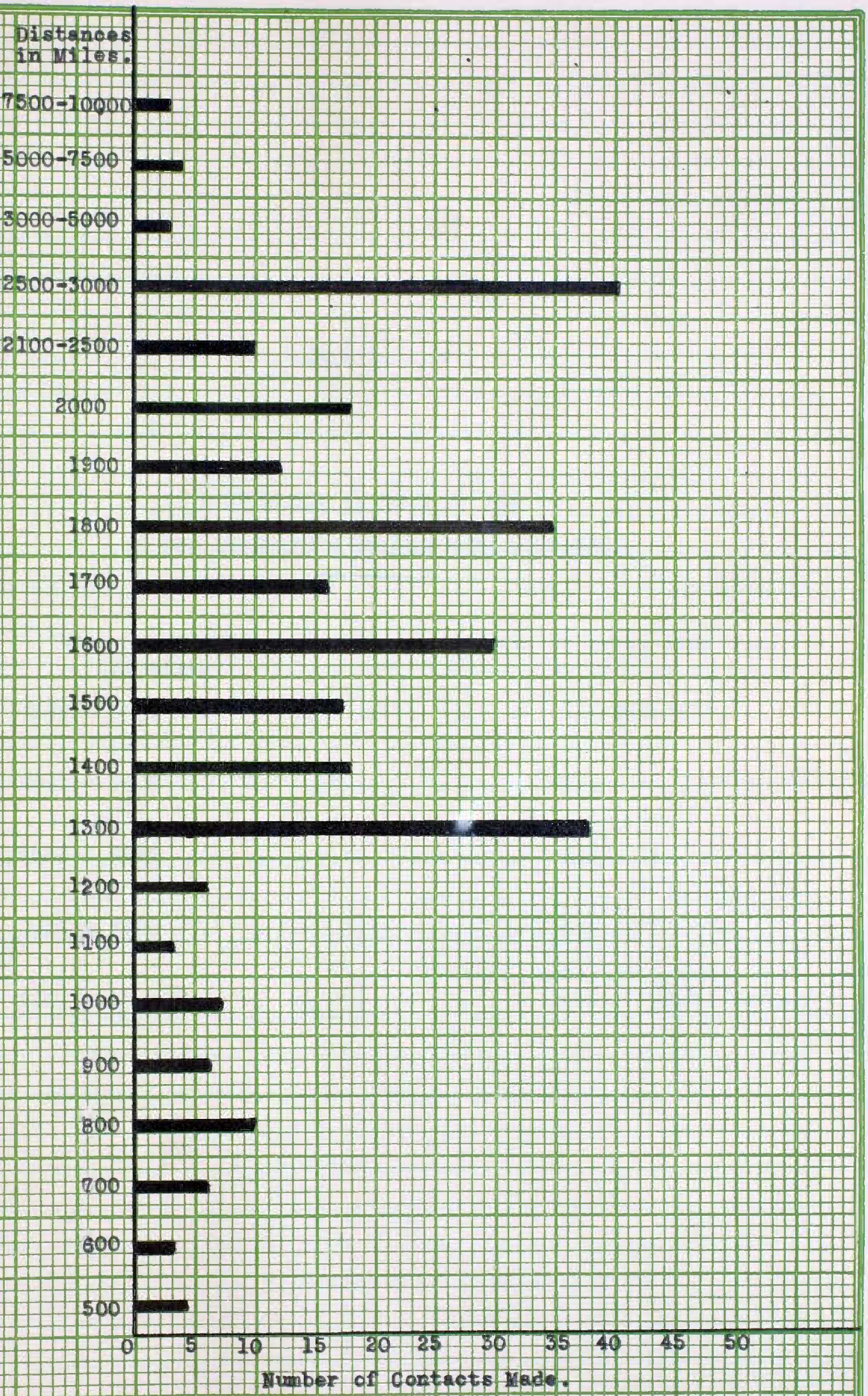

Figure 14. Relation between Distance and Number of Stations Worked.

TABLE I.

DIFFERENCE IN GAIN OF THE

TWO ANTENNAS COMPARED WITH DISTANCE.

Distance Worked. (in miles)	Gain of vert. over hor.
500 - 1000	6.0 Decibels.
1001 - 1500	4.3 ''
1501 - 2000	4.0 ''
2001 - 2500	5.5 ''
2501 - 10,000	-.5 ''(Hor. Better)

TABLE II.

DIFFERENCE IN GAIN OF THE TWO ANTENNAS

COMPARED WITH THE DIRECTIONS OF THE STATIONS WORKED.

Direction in degrees East of North.	Gain of vertical antenna over the horizontal.
0° - 23.5°	27.5 Decibels
24° - 67.5°	10.0 "
68° - 90°	2.0 "
135°	12.6 "
260°	-1.8 "
300°	8.8 "
330°	10.0 "

TABLE III.

DIFFERENCES IN GAIN OF THE TWO ANTENNAS
AND DISTANCES OVER TWO THOUSAND MILES WORKED.

