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Technical Note No. 28

Boulder Laboratories

A HISTORY OF VERTICAL-INCIDENCE IONOSPHERE SOUNDING AT THE NATIONAL BUREAU OF STANDARDS

BY SANFORD C. GLADDEN

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($1.50), available from the Superintendent of Documents, Government Printing Office, Washington 25, D.C.

NATIONAL BUREAU OF STANDARDS

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A HISTORY OF VERTICAL-INCIDENCE IONOSPHERE SOUNDING AT THE NATIONAL BUREAU OF STANDARDS

by

Sanford C. Gladden
Central Radio Propagation Laboratory

September 1959

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Preface

This is an attempt to treat in chronological order the development of vertical incidence ionosphere sounding at the National Bureau of Standards through 1957. Of necessity many phases of the radio work of the Bureau have been omitted or treated lightly as not being germane to the principal purpose of this history. With the exception of early workers in the field, names of individuals are to be found only in the references.

Source material includes the monthly, quarterly, and annual reports of Section 6, Division 1 (the old Radio Section), and of the Central Radio Propagation Laboratory; reports of the Interservice Radio Propagation Laboratory; the declassified reports of the International Radio Propagation Conference; the Bureau of Standards Journal of Research; the NBS Technical News Bulletin; published and unpublished reports of NBS; periodical literature, such as the Proceedings of the Institute of Radio Engineers, the Physical Review, Nature, Journal of Geophysical Research (formerly Terrestrial Magnetism and Atmospheric Electricity), and Science.

Times of service of NBS personnel in charge of field stations have been verified through station correspondence as well as in many instances by personal contact with the individuals concerned.

The Boulder Laboratories of the National Bureau of Standards

ACKNOWLEDGMENTS

Department of Terrestrial Magnetism, Carnegie Institution of Washington, for the photographs of the equipment used by Breit and Tuve, photographs of the records obtained with this equipment, and details of operation of the manual and automatic sounding equipment developed by the organization.

U. S. Army Signal Radio Propagation Agency, for the photographs of its field stations and details of their early operation.

Geophysical Institute of the University of Alaska, for photographs of its field station and the DTM automatic ionosonde. The Department of Terrestrial Magnetism also furnished a photograph of the same ionosonde.

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T. R. Gilliland, present field station engineer for NBS, for the photographs of the first two ionograms made with the initial automatic multifrequency ionosonde of NBS, as well as much information concerning the early work at NBS.

Dr. R. A. Helliwell, of the Radio Propagation Laboratory, Stanford University, for the photograph of the Stanford field station.

At the Boulder Laboratories, NBS

H. G. Sellery, in charge of the Field Operations Group, for making the station correspondence available for study.

E. L. Kilpatrick, for the photographs of the ionograms made with the low-frequency ionosonde.

A. H. Shapley, Chief, Sun-Earth Relationships Section, R. W. Knecht, and T. E. Van Zandt for critical evaluation of the text material.

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A HISTORY OF VERTICAL-INCIDENCE IONOSPHERE SOUNDING AT THE NATIONAL BUREAU OF STANDARDS

I. Historical summary to 1927.

In 1901, Marconi succeeded in transmitting radio signals from England to Newfoundland. As a consequence, considerable discussion arose regarding the mode of propagation of radio waves around the curvature of the earth. Many scientists supposed the mechanism was diffraction, in a manner similar to the behavior of other types of electromagnetic waves, but it was soon revealed that the phenomenon could not be explained by diffraction alone.

In 1902 Kennelly in America, and Heaviside in England a few months later independently proposed the existence of an ionized upper region in the atmosphere which would deflect the radio waves and cause them to follow the curvature of the earth. In his paper Kennelly used the expression "electrically conducting strata", indicating that he had in mind several layers.

Some years later Lorentz stated the theory of propagation of light waves through a system of molecules. In 1912 this theory was applied to radio propagation in the ionized region by Eccles, and by Larmor in 1924. In these two papers two layers, one a high permanently ionized layer, and the other a lower layer ionized daily by sunlight, were required to explain the phenomena then observed.

Additional theoretical support for the idea of ionized layer transmission was given by Watson in two papers published in 1918 and 1919. In the first paper the author showed that the observed facts concerning the rate of decay of field strength of electric waves transmitted over a large sheet of water were not adequately accounted for by a theory of pure diffraction. He found, however, that the ionization theory which results in the upper regions of the atmosphere acting as a reflector of electric waves of great wavelength did adequately account for these facts, and the results of the paper tended to confirm the existence of the Heaviside layer, as Eccles called it. One should bear in mind that at the time of Watson, radio communication was carried on by considerably lower frequencies (longer wavelengths) than is now common.

It was not until 1925 that direct evidence of the existence of a reflecting upper layer was obtained. In that year Appleton and Barnett employed two methods by which the apparent height of the layer was found. In one method a transmitter frequency was continuously changed through a small range and the interference maxima noted at a distant receiving station. In the other, the angle of arrival of the signal for different angles of incidence was studied. For both experiments, a transmitter frequency of about 750 kc was used. The estimated apparent height of the layer was found to be about 80 km.

Later in 1925 Breit and Tuve of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington (hereafter abbreviated as DTM) independently reported similar evidence using the pulse or group retardation method developed by them. Short trains of waves lasting about 1/1000 sec were emitted by two transmitters operating on 4045 and 8650 kc at the Naval Research Laboratory, Bellevue, D. C. The pulses for either frequency were received by a string-type galvanometer. As a result of their work, Breit and Tuve reported layer heights of from 90 to 225 km. They also observed that the reflections varied rapidly both in amplitude and position.

The year 1925 also saw another important contribution. Appleton in England, and Nichols and Schelleng in America, independently pointed out that radio wave refraction and absorption in the ionized regions would be considerably modified by the earth's magnetic field. Nichols and Schelleng showed that in the simple cases in which a radio wave is propagated parallel or perpendicular to the earth's magnetic field, it would be split into two components by magnetic double refraction and, in general, one of these components would be more highly absorbed than the other.

In 1927 Breit showed quantitatively the effect of the earth's magnetic field on a ray propagated in any direction with respect to the terrestrial magnetic field. A few months later Appleton independently solved the same problem and gave an equation for the refractive index.

It was not until about 1932 that the term "ionosphere" was introduced by Watson-Watt of England to designate all the ionized region of the earth's atmosphere. This region had previously been called the Kennelly-Heaviside Layer, after the two pioneers.

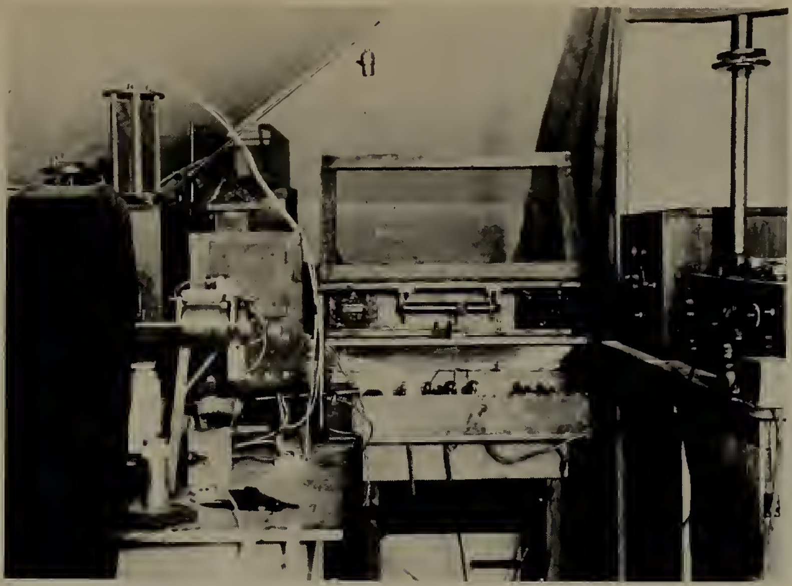


Figure 1

The original equipment used by Breit and Tuve for measurement of virtual heights of the ionosphere
(Photograph supplied through courtesy of DTM, CIW)

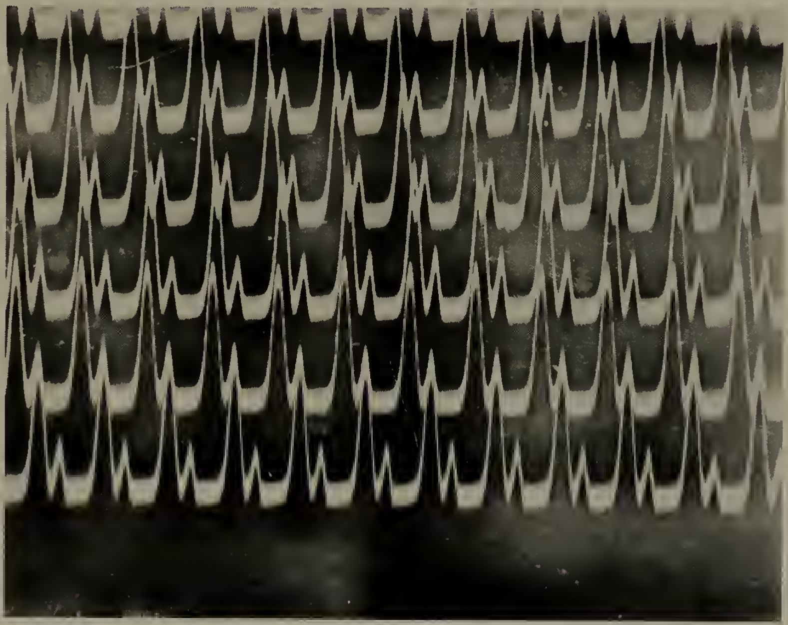


Figure 2

The type of record made by Breit and Tuve using pulse signals from the Naval Research Laboratory transmitter, NKF. The distance between the successive pips was a measure of the layer height.
(Photograph supplied through courtesy of DTM, CIW)

II. Early work at the National Bureau of Standards (1929-1946)

1. Measurements of virtual height at fixed frequencies

The true height of an ionospheric layer is not directly determined by sounding techniques, since the radio wave is retarded on entering and leaving the ionosphere. Consequently heights so observed are termed virtual heights.

While scattered observations of the virtual height of ionospheric layers were made by the National Bureau of Standards during 1929, the first serious work in this field began in January 1930. T. R. Gilliland, still in ionospheric soundings work in 1957 was the pioneer for NBS.

In 1929 there had been some consideration given toward adapting the Bureau standard-frequency transmitting station WWV for transmitting signals for echo studies. This plan was discarded in favor of using pulse signals from the Naval Research Laboratory station, NKF.

The method used was essentially that of Breit and Tuve. It consisted of the receiving and oscillographic recording of signals from a transmitter emitting pulses of extremely short duration, with sufficient intervals of no emission between pulses to record the echoes. The time interval (Δt) between the arrival of the ground wave and the first echo was used to calculate the virtual height, after the method of Kenrick and Jen. The virtual height (h') is defined by the relation $\frac{c\Delta t}{2}$, where c is the velocity of electromagnetic waves in free space.

The transmissions were furnished through the cooperation of the Naval Research Laboratory at Bellevue, D. C. Two 20-kw crystal-controlled transmitters were used, one operating on 4045 kc and the other on 8650 kc, each being modulated by an unbalanced multivibrator circuit. The oscillographic film records were spot shots, each of about a second in length showing the individual pulses. The receiver-recorder was the Bureau of Standards field station, one mile south of Kensington, Maryland, a distance of 21 km (13 miles) from the NRL transmitter, NKF.

Transmissions were made each week on Mondays and Thursdays. 4045 kc signals were transmitted from 11:15 to 11:30 A.M., and from 4:00 to 4:15 P.M. On a few occasions, the transmissions were continued until midnight. In addition, transmissions on 1410 kc from Station WLEX, Lexington, Massachusetts, were received at the NBS field station at Kensington. The Naval Research Laboratory signals as well as those from Lexington were also received and studied at Tufts College near Boston.

Figure 3

Bureau of Standards field station near Kensington, Maryland

Figure 4

The first arrangement of apparatus at the NBS Kensington, Maryland field station. Left to right are shown the receiving set, amplifier and oscillograph.

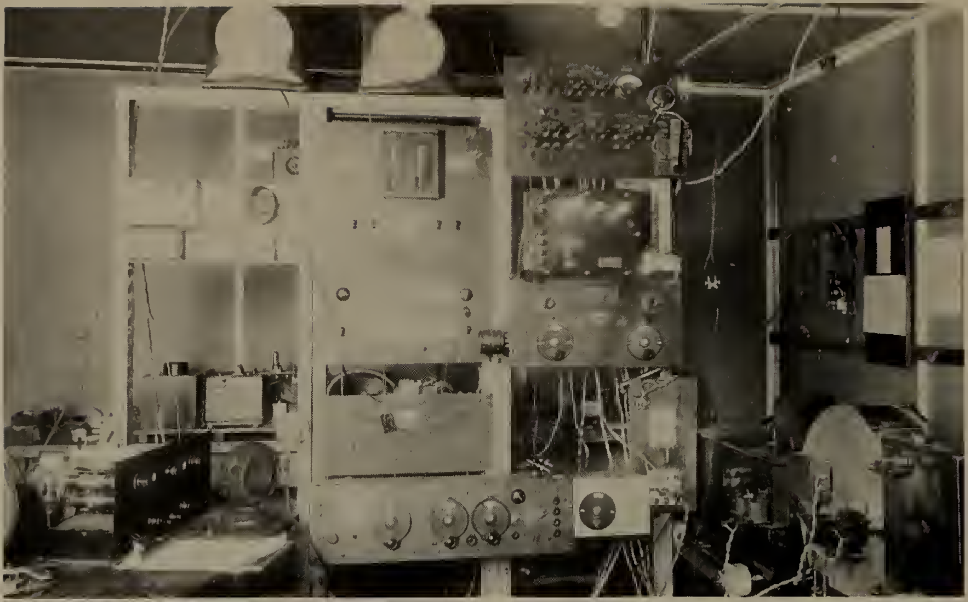
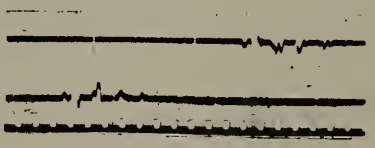
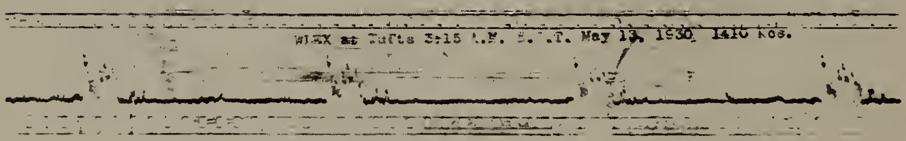


Figure 5

Kensington field station interior. Oscillograph at right, pulse signal receiving equipment in center, communications receiver and laboratory oscillator at left.



Typical 1410 kc pattern as received at Kensington, Md., during night period, (3:33 A.M., April 13, 1930). Note small peak, large peak, and then series of small peaks.



1410 kc as received at Tufts College at 3:15 A.M. E.S.T., May 13, 1930. Note extremely complex dawn patterns.

Figure 6

Typical records obtained at the NBS field station, Kensington, Maryland, and also as received at Tufts College, Boston

The transmissions from NKF for use by NBS started January 13 and ceased the middle of June 1930, when the transmitters were dismantled. The results of the observations furnished considerable evidence for the existence of several layers. Support was thus given to the picture of Appleton and Eckersley of several rather definite strata in the ionosphere.

In order that the echo signal work could proceed after the closing down of the NKF transmitters, a pulse transmitter was set up by the Bureau at Potomac Yards, just north of Alexandria, Virginia, and oscillographic measurements were made of the received pulses at the Kensington field station. These were manual step-by-step measurements. The transmitter had about 500 watts output and a frequency range of from 1.0 to 10 or 12 Mc. This probably marked the beginning of the regular 1-day-a-week series of observations lasting from before sunrise to about sunset one week and from 9 A.M. until midnight for alternate weeks. In the course of the work, observations were made on 10 frequencies from 590 to 10,000 kc. Most of the work was done on 4045 kc, since reflections were obtained more consistently on this frequency.

The difficulty with the method used to record the pulse was that each oscillogram taken gave the virtual height only over a short period. In order to obtain a clear idea of the variation of the layer height over an appreciable time interval, it was necessary for the observer to remain at the apparatus and take frequent oscillograms, each of which gave him but one point on the desired curve of virtual height as a function of time. In order that the pulses be separated sufficiently for accurate measurement, it was necessary to use film speeds of the order of 10 ft/sec, so that several hundred feet of film were required for a 24-hour run.

In 1931, therefore, the equipment was modified so that a continuous record of the virtual height could be made. The recorder used in 1930 was changed, so that in place of a vibrating-string oscilloscope a mirror was used which rotated in synchronism with the interrupter used to key the transmitter. In this manner a pattern was obtained which could be viewed on a screen in the manner customarily employed for viewing recurring phenomena with an oscilloscope.

The installation employed a transmitter of about 250 watts peak power operating on 4045 kc, with the interrupter connected in the grid circuit of the first amplifier. The transmitter was first used at the Kensington field station and the receiver at the old Radio Building of NBS, about five miles from the transmitter. At the recording point a receiving set of the double detection type was used, with the output of the second detector feeding into one stage of d.c. amplification which operated the oscilloscope.

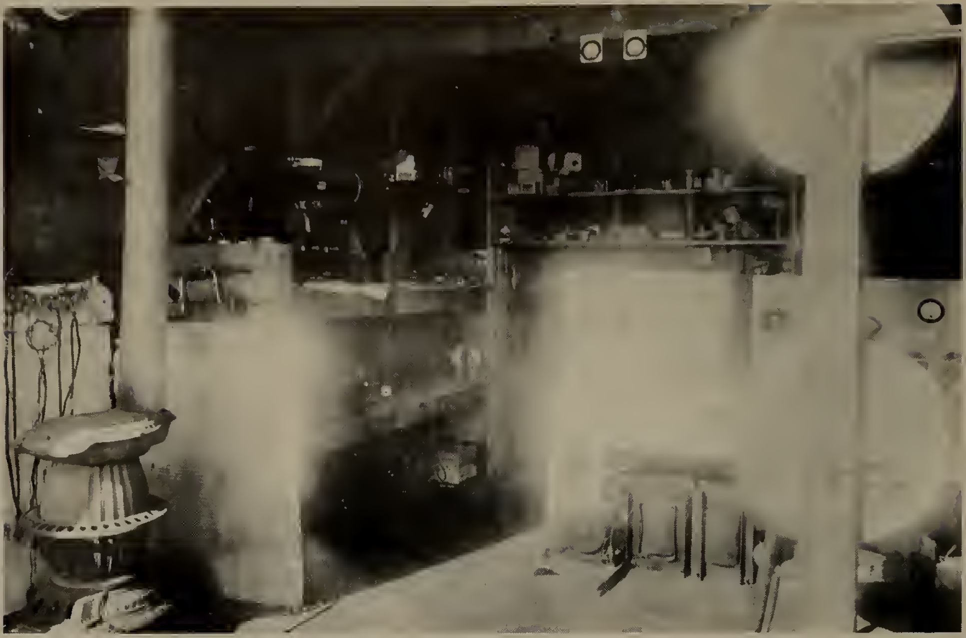


Figure 7

Potomac Yards field station. Pulse signal transmitter is shown left of center. Left foreground shows reels for variable length antenna.