Distance worked in miles.	Gain of vertical antenna over horizontal antenna.
2000 - 2099	1.4 Decibels.
2100 - 2199	5.9 ,,
2200 (one station) . . .	15.0 ,,
2900 (Hawaii).	-2.37 ,,
4500 (South American). . .	18.0 ,,
7500 - 10,000	3.8 ,,

TABLE IV.

DIFFERENCES IN GAIN OF THE TWO
ANTENNAS COMPARED WITH THE TIME OD DAY.

Time of day.	Gain of vertical antenna over the horizontal.
8:00 - 10:00 AM.	1.4 Decibels.
12:00 - 2:00 PM.	5.0 ”
5:00 - 7:00 PM.	2.7 ”
9:00 PM. or later	3.2 ”
Mean	3.1 ”

TABLE V.

DIFFERENCES IN GAIN OF THE TWO ANTENNAS COMPARED WITH THE TIME OF THE YEAR.

Time of year. (1939)	Gain of vertical antenna over the horizontal antenna.
Jan. 1 - 15th.	4.0 Decibels.
Mar. 16 - 30th.	2.2 ,,
May 16th - 30th.	3.2 ,,
Mean . . .	3.1 ,,

TABULATED RESULTS.

TRANSMISSIONS

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO's Sigs.in Rs Vert.	Hor.	Differences in DBs Vert.	Hor.
12-30-38	13:31	W9UDO	1300	50°	8.4	8	2	
	14:06							12
1-1-39	13:55	W9EMB	1500	48°	9	7	12	
1-8-39	11:36	W9PIJ	1400	62°	8	6.5	8	
	11:41						0	0
	14:41	W8RLJ			8	7	6	
1-9-39	8:43	W8KXU	1400	60°	7	8		6
	8:48				8	7	6	
1-10-39	12:38	W9YLV	1300	50°	9	8	6	
1-11-39	16:21	W8PNI	1500	64°	8	7+	3	
	16:45				8	6	12	
	16:55				7	4	18	
1-12-39	8:12	W8RMJ			7	5	12	
	12:30	W9ZOT	1300	56°	9	9	0	0
	12:45				9	8+	2	
1-13-39	8:40	W9WOH	1400	64°	9	8	6	
	13:47	W9WIP	1100	48°	8	8	0	0
	17:10	W8SPL	1500	50°	7	6	6	
1-14-39	15:57	W9OET	1300	62°	9	9	0	0
	17:20	W8RRR			8	8	0	0
	18:10	Ve4UD	1200	10°	8	2	36	
	18:33	K6ETF	2900	260°	5	5	0	0
1-15-39	18:02	W3HJO			6	6	0	0
	18:13				5	4	6	
	18:15				5	3	12	
	18:23				4	2	12	
1-16-39		W8MCC	1600	50°	8	8	0	0

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO's Sig. in Rs Vert.	W6KSO's Sig. in Rs Hor.	Differences in DBs Vert.	Differences in DBs Hor.
2-7-39	1724	W8QWZ	1500	48°	8	9		6
	1735						0	0
	1740						0	0
	1754						0	0
	1803	W8RXY			8	9		6
	1820	W1IYE	2100	62°	9	8	6	
	1838				8+	8	3	
2-8-39	1640	W8QQT	1600	56°	9	8+	2	
	1700	W4FJB			8	7	6	
	1725	W9BMX	1200	45°	9	8	6	
	1755	W8QBO	1600	56°	9	8	6	
	1832	W7KO	1200	336°	7	6	6	
	1900	W5VO			9	9	0	0
	1930				9	6	18	
	2020	W5CFX	800	90°	8	5	18	
2-9-39	1920	W6ITW	600	0°	9	7	12	
	2000	W6PJS	600	0°	5	1	24	
	2030	W6DZX	600	0°	9	4+	27	
2-10-39	1245	W9RHT	1300	46°	8	8	0	0
	1320	W8ANO	1600	64°	7	7+		3
	1720				6+	7		3
	1735	W9DJU	1300	62°	9	7	12	
	1800	W9QCL	900	50°	7	6	6	
	1845	W9JBO	900	50°	9+++	9	22	
	2220	W6NBB			9	8	6	
	2332	W6NX	700	300°	9	8+	2	
2-11-39	1045	W4FCR			8	6	12	
	1125	W9DAX	1300	58°	9	9	0	0
	1418	W9QFL	1300	48°	6	7		6

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO's Sig.in Rs Vert.	W6KSO's Sig.in Rs Hor.	Differences in DBs Vert.	Differences in DBs Hor.
2-11-39	1420	W9QFL	1300	48°	8	6	12	
	1435							3
	1436						3	
	1438							3
	1455				8	5	18	
	1512	W9BOF	1400	70°	8	7	12	
	1635	W4DXN	1650	80°	9+	9	6	
	1700	W9ALE			9	6	18	
	1835	K6PLZ	2900	260°	8	8	0	0
	1850	W6ASZ	500	295°	9	9	0	0
	1935	W6MOU	500	295°	8	8	0	0
2-12-39	1340	W4AXV	1400	70°	7+	9		9
2-13-39	1717	W4DEK	1400	70°	9	8+	4	
	1722						13	
	1735						20	
	1740						8	
2-14-39	1846	W4FUM			9	8	6	
	1850	W6PMB			6+	8		8
	1916	W6MWK	800	310°	6	6+		2
2-15-39	1618	W8AIU	1600	60°	9+	8+	6	
		(Heard me testing 2-12-39)					12	
2-16-39	1735	K6DV	2900	260°	5	5+		2
2-17-39	1705	W9IUJ	1300	54°	8	6+	8	
2-18-39	1440	W9WXT	1300	54°	7	8		6
	1747	W4AAU	1800	70°	8+	9		4
	1810	W4AAU	1800	70°	8	8	6	0
	1818	W9TGB	1300	54°				8
		(Heard me testing 2-12-39)					20	
	1840						8	
	1851	W9TBP	1300	54°	9	8	6	

Date	Time M.S.T.	Worked	Distance.	Direction.	W6KSO's Sig. in Rs Vert.	W6KSO's Sig. in Rs Hor.	Differences in DBs Vert.	Differences in DBs Hor.
2-18-39	1912	W9TBP	1300	54^0	9	7	12	
2-19-39	1156	W9VEK	1400	60^0	9+	9+	0	0
	1202				9+	9	2	
	1315	W9RIY	1400	60^0	9	8	6	
	1835	W5GTC	1000	90^0	7	9		12
	1850	K6LNP	2900	260^0	7	6	6	
2-20-39	835	W3DPN	2000	66^0	9	7	12	
2-21-39	1758	W5HMQ			8	9		6
2-22-39	842	W9YIT	1200	62^0	9+	9	3	
	1324	W8MMH	1600	58^0	9	7	12	
	1724	W9QCD	1300	58^0	8	9		6
2-23-39	839	W8NFX	1800	62^0	8	7	6	
2-24-39	1555	W8QHH	1600	58^0	9	7	12	
	1620	W8DVC	1500	56^0	8+	9+		6
2-25-39	1133	W4FUO	1600	90^0	9	8	6	
	1140				9	8	6	
	1158	W7FRM	1100	340^0	9+	9	4	
	1255	W9SPV	1400	46^0	9	9	0	0
2-27-39	1710	W9UUR	1600	68^0	9	8+	4	
2-28-39	835	W9MMN	1300	50^0	9+	9	4	
	1720	W8PYP	1500	48^0	9	8	6	
	1753	W4FJB	1800	74^0	9	8	6	
	1812	W8JNF	1600	60^0	9	8	6	
	1905	K6LNP	2900	260^0	3	4		6
3-1-39	1812	W4FT	1800	70^0	8	9		6
	1815				8	6	12	
	1818				8	8	0	0
3-2-39	1736	W4PB	1600	90^0	7	7	0	0

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO's Sigs.in Rs Vert.	Hor.	Differences in Dbs Vert.	Hor.
3-2-39	1800	K6MHY	2900	260°	9	6	18	
	1835	K6PTW	2900	260°	7+	7	4	
	1853						4	
3-3-39	835	W8CKT	1900	60°	8	6	12	
	1240	Ve4TM	1300	356°	8	4+	21	
	1754	W9SYH	1200	45°	9	6	18	
	1814	W8SDR			8	7	6	
	1832	W9RAW	1400	62°	9+	9+	0	0
3-4-39	1120	W4DXM	1600	84°	9+	8	12	
	1135				9	9	0	0
	1140	W4FUA	1700	86°	9	8	6	
	1205	Ve3AIW	1700	48°	8	7+	3	
	1302	W5GAF	1200	86°	8	7	6	
	1617	W8PYP	1300	48°	9	9	0	0
	1625							12
	1655	K6DV	2900	260°	5	5+		3
	1702	W2PR	1900	66°	9	9	0	0
	1717				9	9	0	0
	1721				5	6		6
	1810	VK2ADJ	8100	260°	3	4		6
3-5-39	1055	W4FJB			9	8+	3	
	1140	W8REU	1500	58°	9+	8+	6	
	1333	W4FBH					6	
	1640	W4FUO			9	8+	3	
	1805	W1LOS	2100	60°	9	8+	3	
3-6-39	1336	W9CST			9	8+	3	
3-7-39	825	W8QOV	1600	60°	7	7	0	0
	835				6+	7		3
	1840	W5FRA	700	90°	9+	9	2	
	1850						0	0