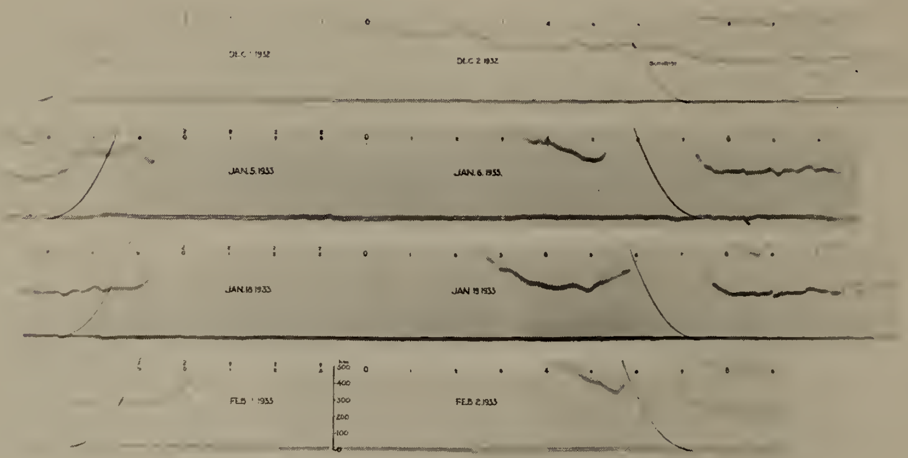


Figure 8

Continuous automatic records of the virtual height of the ionosphere on 4100 kc.

In order to eliminate difficulty encountered from interference coming in over the power lines, the interrupter and rotating mirror were geared to the synchronous motors by an odd gear ratio, namely 127 to 64, so that any disturbance patterns occurring at power frequency would not remain stationary and thus give spurious traces on the film. 35-mm film was used, driven through a system of gears by the same synchronous motor used for driving the rotating mirror. A film speed of 2.5 ft per 24 hours was used.

In August 1932 preparations were made for layer height measurements during the solar eclipse of August 31. A simple oscillator of 150 watts output was tried out as a pulse transmitter on 4200 kc and found to work satisfactorily. Four such transmitters were built, two being taken on the NBS eclipse expedition to Sydney, Nova Scotia and two being used at Beltsville to supplement the transmissions from the old transmitter. One of these transmitters was set up at the Kensington field station adjacent to the receivers and satisfactory pulse records were obtained. A doublet antenna was used for transmitting and an inverted L antenna for receiving.

In November 1932, the automatic height recorder was moved from Kensington to the field site at Beltsville. Other ionospheric equipment was moved about the same time from Kensington to Meadows, Maryland.

In March 1933, a pulse transmitter was completed and installed at Beltsville. The frequency range of the set was found to be from 1750 to 25,000 kc with all tubes in. By removing one power amplifier, the set could be made to operate up to 28,000 kc. The output was found to be 2 kw up to 10,000 kc with a decrease in output for higher frequencies. Manual step-by-step measurements were made at Meadows, Maryland. Regular observations were made one day a week, supplemented by special measurements at other times. Transmissions were made without reference to the hour, with the frequency being changed until the extraordinary critical frequency of the F2 layer was passed. Then the recording observer at Meadows would telephone the operator at Beltsville and another sweep would start.

In September 1933, condensers were added in parallel with the tuned stages of the pulse transmitter at Beltsville so that it would operate on frequencies as low as 1600 kc.

In September 1933, also, shop work was begun on a pulse transmitter capable of covering the broadcast frequency band and also overlapping the low frequency end of the high-frequency transmitter previously installed at Beltsville in March. The transmitter was completed in October 1934 and was installed at Meadows, Maryland. It initially had a frequency range of 500 to 2500 kc, but went through a number of changes, finally evolving into the Model B ionosonde which was destroyed by fire at Sterling, Virginia in January 1947.

Figure 9

Building at Beltsville field station which housed the automatic equipment for ionosphere height measurements.

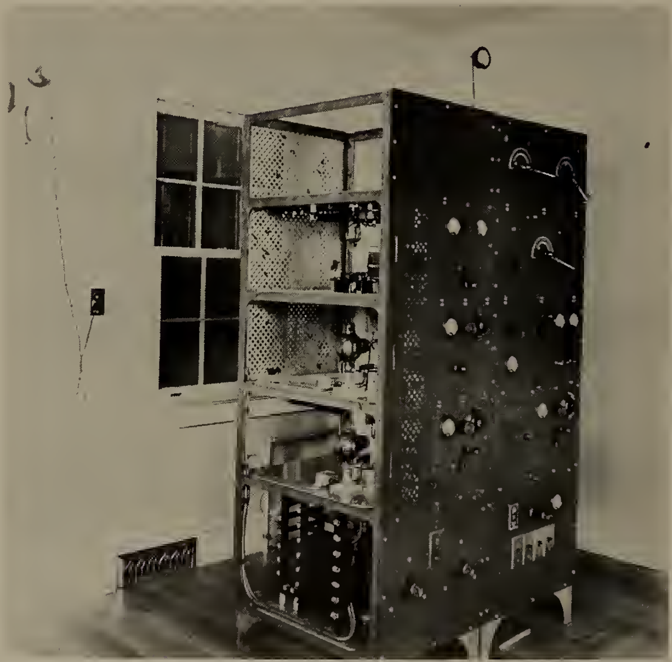


Figure 10

The 1-kw transmitter used at the NBS field station at Beltsville, Maryland (1750-25000 kc)

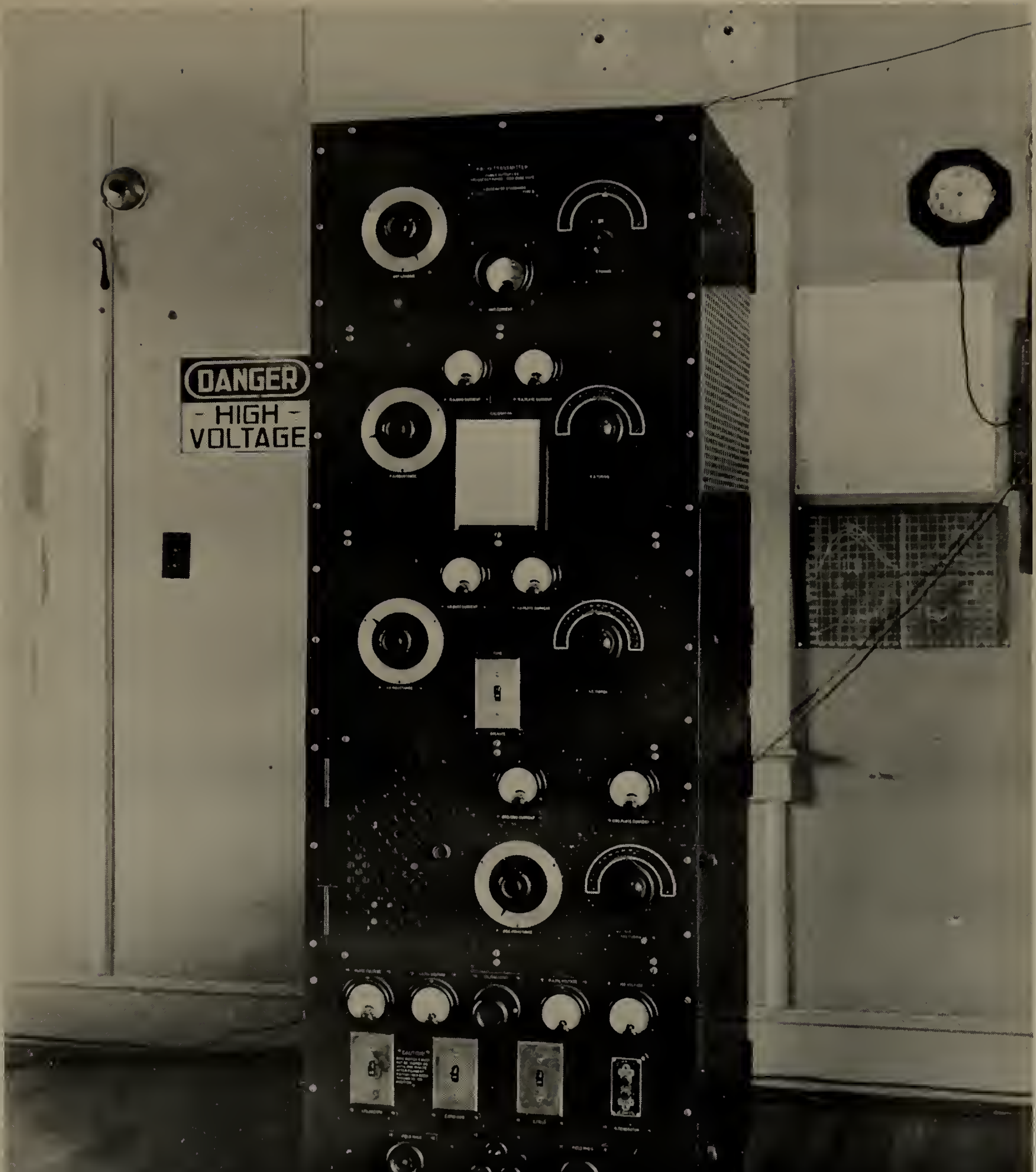


Figure 11

The broadcast band transmitter at the NBS Meadows, Maryland field station (500-2500 kc)

2. Early NBS Ionosondes

In 1933, the ionosonde used for fixed-frequency automatic height recording on 4100 kc was modified to cover the frequency range from 2.5 to 4.4 Mc continuously. The records were made on sensitized photographic paper four inches wide. This was the first sweep-frequency sounder to be used by NBS.