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO's Sigs.in Rs Vert.	Hor.	Differences in dbs Vert.	Hor.
3-8-39	839	W4FPB			9	9+		3
3-9-39	1246	W9NWN	1300	50°	9	9	0	0
	1715	W8SHG			7+	8		3
	1732	W4EDD	1800	92°				3
	1750	K6DV	2900	260°				3
	1812	K6OES	2900	260°	8+	9		3
3-10-39	1730	W4CLK	1800	92°	8	8	0	0
	1807	W7HGW	1100	340°	9++	9	12	
3-11-39	1215	Ve3ABZ	1600	45°	8	7	6	
	1243	W3EZL	1800	68°	8	7+	3	
	1325	W5AVO	1000	88°	7	7	0	0
	1843	K6GQF	2900	260°	9	7	12	
	1850				8	7+	2	
	1944	ZL1KJ	7200	240°	8	6	12	
	1950				6	5	6	
3-15-39	1650	W4FPC	1700	90°	9	8	6	
3-16-39	1627	W4EZK	1700	89°	8	3	30	
3-17-39	843	W5FTA	1000	89°	7+	7	2	
	1245	W8SDJ			8	6+	8	
3-18-39	1140	W3FFR	1800	62°	9	8	6	
	1225	W9UHI	1300	50°	9	8	6	
	1250	W8SYL	1800	64°	9	8+	2	
3-19-39	1257	W9PIJ	1400	60°	9	8	6	
	1432	W8CLS	1800	64°	9	9	0	0
	1450				9	8	6	
	1700	W8OTC	1500	60°	8	8+		3
	1703				8+	8	3	
	1709	W8OTC	1500	60°	8	6	12	

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO's Sigs.in Rs Vert.	Hor.	Differences in dbs Vert.	Hor.
3-20-39	845	W3GQS	1500	62°	7	7+		3
	1250	W8QXV	1600	64°	9	8	6	
3-22-39	1645	W1LTC	2100	62°	9	8	6	
	1740	K6LPW	2900	260°	8	9		6
	1758				7	9		12
3-23-39	1227	W8LIA	1800	60°	9++	9	12	
3-24-39	1305	Ve2KX	1900	58°	8+	8	2	
	1436	W8SLC			8	1	42	
	1503	W3AIB	1800	68°	8	7	6	
	1520				7	8		6
	1529				8	8	0	0
	1653	W4DUI	1600	90°	8	6	12	
3-25-39	1105	W2EFL	2000	66°	8	8	0	0
	1200				8+	7+	6	
3-26-39	1250	W8RYU			8	6	12	
					8	8	0	0
					8	6	12	
					9	9	0	0
	1715	W3HVS	1900	66°	9	7	12	
	1802	K6QNX	2900	260°	8	9+		7
	1856	K6PCK	2900	260°	5	9		24
3-27-39	1455	W4BUI	1600	90°	8	7	6	
	1655	W8RLT			9	7	12	
	1735	W4MS	1800	90°	7	9		12
	1745				7	8		6
3-28-39	1238	W9ATJ			8	8	0	0
	1816	W3FIL	1900	67°	7	6	6	
	1855	K6PTW	2900	260°	7	6	6	
3-30-39	842	W2GIJ	2000	66°	9+	9	4	
	1659	W8SDD			9	9	0	0

Date	Time M.S.T.	Worked	Dist- ance.	Direc- tion.	W6KSO's Sigs. in Rs Vert.	Hor.	Differences in dbs Vert.	Hor.
3-30-39	1814	Xe3AX	1700	130°	7	8		6
4-1-39	1710	K6OXT	2900	260°	3	4		6
4-3-39	1614	W8NFX	1700	64°	9+	8	9	
	1641	W4AMD	1300	70°	9	8+	3	
	1652	W4BTV			9	7+	10	
	1708	W4FAP			9	8	6	
	1727	W2CQB	2000	66°	9+	9+	0	0
	1744	W4AMF			9	7	12	
4-4-39	1327	W4AMF			9	8	6	
	1710	K6PLZ	2900	260°	5+	6		4
4-5-39	835	W2CNR	2000	66°	9	8	6	
	1621	W8PNJ			9+	9	3	
	1651	W8BMH			8	7+	3	
	1755	W8NFX			9+++	9	18	
	1803	W3AGM	1900	66°	9++	8	15	
	1825	W4PB	1600	88°	5+	6		3
	1829				6	6	0	0
4-6-39	1653	W4DTJ	1600	90°	9	9	0	0
	1715	W4DTJ	1600	90°	9	8	6	
	1755	W4DUI	1600	88°	8	7	6	
	1832	ZL4FK	7200	240°	8	6+	9	
	1843	ZL3KZ	7200	240°	5	7		12
	1937	K6OQM	2900	260°	9+	9	3	
	1858				9+	9+	0	0
4-7-39	1324	W8ERG	1800	62°	8	6	12	
	1345	W8OYQ	1600	66°	9	7+	9	
	1402				9	7+	9	