In 1940, a new type of ionosonde was designed and put into use by NBS. It consisted of a pulsed transmitter (operating over the frequency range 0.79 to 14 Mc) linked to a receiver by a beat-frequency system. The output of a variable-frequency oscillator was mixed with the output of an oscillator operating at the intermediate frequency of the receiver. The difference of these two frequencies was selected and amplified in the transmitter. Signals to be received were mixed with the output of the variable oscillator, the frequency difference then being the receiver intermediate frequency which was amplified and detected in the usual manner. The records were made on 35 mm film. Until the first quarter of 1946, this ionosonde was designated as the portable ionosphere recorder. At that time it received the new designation of the CRPL Model A ionosphere recorder. The present procedure is to call all such devices ionosondes rather than recorders.

Also in 1946 the ionosonde originally installed at Meadows, Maryland, with a frequency range of 500 to 2500 kc was designated as the Model B ionosphere recorder. By this time the ionosonde had been modified to cover the frequency range from 0.75 to 16 Mc in five bands. Photographic paper was used for making the records. This ionosonde was destroyed by fire in the latter part of January 1947.

Details of operation of the first sweep-frequency ionosonde, the Model A and the Model B ionosondes, are to be found in Appendix I.

III. The Interservice Radio Propagation Laboratory (1942-1946)

1. Organization and functions

In 1941 an aircraft disaster in the European Theater led to the formation of the British Interservice Ionosphere Bureau (ISIB), and the critical requirements of air force operation in the Southwest Pacific resulted in the establishment of the Australian Radio Propagation Committee (ARPC), the purposes of both being to furnish radio propagation data and predictions to their respective military services. Similarly in 1942 the Interservice Radio Propagation Laboratory (IRPL) was established in the National Bureau of Standards by order of the U.S. Joint Chiefs of Staff, acting through the Wave Propagation Committee of the U.S. Joint Communications Board.

Figure 12

Prototype of Model B ionosphere recorder as used at NBS field station at Meadows, Maryland

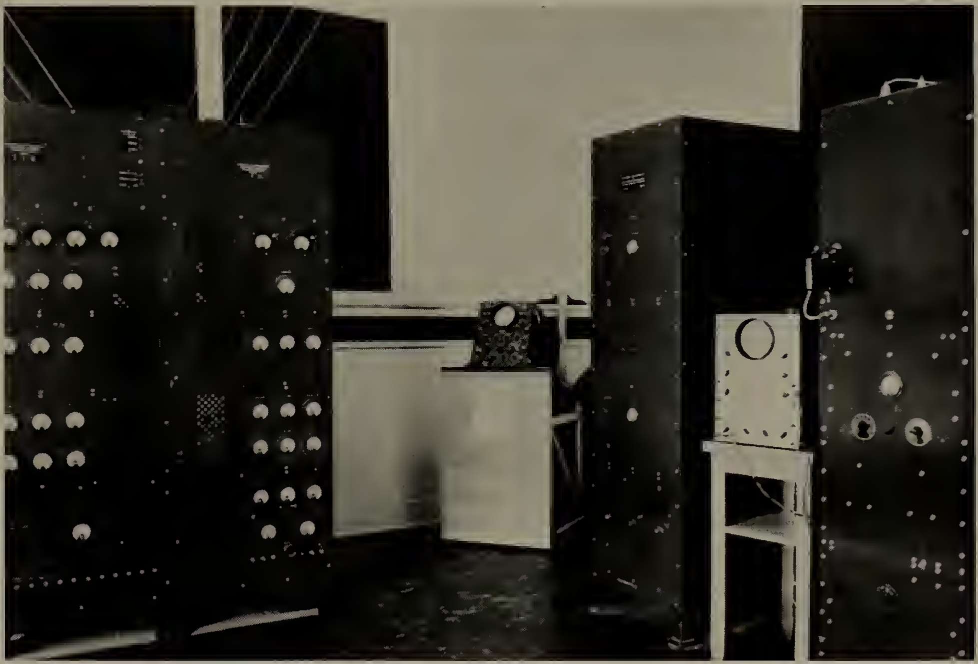


Figure 13

Final form of Model B ionosphere recorder as used at NBS field station near Sterling, Va.

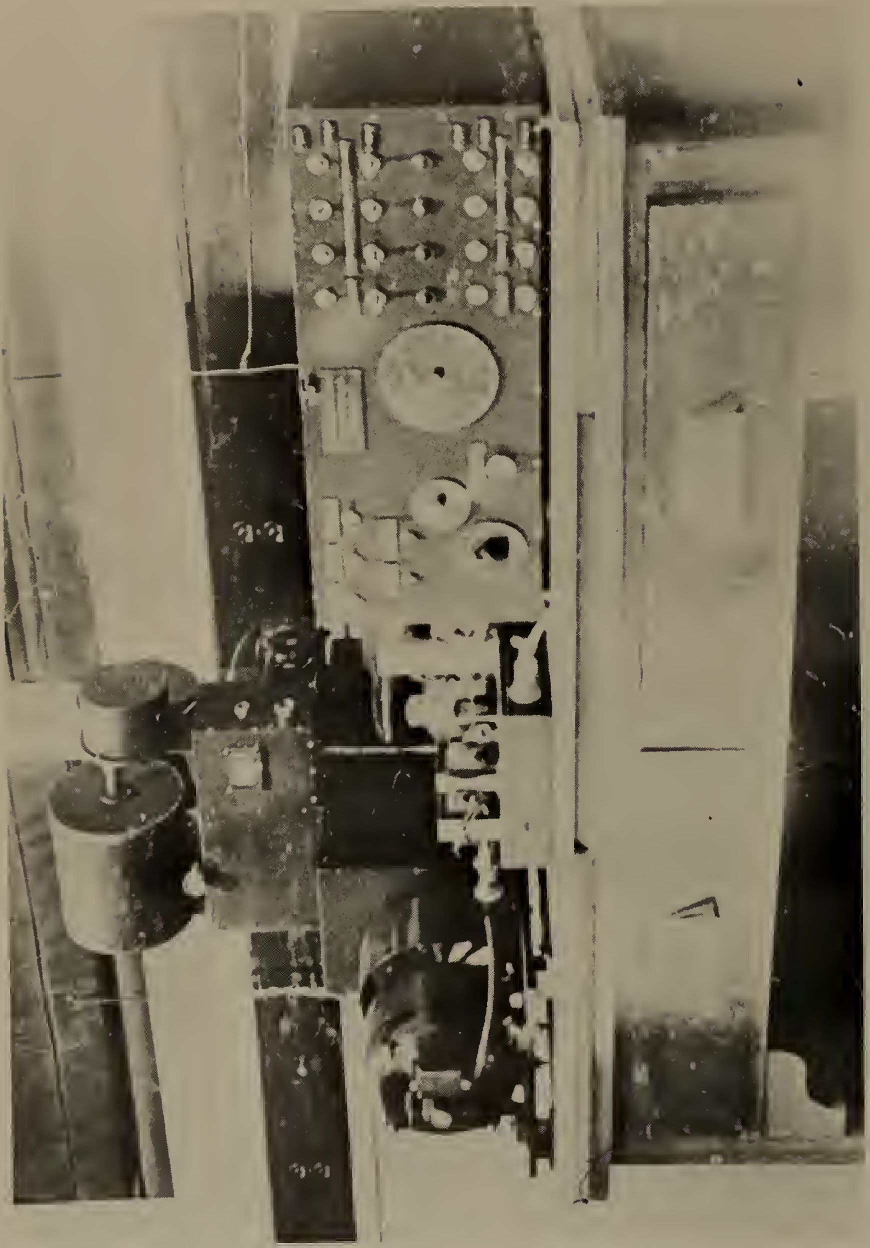


Figure 14

Control and recording equipment for Model B ionosonde as used at the NBS field station near Sterling, Va.