Date	Time M.S.T.	Worked	Dist- ance.	Direc- tion.	W6KSO's Sigs.in Rs Vert.	Hor.	Differences in dbs Vert.	Hor.
4-7-39	1705	W4AYU	1300	70°	9	9	0	0
	1753				8+	9		2
	1805	W4NY	1800	72°	7	3	24	
		(Heard me working W8ERG)					24	
	1825	KalER	8000	290°	9	7	12	
	1848	K6LPW	2900	260°	9+	9++		6
	1915				9+	9++		6
4-8-39	1700	W3ASZ	1900	68°	9	7	12	
	1713	W3HPD	1900	68°	9	7+	9	
	1733	W2KKK	2000	66°	5+	4	9	
	1745	W4CRW	1800	72°	9	9+		4
	1815	W4BUX	1500	70°	8	9+		12
	1833	W2IXE	2000	66°	8	8+		2
	1844	K6LPW	2900	260°	9+	9++		6
4-9-39	1054	W8GLJ	1600	64°	9+	8	8	
4-10-39	1751	W2CUF	2000	66°	7	8		6
4-11-39	1236	W8RSR			9	6	18	
	1659	W3AWX	1800	68°	9	5	24	
	1718	W3GSV	1800	68°				12
	1740							7
	1741						42	
	1742						6	
	1743							12
	1744						24	
	1745						6	
	1755	W3FHF	1800	68°	9	8	6	
	1812	W1LFX	2100	64°	9	6	18	
	1815				9	7+	9	
4-13-39	1742	W8CRI			8+	9		1
4-15-39	1632	W3AWX	1800	68°	9	9+		2
4-16-39	1536	W4BTV			9	8	6	

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO's Sigs.in Rs Vert.	Hor.	Differences in dbs Vert.	Hor.
4-16-39	1619	W2CNR	2000	66°	9+	9	2	
	1649	W2APU	1900	66°	4	2	12	
	1727	W2GV	2000	66°	8	9		6
4-18-39	1815	W4NBB	1700	88°			4	
4-21-39	841	W5GZK			9	9	0	0
	845				9	9+		4
	1053	W5HTZ			9	8	6	
	1137	W1CCD	2100	60°	9	8+	2	
	1157	W5GZK			9	8	6	
	1743	W4EWK	1700	90°	8	6+	9	
	1807	W5AFX	800	68°	6	6	0	0
4-22-39	1546	LU8AB	4500	150°	9	4	30	
	1856	VK3CP	8200	250°	6	6	0	0
4-24-39	1810	W7BQX			9+	9+	0	0
	1820	W4FT	1800	70°	9	8+	3	
	1835	K6DV	2900	260°	6	6+		3
4-25-39	1725	Ve3UT	1500	32°	9+	9	6	
	1733	W5FXD	900	66°	9	8+	6	
	1806	W5ERX	900	66°	8+	9		2
	1848	W9PGL	800	56°	7	7	0	0
	1905	W9VRZ	1400	52°	8	7+	2	
	1945	W5AFX	800	68°	5	6		6
4-26-39	1643	W2IKS	1900	66°	9	8	6	
	1826	W5AFX	800	68°	7	7	0	0
	1858	LU1DJ	4500	140°	8	7	6	
4-28-39	1915	W5FYB	800	86°	8	8	0	0

Date	Time M.S.T.	Workd	Dist-ance.	Direc-tion.	W6KSO's Sigs.in Rs Vert.	Hor.	Differences in dbs Vert.	Hor.
4-28-39	1927	W5HEP	700	92°	7	9		12
	2030	W5NU	700	92°	8	8	0	0
4-29-39	1027	W8CLS	1800	64°	6	6	0	0
	1055	W2EBT	2000	64°	8	7+	2	
	1158	W3ACF			9	9	0	0
	1240	W1LOS	2100	64°	9	8	6	
	1325	W3HFD			9	8+	5	
	1531	W1CQR	2100	64°	7	6	6	
	1640	W3GRO	1900	66°	9	8+	5	
	1706	W4EBM	1800	72°	9	9	0	0
	1742	W2PR	2000	64°	9	7+	8	
	1809	W4DTJ	1700	70°	9	7+	9	
4-30-39	1110	W3DYR	1900	66°	9+	9	6	
	1510	W2NX	2000	64°	7	7+		1
	1520				7	6	6	
	1627	W3SWJ			8	7	6	
	1703	K6DV	2900	260°	7	8		6
	1733	W4GAC			7	8		6
	1740				8	8	0	0
	1752	K6QXU	2900	260°				6
	1802							6
	1823	K6RDB	2900	260°	7+	7	2	
	1848	W6KHI			7	8		6
5-2-39	1236	W4FWA			5	5	0	0
	1627	K6RDB	2900	260°	6	6+		3
	1636	W4DTJ	1700	90°	9	9	0	0