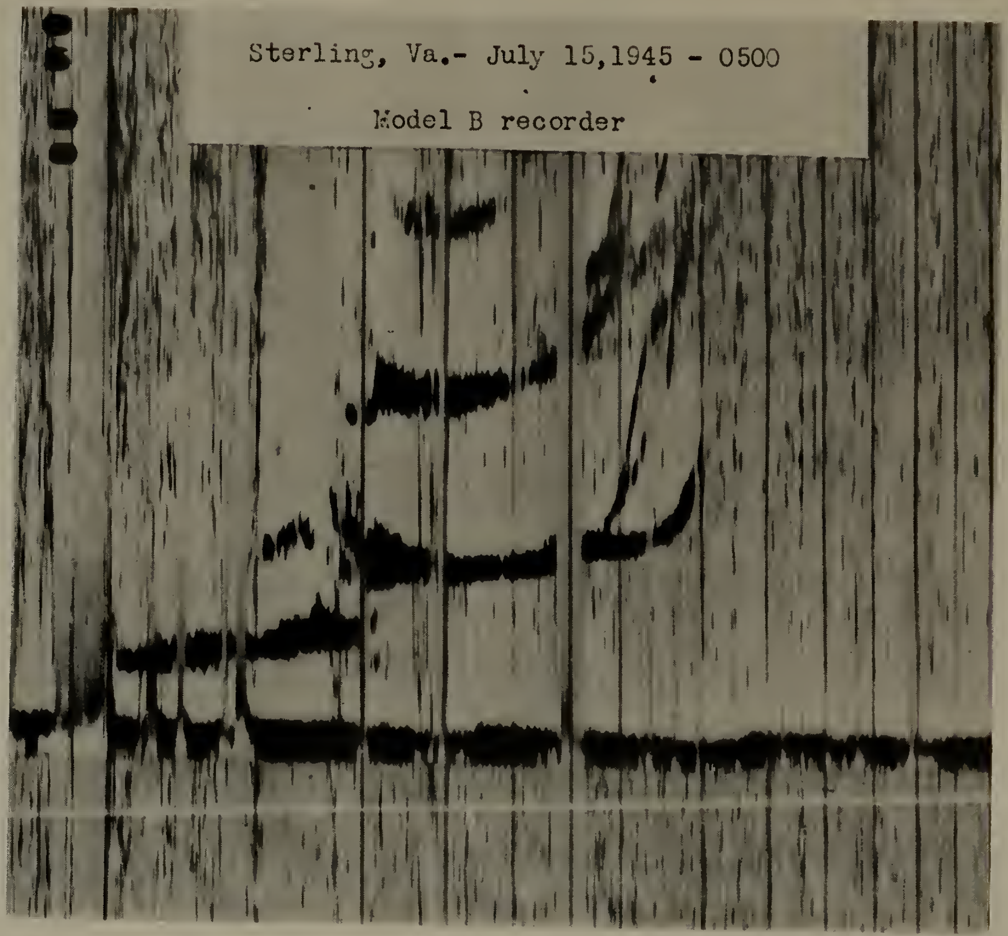


Figure 15

Typical ionogram made with Model B ionosonde at Sterling field station

Personnel of IRPL consisted essentially of the staff of the Radio Section of the Bureau (Division 1, Section 6), and were under the general supervision of J. H. Dellinger and Newbern Smith. The IRPL was to operate as the United States centralizing group for ionospheric and radio propagation data taken all over the world.

The functions of IRPL were to: (1) Centralize data on radio propagation and related effects, from all available sources; (2) Keep continuous world-wide records of ionosphere characteristics and related solar, geophysical and cosmic data; (3) Prepare the resulting information and furnish it to the Allied Military Services.

Associated directly with the IRPL besides the NBS field station at Washington, D. C. were laboratories at Stanford University, California; Louisiana State University, Baton Rouge, Louisiana; University of Puerto Rico, San Juan, Puerto Rico; Harvard University and Massachusetts Institute of Technology, both at Cambridge, Massachusetts. Except for the Massachusetts Institute of Technology, all these stations made routine soundings of the ionosphere.

Valuable help was received from the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, which maintained observatories at College, Alaska; Huancayo, Peru; Maui, Hawaii, T.H.; Clyde, Baffin Island; Reykjavik, Iceland; Trinidad, British West Indies; and Watheroo, Western Australia. In addition, DTM, CIW centralized solar and magnetic data.

Ionospheric and radio propagation data were eventually collected by the National Bureau of Standards from about 50 stations operated by the United States, Great Britain, Canada, Australia, New Zealand and the U.S.S.R. These data were published each month in the IRPL-F series of reports, starting in September, 1944 and stopping with the June 1946 issue (IRPL-F22). Thereafter the CRPL-F series continued the task of circulating the information.

At the outset of World War II, ionospheric observations were available to the Allied powers only at seven locations in the world: Washington, D. C.; University of Alaska; Slough, England; Huancayo, Peru; Watheroo and Canberra, Australia; and Christchurch, New Zealand. By the end of World War II, 44 stations were regularly reporting ionospheric observations to IRPL.

Of the original field stations, three were equipped with the automatic multifrequency pulse type ionosonde developed by DTM, namely Huancayo (installed in 1937), Watheroo (installed in 1938), and University of Alaska (installed in 1941). The stations at Huancayo and the University of Alaska later became associated with the Central Radio Propagation Laboratory of the National Bureau of Standards (CRPL).

In the early part of 1943, four automatic multifrequency ionosondes of the frequency modulation type developed by the National Physical Laboratory (British Type 249) were allocated to DTM by the British Admiralty. After several major changes were incorporated by DTM, these ionosondes were installed in 1944 at Clyde, Baffin Island; Reykjavik, Iceland; Trinidad, British West Indies; and Maui, Hawaii, T.H.

In 1943 also, DTM developed a manual type of ionosonde, one of the early models being used at Maui to supplement the BAD Type 249. Three ionosondes of this model were modified at the Kensington Laboratory of DTM to incorporate a 12-inch cathode-ray tube instead of the 3-inch tube normally used.

These modified ionosondes were used at Guam, Okinawa and Maui, and for a short time at Leyte.

In 1945, the DTM Model 3 manual multifrequency ionosonde was constructed by DTM and used at Trinidad, Maui and Adak.

Besides these stations operating under the sponsorship of DTM, a number of institutions in the United States began ionospheric measurements. Among these might be mentioned the University of Puerto Rico (1941); Leland Stanford University (1942); Louisana State University (1943); and Harvard University (1945). All of these developed their own design of ionosonde. It was not until 1949, when the CRPL Model C-2 ionosonde became available, that standardization of U.S. sounding equipment took place, with the C-2, and later the C-3, replacing the various types of manual and automatic ionosondes.

Thus by 1944 there were operating as U.S. controlled or associated stations some dozen more than when IRPL was established. Most of these were later associated with CRPL. In addition the other stations established by Canada, Great Britain, Australia and the USSR channeled their ionospheric data into IRPL for use on a world-wide basis. The prediction of radio propagation conditions was aided greatly by this large amount of data.

During the war the IRPL performed many specific services for the armed forces and commercial companies doing war work, involving consultation and advice on their special problems involving radio propagation. Types of problems included the determination of best usable frequencies for specific services, such as point-to-point, short-distance tactical operations, plane-to-ground, high frequency broadcast, the prediction of ground-wave and sky-wave distances under different conditions, advice as to types of antennas and lowest radiated power for specific purposes, and frequency allocation.

2. The International Radio Propagation Conference

In the spring of 1944, a series of meetings were held, first in England, and during April and May at the National Bureau of Standards in Washington, D. C., the purposes of which were to clarify and implement the existing information and procedures relating to radio communication problems.

Attending the meetings were representatives of the IRPL, DTM, ISIB, and ARPC as well as members of the armed services of the United States, Great Britain, Canada, Australia and New Zealand.

Among the topics considered were: Operational requirements of the armed services; characteristics of ionospheric observing systems; reduction of ionospheric records; inter-laboratory reporting of ionosphere data; general considerations in the interpretation of ionosphere data; characteristics of absorption measuring systems; reduction of field-intensity data; radio traffic records; and radio disturbance forecasting.

It was during the IRPC that the first set of international definitions of symbols and terminology for ionospheric use was provided. It was decided by the Conference that the transmission curves developed at NBS were to be used by all laboratories, and that standard time rather than local time be used for reporting data. During the series of meetings at NBS it was also decided that the location of the various observatories should be designated, in general, by the name of the nearest well known place, rather than by the exact location. (IRPL-C50, 1 May 1944).

3. Types of ionosondes used by stations affifiated with CRPL

a. Types developed by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington

(1) Automatic multifrequency equipment

This was a pulse-type ionosonde developed about 1936. It had a frequency range of from 16.0 to 0.516 Mc in six bands. Photosensitized paper 12 cm wide was used to record the sweeps.

Photographs and details of operation of this and other ionosondes used by stations affiliated with IRPL are to be found in Appendix II.

(2) Manual ionosphere recorder Model 1

This was an ionosonde developed by DTM in 1943 to implement the expanded U.S. program of ionospheric research as a result of the establishment of IRPL. The transmitter was a separate unit from the receiver.

Manual sweeps were made through a frequency range of 1.2 to 13.2 Mc in four bands, and the information thus obtained plotted on special graph paper. From 3 to 15 minutes was required to plot the information for one sweep, depending on the complexity of reflections.

(3) Manual ionosphere recorder modified Model 1

In 1945, three Model 1 manual recorders were modified to use a 12-inch cathode-ray tube in place of the original 3-inch tube. Sometimes this recorder was designated as the DTM Model 2.

(4) Manual ionospere recorder Model 3

This ionosonde differed from the Model 1 in that five frequency bands were used, and the top frequency was about 20 Mc as compared to 13.2 Mc for the Model 1. It was first placed in use the latter part of 1945.

b. British frequency-modulation Type 249

This comprised a continuous-wave transmitter, the frequency of which was repeatedly varied over the approximate range of 2 to 16 Mc at a rate of 25 times per second. A wide band-pass filter was incorporated in the output circuit of the transmitter, in order to limit the radiation to a band covering the frequency to which the receiver was tuned. The receiver tuning was varied over the whole band from 2 to 16 Mc in about one minute.