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO's sigs.in Rs Vert.	Hor.	Differences in dbs Vert.	Hor.
5-2-39	1646	W4DTJ	1700	90^0	8	9	6	
5-3-39	1242	W6PUE			9+	9	3	
	1302	W6MRF	500	295^0	9+	9	3	
	1316	W9ZNA	1000	48^0	7	6	6	
	1329	W6MYS	500	295^0	8	4+	21	
	1807	W5HDU			9+	9	2	
	1952	W5HOM			9	9+		2
5-4-39	1320	W1LNE	2100	64^0	9	4	30	
5-6-39	1740	W5FUS	1000	48^0	9	4	30	
5-7-39	1244	W4DTJ	1700	90^0	8	9	6	
	1322				8	9	6	
	1510	K6AYD	2900	260^0	8	8+		3
	1544							2
	1555				9++	9+		3
	1816	K6MVV	2900	260^0	9	9++		9
5-8-39	1615	K6PIT	2900	260^0	4	4+		3
	1707	W5HTY			6	8		12
5-10-39	833	W1GUY	2100	60^0	9+	9	4	
	1320	W2APU	2000	60^0	9	5	24	
	1730	W3HFW	1900	62^0	9	9	0	0
	1845	W3HOZ	1900	62^0			4	
5-11-39	1745	W1KRW	2100	60^0	6	4	12	
	1856	W8BZY	1600	62^0	8	6	12	
5-13-39	1219	W4VM	1600	72^0			3	
	1512	K6DV	2900	260^0	6+	6	3	
5-14-39	1322	W1JUJ	2200	60^0	9	6+	15	

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO'S Sigs.in Rs Vert.	W6KSO'S Sigs.in Rs Hor.	Differences in dbs Vert.	Differences in dbs Hor.
5-14-39	1423	W2FQK	2000	66^0	9	8	6	
	1451	W4EFH	1700	90^0	9	8	6	
	1535	W1EUG	2100	62^0	9++	9+	6	
	1605	W3GRO	2000	60^0	9+	9	6	
	1617				9+	8	12	
	1723	W4QA	1800	68^0	7	7	0	0
	1901	W3HJO	2000	60^0	6	7		6
5-15-39	1824	W4EFH	1700	90^0	9+	9	6	
	1836	K6QJE	2900	260^0	8	8	0	0
	1905	W5FTA	1900	94^0	9	8+	3	
5-17-39	845	W2JAZ	2000	66^0	7	9		12
	1725	K6OES	2900	260^0	6	6+		3
	1816	W9VHR	1000	44^0	4	3+	3	
	1835	W2AMO	2000	66^0	9+	9+	0	0
	1845	W4FPC			9	9	0	0
5-18-39	1247				7	6+	3	
5-20-38	1301	Ti3AV	2000	135^0	8	8	0	0
5-22-39	1223	K6AN	2900	260^0	6	6	0	0
5-25-39	1659	W5GZK			8	6	12	
	1730	W4FVW	1600	88^0	9	8+	3	
5-28-39	1225	Xe2FC	1500	130^0	5	4	6	
	1248	W6OZC	800	305^0	7+	7	1	
	1326	W6KG	800	305^0	9	5	24	
	1434				9	6	18	
5-29-39	1728	W5FSD	900	90^0	8	5	18	

Date	Time M.S.T.	Worked	Dist-ance.	Direc-tion.	W6KSO's Sigs.in Rs Vert.	Hor.	Differences in dbs Vert.	Hor.
5-31-39	900	W2LMW	2000	64°	8	9		6
	1228	W5EEL	1100	88°	8	7	6	
	1831	W6QAY			8	9		6
	1839				7	9		12
	1850	W6HRS			9	9	0	0
	1859				9	8	6	
							1964	581

No. of reports = 375

Vertical gain (1964-581) ÷ 375 = 3.7 Decibels

Checks on receiving only ---

6-2-39	1826	W5HNW	9	8	6	
	1850	W9TFQ	9	8+	4	
	1905	ZL4FW	8	7	6	
	1932	W9TKF	7	8		6
	1942	W5GZK	8	7	6	
	1955	VP3CO	7	5+	9	
6-3-39	1500	W9YPV	7	6+	4	
	1540	W5AQB	8	9		6
		Vertical gain-			35	12

(35 - 12) ÷ 8 = 3 Decibels.

SUMMARY

The answer to the first question, "Is there a relation between the amount of reflected radio wave energy and the angle of polarization?" was soon found to be in the affirmative. The suprising fact to the investigator was that although the vertically polarized wave from the vertical antenna produced the stronger signal, the results arranged and studied showed a wide range of variation. It was soon discovered that at one moment the horizontal antenna would produce a signal several times stronger than the vertical antenna, and in a few minutes the vertical would produce a signal many times stronger than the horizontal antenna. The greatest difference in favor of the horizontal antenna was 24 decibels (or a power gain of 250); the greatest difference in favor of the vertical antenna was 42 decibels (or a power gain of 10,000 times); while the average difference for the 375 tests made was 3.7 decibels (or 2.35 times) in favor of the vertical antenna. Check on recption, both at W6KSO and at other stations showed a similar variation in signal strength. The results indicated the presence of one or more varying factors other than; the type of polarization of the propagated wave; a simple reflecting layer of ionized gases, or the angle of polarization of the receiving antenna. This new unknown factor or factors was called, factor X.

To better study the relation between vertical and the horizontal waves, the special receiver set-up (Fig. 4) was made

The variation of signal strength on the two antennas could now be studied easily and simultaneusly. The variation of signal strength as indicated by the two receivers suggested elliptically polarized waves. The variation of signal strength on the vertical antenna governed the vertical axeis, while the variation of signal strength on the horizontal antenna indicated the magnitude of the horizontal axeis of an ellipse.

In the graph (Fig. 9-a), the variations of signal strength are shown. The signal strength is given in R's, DB's, and in power gain on the vertical axis, while the horizontal axis represents the time factor. If the radio wave had remained polarized in, for example, the horizontal plane as it left the transmitting antenna, the dashed line representing the horizontal plane of polarization would have been several R's above the solid line. This was not the case. If the horizontally polarized waves had been reflected by about 90° as has been suggested, the solid line would have been several R's above the dashed line. It has been stated[22] that these waves are elliptically polarized. In figure 9-b an ellipse has been constructed with the height and width representing the average signal strength (found from the 375 reports) of the vertical and the horizontal electrical components respectively. The height of the ellipse corresponds to the signal strength on the vertical antenna, and is not necessarily the major axis of the ellipse. Such an ellipse is dynamic. rot-

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[22]Terman, Frederick Emmons, Fundamentals of Radio. New York, McGraw-Hill Company, Inc., 1938. p. 335.

ating about the intersection of the axis, and would explain the results obtained.

The elliptically polarization, or the unknown X, of radio waves is thought to be caused[23] by the interaction between the earth's magnetic field and the magnetic component of the radio wave. The writer would like to suggest two other factors that should be considered in the elliptical polarization of radio waves — 1st. the effect of multiple reflection and multiple paths; and 2nd., the effect of strong electrical fields within the earth's atmosphere, upon the electrical component of the radio wave. In the study of television made by RCA engineers on Long Island, they found that signals coming from England did not all follow the same path. Some would arrive late and produce double images. Radio waves do not all follow the great circle route. For example, W6KSO worked a ship off the coast of Florida, and had its signals reported as arriving from South America, and while working a California station W6KSO's signals were reported as coming down vertically. It is not unusual for stations having beam antennas to find it necessary to turn their beams at right angles in order to work one another successfully. There have been many experiences in which radio waves were received from direction far from the normal great circle path.

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[23]Terman, Frederick Emmons, Fundamentals of Radio, New York, McGraw-Hill Company, Inc., 1938. p. 335.

The reflecting layers are not smooth layers parallel to the earth's surface, but may have sections varying from parallel to the earth's surface to even perpendicular to the earth, and curved like gigantic curved mirrors found in amusement places, playing pranks upon the perplexed radio operator. If a single reflection will change the angle of polarization 90°, a double reflection will return the wave to its original plane of polarization and out of phase by 180°. Any even number of reflections would return the wave to its original plane of polarization. Reflections from land will produce similar effects, the degree of rotation of the plane of polarization depending upon the conductivity of the reflecting medium. Sea water will change the angle of polarization 178°.

Owing to the large angle of incidence necessary for reflection of radio waves with a frequency above the critical frequency, several reflections would be necessary for a change of direction that could be detected by a beam antenna. So in place of a single radio wave we really have several waves, each having traveled a different path and having a different angle of polarization, and the effect produced upon the receiver is the sum of many waves. Therefore, plane polarized waves could produce the observed the effects as shown in figures 9-b, and 9-c, and the problem becomes more complex.

An Aurora is an electrical phenomenon due to electrical

particles[24] shot off from the sun. These particles create a strong electrical field between the earth and the upper strata of the atmosphere, and it is through this field that radio waves move at right angles to the electrical field. It is suggested that a polarizing effect may be produced by the interaction of the strong electrical field of the atmosphere, and the electrical component of the radio wave. Also it is possible that a reaction between the radio wave's elec-component and the heavily ionized E layer results in the production of the F_2^o and the F_2^x radio waves having different velocities, and having critical frequencies differing by 800 kilocycles. It is here suggested that; the real effect of the earth's magnetic field upon the propagation of radio waves, the effect of electrical current drifts within the atmosphere upon the propagation of radio waves, the effect of electrical current drifts upon the weather, and the nature of electrical particles producing the different layers of ionization within the ionosphere, are momentous problems on which very little research has been done. Here is a rich field for further investigation.