The frequency-modulation method was inefficient as compared to pulse methods, since the transmitter had to operate continuously and only a portion of the total received energy was utilized by the receiver. In addition the effective pulse width was in general not constant, since the rate of change of the transmitter frequency was not maintained at a uniform level over the frequency range. As a result, the height resolution of the equipment varied over the frequency band employed.

Four of these ionosondes were allocated by the British Admiralty to DTM in 1943, which modified them before placing them in use.

c. Australian Model Mark V automatic multifrequency ionosonde

This was a pulse-type sounder designed and built about 1945 by the Commonwealth Scientific and Industrial Research Organization of Australia for the Australian Radio-Wave Propagation Committee at the Radio Physics Laboratory, University of Sydney.

It had a frequency range of 1.0 to 13.0 Mc in four bands. The records were made on 35-mm film.

d. Ionosondes developed by various laboratories associated with NBS:

(1) Harvard University -- This was a pulse-type sounder developed about 1945 having a frequency range of from 0.79 to 14.0 Mc in four bands. Photosensitized paper three inches wide was used for recording the sweeps.

(2) Leland Stanford University -- This was a pulse-type sounder developed about 1946 with a frequency range of about 1.3 to 18.0 Mc in three bands. Photographic paper 3-5/8 inches wide was used for the records.

(3) Louisiana State University -- This ionosonde, developed about 1946, had a frequency range of from 2.62 to 15.68 Mc in three bands, the time for one frequency sweep being 10 minutes. Sensitized photographic paper, four inches wide, was used to record the sweeps.

(4) University of Puerto Rico -- This ionosonde had a frequency range of from 3 to 12 Mc and used 35-mm sensitized paper for recording the sweep. It used a mechanically driven mirror and a gas discharge tube. The time of a sweep was 11 minutes. This ionosonde was placed in service during the summer of 1945. Photographs either of the ionosonde or of the records were not available.

(5) U. S. Signal Corps Type AN/CPQ-7 (XE-1) -- This ionosonde was a multifrequency pulse-type, with a frequency range of 1 to 24 Mc. The time for one frequency sweep was one minute, and sensitized photographic paper was used to record the sweep. It was placed in service in the winter of 1949.

IV. Development of Practical Applications

1. Determination of maximum usable frequencies.

In high-frequency radio transmission there is, for any fixed distance of transmission, an upper limit of frequency which can be transmitted. The existence of this upper-limit frequency depends on the fact that the ionization in the atmosphere will reflect only waves of frequencies less than a certain critical value, which is called the maximum usable frequency (MUF).

The maximum usable frequency for high-frequency transmission via the ionosphere over any given path at any instant is an important quantity. If the operating frequency is above the maximum usable frequency the wave skips, since it will then not be reflected so as to reach the desired reception point. As the operating frequency is decreased below the maximum usable frequency in the daytime, it becomes increasingly attenuated. Hence it is desirable for transmission to occur on a frequency as near to the maximum usable frequency over the path as is feasible under prevailing conditions. For this reason a technique of prediction whereby the proper operating frequency may be chosen with regard to the maximum usable frequency is highly desirable.

In an ionized layer there exists a maximum usable frequency for reflection at oblique incidence which corresponds to the critical frequency at vertical incidence. This was determined by Smith, Kirby and Gilliland of NBS in 1936. In May of the next year, the basic idea for the application of this to the determination of MUFs from vertical incidence critical frequencies was described by Smith. The procedure involved the "secant law". This law states that the frequency which will be reflected from a plane ionosphere at a given height at oblique incidence is equal to the product of the secant of the angle of incidence (Φ) and the critical frequency which will just be reflected at vertical incidence at the same true height.

In 1938 the method was expanded to include the effects of the earth's curvature and the earth's magnetic field, as well as absorption or reflection from lower layers.

In practice, a coordinate scale, coinciding with that on which the ionograms are made, is used to plot a family of curves of virtual height against maximum usable frequency, where the MUF is obtained from the secant law for values of $\sec\Phi$ corresponding to different values of the virtual height for a fixed distance. These graphs, known as "transmission curves", are made parametric in the MUF. A transparent overlay is made to scale with this family of transmission curves drawn on it. If the overlay is then placed on the ionogram, the intersections of the curves with the h'f trace will give, for the fixed distance, values of the MUF reflected at the oblique incidence from the virtual heights of the intersection. At first the fixed distance was chosen as 3500 km, but in the early 1940's the distances of 1500 and 3000 were used.

With a few modifications, this method of determining MUFs from vertical-incidence soundings is still employed by CRPL field stations and associated laboratories. When the CRPL Model C-2 ionosonde was developed in 1949, the logarithmic character of the frequency scale was used to devise a MUF-factor scale and thus eliminate the need for the family of MUF curves. The MUF-factor is the ratio between the MUF and the vertical-incidence critical frequency of the ordinary wave.

2. Sudden ionosphere disturbances.

During the period 1927-39, Mogel in Germany observed that the field strength of short-wave signals decreased during magnetic storms.

In October 1935, Dellinger of NBS reported the occurrence of radio fade-outs on March 20, May 12, July 6 and August 30, 1935. The radio evidence of the phenomenon was a sudden disappearance of high-frequency long-distance radio signals for several minutes, the complete process of fading out and reappearing occupying about 15 minutes.

At Mount Wilson Observatory, on July 6 and August 30, 1935, bright eruptions (solar flares) had been observed on the sun within a few minutes of the time of the radio fade-outs, while for the other two dates no observations had been made at the time of the fade-outs. Beverage of the Radio Corporation of America reported to Dellinger the occurrence of a large sharp pulse on an earth-current recorder within a few minutes of the time of several of the radio fade-outs.

From much more data of this sort, the fade-out (known as the Mögel-Dellinger effect until 1937, and thereafter called a sudden ionosphere disturbance or short wave fade-out) has been correlated with solar flares. Below about 1 Mc the enhanced ionization produced by the flares frequently causes an increase in signal strength instead of the fade-out observed on higher frequencies.

3. Predictions of ionospheric phenomenon.

a. Prediction of critical frequencies

As early as 1936 a relation between solar activity and ionospheric characteristics had been found. During times of low solar activity, as evidenced by a low sunspot number, the critical frequencies of the F2 layer were found to be appreciably lower than during periods of high solar activity. This was graphically indicated by workers at the National Bureau of Standards, using data obtained with the multi-frequency ionosonde developed in 1933, and covering half of a sunspot cycle.

Since it appeared that a high value of sunspot number usually corresponded to a high value of ionizing radiation, it followed that a method of predicting solar activity (i.e. the average sunspot number) was the first step in making an ionospheric prediction.

In order that IRPL might use the data which were being received from all over the world for prediction purposes, it was necessary not only to understand their geographic, diurnal and seasonal variations but also to determine their relationship to relative sunspot numbers. While a simple correlation of ionosphere characteristics with relative sunspot numbers had been found, during the war the trends of the variation of these characteristics with sunspot number were determined for the locations on earth of many of the ionosphere stations.

In 1943 a method of predicting the ionospheric characteristics was presented which involved the extrapolation of a curve of 12-month running average sunspot number against time. It was found advantageous to group the various months into seasons, within which the solar radiation did not vary appreciably. For temperate latitudes, the months were grouped as follows: (a) November, December, January and February; (b) March and April; (c) May, June and July; (d) September and October.

The variation of critical frequencies at any station with sunspot cycle, without regarding seasonal variation, but for any particular hour, was represented by curves of 12-month running averages of the monthly average critical frequencies plotted against the 12-month running averages of the monthly average Zurich sunspot numbers. These so-called trend curves, for all stations and for all times of day, appeared to exhibit the same slope, a feature of advantage when but few data were available.

From the predicted average sunspot number for a given season, the predicted seasonal value of the 12-month running average of the monthly average critical frequency could be made for any stations, for any time of day, simply by extrapolating the particular trend curve. For the F1 and E layers, it was found necessary only to estimate the 12-month running average critical frequency for one time of day, usually noon, since the diurnal variation of the critical frequency expressed as percentages of the noon value was independent of sunspot number.

To correct for seasonal variations, an average seasonal value of the predicted critical frequency was obtained by multiplying the predicted 12-month-running-average-value for the middle of the season by a "seasonal index", defined as the ratio of the seasonal average to the 12-month running average at midseason.

World-wide prediction charts of critical frequencies were prepared, in terms of the parameters latitude and local time. Where data were scanty, the critical frequencies for corresponding points in the opposite hemisphere and the reversed season were used.

b. The longitude effect.

Another result of the improved world-wide coverage, the so-called "longitude effect", was put into operational use by IRPL in 1943. This effect indicated that ionosphere characteristics were not the same at the same local time for stations at about the same latitude but different longitudes, as had been supposed. The phenomenon of variations of ionospheric characteristics at a given latitude other than those attributable solely to local time was termed the "longitude effect". The results for different stations at the equinoxes plotted against both magnetic latitude and geographic latitude indicated that magnetic as well as geographic latitude played a part in controlling the F2 layer morphology.