The second question — which angle of polarization will be more effectively reflected? has been partly answered. It has been shown that the 3.7 decibel gain of the vertical antenna over the horizontal antenna could not be due to the angle of polarization of the radio wave, as the angle is constantly changing as the wave moves through the earth's atmos-

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[24]Moulton, Forest R. <u>Astronomy</u>, New York, The Macmillion Co. 1931 p. 107.

phere. After carefully checking every factor involved the difference cited above must be due to some inconsistency in the radiation patterns of the two antennas used. Some outside factor must have raised the angle of elevation of the radiation pattern of the horizontal antenna a few degrees. Such an assumption would explain the several peculiar effects observed during the course of the research. In figure 10, the relation between the height of the antenna above ground and the angle of maximum radiation is shown. The antennas were two wave-lengths above the street, this should have given an angle of maximum radiation of about 8 degrees. The building was located upon dry volcanic rock, this should have lowered the angle of maximum radiation an-nother degree or two depending upon the conductivity of the rock. The ceilings in the building consisted of plaster on metal lath, this would tend to increase the angle of radiation of both antennas an equal amount. This amount would be very little due to the small size of the metallic screen and that reflection from the ground takes place at some distance from the base of the antennas.

A copper cornice, three feet wide, surrounds the building and at a distance of one and one-half wave-lengths. This cornice runs parallel to the horizontal antenna and would affect the radiation pattern of the horizontal antenna more than that of the vertical antenna. To the west side of the horizontal antenna, the ridge of the roof to the auditorum was capped by a metal strip running parallel and one wave-

length away from the horizontal antenna, also to the west the ground slopped upward. These two facts would tend to increase the conclusion that the horizontal antenna would have a higher maxmimum angle of radiation to the west, as was discovered to be the case.

The radiation pattern of a dipole antenna in free space is shown in figure 11. This diagram shows a gain of 14 db at right-angles to the antenna and a lose of 10 db at the ends. The pattern of the vertical antenna may be found from figure 11 by rotating the diagram through an angle of 90^0, and is uniform in all direction. A study of tables I and II show a high correlation between theory and results with one exception. By rechecking data this was found (Table III) to have been caused by the reports from the Hawaiian Islands. There were forty reports which showed a gain of 2.37 db in favor of the horizontal antenna. In figure 12 the relation between the angle of radiation, the reversing layer and the skip distance is shown by a diagram. A more accurate means used by the National Bureau of Standards, is shown in figure 13. The Hawaiian Islands are just beyond the first maximum skip distance and so must be worked on double skip. This will require a higher angle of radiation which was apparently produced by the metallic ridge-roll and possibly the higher ground to the west.

The answer to the third question —— the relation between the angle of polarization of the transmitted signal and

the received signal strength at various distances, is shown in tables I and III. The distance 500 - 1000 miles shows a gain for the vertical of 6db which was not expected. Amateurs generally consider a higher angle of radiation better for short distances. Probably all stations worked at this distance were worked on short skip or by reflections from the extra-heavy ionized E layer. A lower angle of radiation would be necessary so there is no inconsistancy.

In reference to the relation between the type of radiation used and the signal strength reported at different times of day, table IV shows little differences. Why the vertical antenna showed a smaller gain in the morning may be due to the working at that time of stations to the east or along the eastward slope of the F_2 layer. The higher gain in the evening while working distant station was expected because of the lower angle of radiation of the vertical antenna. The last calls worked shows an increase for the horizontal antenna due to the short multiple skip worked at this time of day.

The relation between the angle of polarization of the transmitted wave, and the received signal strength at different times of the year, shows little difference (Table V). The reason for the vertical being lower in gain in the spring is not known, but if more data had been collected it might not have been present.

On reception, checks on the vertical antenna and on the horizontal antenna were made, but due to a poor antenna con-

nection discovered only near the close of the research, the data was considered worthless. The amount of data collected after the defect had been corrected was not great enought to give the results very much weight. The tests made on receiving showed the vertical antenna to have a gain of 3 db over the horizontal antenna. This is consistanct with the results found from transmitting. Another factor should be taken into consideration: A radio wave that has been traveling close to the ground is vertically polarized because a horizontal electrical component in the immediate vicinity of the earth has its electrostatic field short-circuited by the earth and by horizontal metallic conductors near the earth.

The vertical antenna was found superior to the horizontal antenna. The radiation pattern was uniform, there was less fading and the signals were stronger. It was found that 100 watts radiated from a vertical antenna was equivalent to 237 watts from a horizontal antenna. It was seen that reflected radio waves are apparently ellipically polarized. The major and the minor axis of the ellipse are constantly changing. The received wave is not a single wave, but the result of several waves arriving at the same time. Little is known of the real nature of the ionosphere and the propagation of high frequency radio waves, therefore, this region should be a rich field for further investigation. For such investigation the co-operation of the Astronomer, the Radio Engineer, the Weather Bureaur man, and the Scientist of the

magnetic observatory are necessary to reveal the mysteries of the ionosphere. From such investigation, radio communication over great distances will be more reliable and possible with less power. From a better knowledge of the nature of the electrical charges in the atmosphere, more accurate weather forecasts may be made and over a longer period of time. And of equal importance, we may learn by the study of the ionosphere, more about the real nature of those tiny electrical charged particles that go to make up the atom, and open up new realms for the study of the Scientist and for the betterment of Mankind.

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