As a result, the world was divided, for practical operational purposes, into east, (E), west, (W), and intermediate (I) zones. The "E" and "W" zones were each chosen so as to extend for 60° of geomagnetic longitude on either side of their respective center meridians passing through the two geomagnetic poles. The two "I" zones each had a width of 60°. In each zone the characteristics of the ionosphere were averaged for the range of longitudes, to obtain a practical approximation.

c. Forecasting of ionosphere storms.

A program was undertaken by IRPL, in collaboration with DTM, to study the relations between ionosphere storms and the sun, whose radiations produced the storms. Improved observational techniques, like the Harvard University coronograph, a device for photographing the extremely active solar corona, contributed to the study. As a result of the analysis, a weekly forecast was issued, which proved to be of some value to the armed services.

A different approach, however, led to a considerably more accurate service of forecasting. In this, studies of the behavior of radio direction-finding bearings over the North Atlantic path showed that it was possible to issue warnings of radio disturbance from a few hours to a half day or more in advance.

The direction finder was operated in the usual manner. Its important characteristic was that it gave an instantaneous bearing indication, so that rapid shifts could be noted. The bearing data were used in conjunction with observations of the fluctuation of the horizontal component of the earth's magnetic field. The fluctuations of magnetograph readings were taken over the most active three-hour period in the preceding 24-hour period and classified into a disturbance figure. By the use of these techniques, it was often possible to recognize ionosphere storms in their initial phase.

d. MUF over long paths.

Another problem faced by the IRPL was the development of a simple and rapid method of obtaining the maximum usable frequency (MUF) over any path in any part of the world. The groundwork for this was laid in 1936 when the "transmission curve" method of scaling ionospheric records was devised, which led to values which could be applied to critical-frequency data to obtain MUF values. These values were satisfactory for distances up to 2500 miles (4000 km), but for greater distances, the method of multiple hops proved clumsy, and indeed, quite inadequate in the light of observed radio propagation data.

Consequently the empirical "two-control point" method was devised (independently at the IRPL and ISIB) for paths longer than 2500 miles. In this method the MUF over such a path is limited by the lower of the 2500-mile MUF at two control points, 1250 miles from each station along the great-circle path connecting the two stations. Considerable further improvement was made in MUF calculations by including the effects of "sporadic-E" propagation, also on a two-control point basis.

World charts were prepared from this information, giving predictions of maximum usable frequencies three months in advance.

V. The Central Radio Propagation Laboratory (Since 1946)

1. Organization and functions

On May 1, 1946, the Central Radio Propagation Laboratory was formally established as Division 14 of the National Bureau of Standards, with J. H. Dellinger as Chief. The Division's work had been previously carried on as Section 6 of the Electricity Division (Division 1). The new Division took over the work of radio propagation research and prediction which had been done by the Interservice Radio Propagation Laboratory, as well as the measurements and standards work of NBS in the radio field.

The Division operated the standard-frequency transmitting station at Beltsville, Maryland, and the 450-acre radio propagation laboratory at Sterling, Virginia. In addition, six other radio propagation field stations were placed under the control of CRPL. These were: Adak, Alaska; Maui, T. H.; Palmyra Island; Guam Island; Manila, P. I.; and Trinidad, B.W.I. The stations at Adak, Maui, and Trinidad had been operated by DTM; that at Guam by the U. S. Signal Corps; while the stations at Manila and Palmyra were activated by CRPL.

Nine sections were established in CRPL. They were: Basic Ionospheric Research; Basic Microwave Research; Regular Propagation Services; Frequency Utilization Research; Experimental Ionospheric Research; Experimental Microwave Research; Regular Propagation Measurements; Ionospheric Measurements; and Microwave Measurement Standards.

In February 1949, Division 14 of NBS was reorganized and three subdivisions formed: the Ionosphere Research Laboratory, the Systems Research Laboratory, and the Measurements Standards Laboratory.

The Ionosphere Research Laboratory, consisting of three sections, carried out basic research on the upper atmosphere and its ability to reflect radio waves. It also controlled the operation of the various NBS field stations.

The Systems Research Laboratory, which also consisted of three sections, applied propagation information to the practical problems of communications with particular consideration for the advantages and limitations of the types of systems involved.

The Measurements Standards Laboratory, consisting of two sections, conducted research in methods for measuring electric quantities at H.F. and microwave frequencies.

A shortage of space confronted CRPL from the start. At various times different sections or parts of sections were quartered in several buildings on the Bureau grounds or in other buildings in Washington. In 1950 Congress provided authorization for a laboratory building for CRPL with the suggestion that it would be desirable to locate the facilities outside of the Washington area. A Site Selection Board finally recommended Boulder, Colorado as the location best meeting all of the important criteria. Shortly thereafter, the citizens of Boulder through private contribution offered to the Government a tract of 217 acres, on which the laboratory buildings are now located.

The Radio Building, which houses the Central Radio Propagation Laboratory, was completed in April 1954. It is a reinforced concrete wing-type structure, having a gross area of 227,000 square feet and a net floor space of 172,000 square feet. The design of the building included a number of special features, such as stable platforms for mounting delicate instruments, an open-air roof laboratory for unconfined experiments, and ground-level access to all floors, except the roof.

Portions of the staff of CRPL were transferred to Boulder in 1951 and were assigned temporary quarters. The rest of the staff which was to make the transfer from Washington occupied the Radio Building during May, June and July 1954.

On September 14, 1954, President Dwight D. Eisenhower formally dedicated the Boulder Laboratories of the National Bureau of Standards. Also participating in the program were Sinclair Weeks, the Secretary of Commerce; Dr. Allen V. Astin, Director of the National Bureau of Standards; and Dr. Frederick W. Brown, Director of the NBS Boulder Laboratories.

By 1957, the organization of CRPL at Boulder had taken the form of three divisions: Radio Propagation Physics, Radio Propagation Engineering, and Radio Standards.

The Radio Propagation Physics Division deals with the physics of radio wave propagation with particular reference to the ionosphere. This work includes studies and experiments to find out how the ionosphere is formed and how it affects radio communications. The work of this Division consists of the following broad phases: 1. Laboratory experiments to develop suitable types of equipment for specific kinds of investigation. 2. Accumulation of data on a routine basis from fixed and mobile field stations, together with supervision of the operational procedures. 3. Utilization of these data in applications to problems of radio communication or to basic research. 4. Development of better methods of securing and processing basic data. Five sections make up the division; Upper Atmospheric Physics; Ionospheric Research; Regular Propagation Services; Sun-Earth Relationships; and Very High Frequency Research.

The primary responsibilities of the Radio Propagation Engineering Division are tropospheric or "line-of-sight" propagation research and related studies of frequency utilization. Tropospheric propagation research is necessary to measure and evaluate the effects which terrain, climate and meteorology have on very-high-frequency, ultra-high-frequency and microwave radio systems. Frequency utilization studies are designed to provide technical data which will assist in the allocating, regulating, and advisory activities of such agencies as the Federal Communications Commission and the Department of Defense. The division consists of eight sections: Data Reduction Instrumentation, Modulation Systems, Navigation Systems, Radio Noise, Tropospheric Measurements, Tropospheric Analysis, Radio Systems Application Engineering, and Radio Meteorology.

Through the Radio Standards Division, the National Bureau of Standards conducts a continuing program for the establishment, maintenance and improvement of basic standards and precision methods of measurement throughout the radio frequency spectrum. Six sections comprise this division: High-Frequency Impedance Standards, Electronic Calibration Center, Microwave Circuit Standards. The Division also operates the two standard-frequency transmitters WWV (located near Washington, D. C.) and WWVH (Maui, Hawaii).

2. Development of the CRPL Model C-ionosondes.

Starting in 1946 a new series of ionosondes was developed at NBS. The first in the series was designated as the CRPL Model C ionosphere recorder. For consistency, it will be referred to as the Model C-1, since the three models following were named the C-2, C-3 and C-4. Complete details of all these ionosondes are to be found in Appendix III.

a. The Model C-1

This ionosonde employed a heterodyne method similar to that used in the NBS Model A ionosonde. It was designed by P. G. Sulzer, and incorporated his idea of untuned receiver input and transmitter circuits. It had a frequency range from 1.0 to 20.0 Mc and used 35 mm film for recording the sweeps, but there was no scale of frequency or height on the record. A lady's wrist watch was photographed with each sweep to provide the time at which the sweep was made.

b. The Model C-2

The experience gained in the development of the Model C-1 was used in the design of an improved model, the CRPL Model C-2.

This was the first completely automatic ionosonde to use in continuous heavy duty the heterodyne pulse transmitter arrangement described by Sulzer. It was first placed in use in 1947.

The Model C-2 differed from the C-1 in that the frequency range was increased to 24 Mc in the prototype model, and to 25 Mc in the production model. In addition, both frequency and height markers appeared on each sweep record (or ionogram), and the date and time of each sweep was photographically recorded on each ionogram.

c. The Model C-3

While the fundamental features of the Model C-3 were the same as those of the Model C-2, a number of basic improvements were incorporated. It was first placed in use in 1950.

d. The Model C-4

This model, while basically resembling the Model C-3, had a number of major changes made in its design. This ionosonde was placed in service in 1957.

3. Antenna testing and design

Prior to 1949, little attention was given to the design of antennas primarily for vertical incidence sounding. Those antennas in use for radio receiving were employed or adapted to the particular sounder. The earliest ionosondes used combinations of inverted-L antennas, each antenna serving for two different frequency ranges. By the early 1940's, vertical rhombic antennas and single wire delta antennas had come into use.

With the development of the CRPL Model C ionosondes having a frequency range of 1 to 25 Mc, it became apparent that serious attention had to be given to the determination of the best type of ionosonde antenna.

The requirements of such an antenna were:

(1) The impedance of the antenna system had to be relatively uniform over the frequency range, and, for purposes of maximum power transfer, as nearly equal as possible to the output impedance of the transmitter (of the order of 1,000 ohms).

(2) The radiation had to be substantially in the vertical direction.

(3) The antenna had to be as efficient a radiator as possible.

During the first quarter of 1949, personnel of NBS made operational tests of three types of ionosphere antennas: a vertical rhombic, a new double-W, and a multiple-wire delta. Using the double-W as a reference, automatic ionosphere records were made on each antenna and compared. The results indicated that the double-W antenna was slightly the best, with the delta a close second. In view of its simpler, more rugged and more economical installation, the delta antenna was tentatively selected for operational use.

In May 1950, Cones, Cottony and Watts of NBS reported on tests made with scale models of antennas, which led to the ionospheric measurements.

The radiation pattern of the test antenna was measured using a model antenna technique. The principles of this technique consisted of constructing a model antenna having the configuration of the full-sized antenna under study, but with the linear dimensions reduced by some scaling factor n. A vee frame carries a target transmitter along an arc of a circle having a 53-foot radius. The model antenna is located at the center of the range, and its response at different vertical angles is measured by moving the target transmitter over the

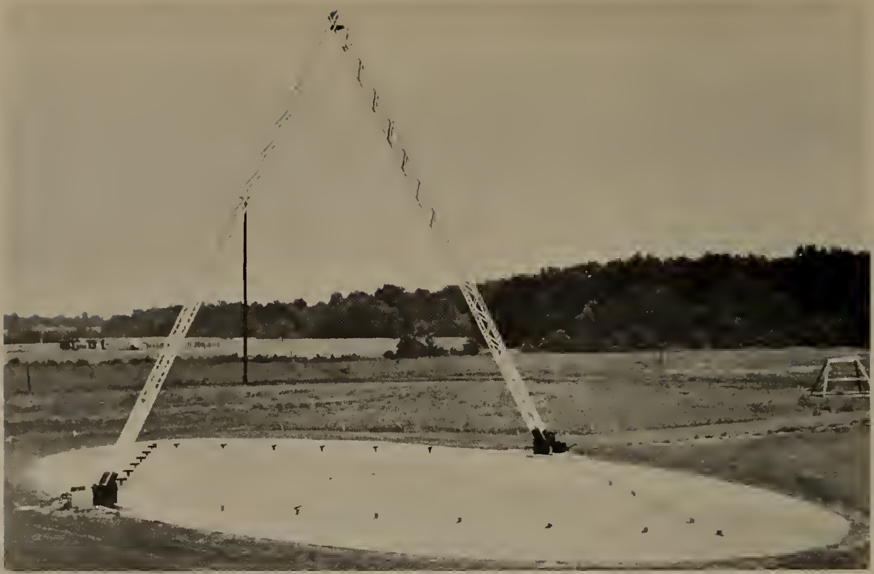


Figure 16

Model antenna range at the Sterling, Va. field station. The target transmitter is mounted at the top of the vee, and the model antenna at the center of the range.

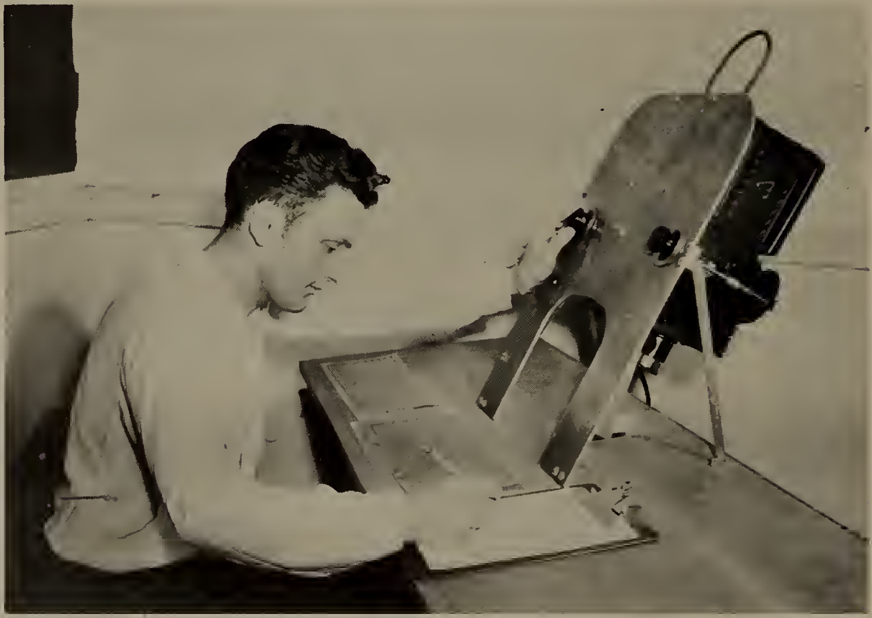


Figure 17

The original form of scaling table

antenna from one side to the other. The transmitter is operated at a frequency n times the operating frequency of the full-sized antenna. It thus became possible to bring the target transmitter much closer physically to the antenna under test and still maintain a spacing of several wave lengths at the scaled-up frequency.

The study showed that the impedance of the multiple-wire delta antenna was reasonably uniform over the operating range of 1 to 25 Mc, and compared favorably with the double-W antenna. The mean impedance of the delta was sufficiently close to 600 ohms to permit satisfactory operation with a 600-ohm transmission line of any moderate length. The legs of the multiple-wire delta used operationally were nominally 130 ft. long. In 1955, some test installations were made of multiple-wire delta antennas having a 300-ft. leg length, in order to obtain better low-frequency response of the antenna. The initial results indicated that considerable improvement in low-frequency response was obtained.

In practice, one multiple-wire delta antenna is used with the transmitter, with a similar antenna used for the receiver of the ionosonde.

The present experimental facilities of the Antenna Studies project at Boulder, Colorado include a model antenna range on Table Mesa about ten air miles north of the Boulder Laboratories of NBS, which contains a turntable and an automatic radiation pattern recorder, for measurement of the antenna patterns as well as equipment for measurement of gain, impedance, and other properties of antennas. In addition to this installation, there is another antenna range on top of the Green Mountain Mesa which is located on the western edge of the Boulder Laboratories' property. This range is equipped to measure the radiation patterns of antennas designed for vertical incidence soundings.

4. Ionospheric field stations operated by or associated with NBS.

Until 1946, NBS operated only the Washington field station for making vertical incidence soundings. With the establishment of CRPL in that year, six additional field stations were placed under its supervision. These are named in Section IV.1.

Besides the stations operated by CRPL, a number of field stations became associated with the organization, prior to 1950. These were Fairbanks, Alaska (the Geophysical Institute of the University of Alaska), Harvard University, Louisiana State University, and Huancayo, Peru.

During 1949, 1950 and 1951, CRPL activated stations at Barrow, Alaska; Anchorage, Alaska; Narsarssuak, Greenland; Panama Canal Zone; and near San Juan, Puerto Rico. Over the same period the U. S. Army Signal Corps activated a station at Belmar, N. J. (later moved to Ft. Monmouth, N. J.), while the Danish URSI Commission established a station at Godhavn, Greenland and the Icelandic Post and Telegraph activated a station at Reykjavik, Iceland. The stations at Belmar, Godhavn and Reykjavik were regarded as associated laboratories of the National Bureau of Standards. In 1952 the Manila Observatory activated a station in the Philippines at Baguio.

During the period from 1954 to 1956 the Geophysical Institute of Huancayo, Peru established another station at Talara, Peru; and the U. S. Army Signal Corps activated a station near the geomagnetic north pole at Thule, Greenland. Both of these stations were regarded as associated laboratories of the National Bureau of Standards.

In the late fall of 1956 plans were made for the operation of several stations in connection with the International Geophysical Year, - one at St. Johns, Newfoundland, several in Antarctica, and a number in the temperate zones.

The present classification of field stations is as follows:

(1) Stations manned by NBS personnel, such as Maui, T. H.

(2) Stations operated under contract with NBS, such as the one at Fairbanks, Alaska.

(3) Stations operated by the U. S. Signal Corps, but following the operational procedures of NBS stations, such as White Sands, N. M.

(4) Stations operated by foreign nationals, but amenable to the operational procedures of NBS stations, such as Godhavn, Greenland.

Details of operation of all these field stations are to be found in Appendix IV. Information included comprises the dates of operational starting and ending (where appropriate), organization sponsoring the station, ionosondes used, and names of NBS personnel in charge of the respective stations.

5. Reduction of ionospheric data

In order to be useful, the ionograms must be interpreted as a series of numerical values of the various ionospheric characteristics. In addition, a set of alphabetical symbols has been established by international agreement to indicate particular ionospheric or non-ionospheric conditions which modify the numerical values. Periodically, representatives from various nations meet and discuss ionospheric problems of interpretation, with the meetings followed by new pronouncements as to procedures.

Of particular importance is the measurement of the penetration or critical frequencies of the different layers of the ionosphere, the minimum virtual heights of the layers, and the transmission factors (known as MUF-factors) for selected distances. The design of ionosondes and the scaling procedures are aimed at the most practical and efficient method of making these measurements.

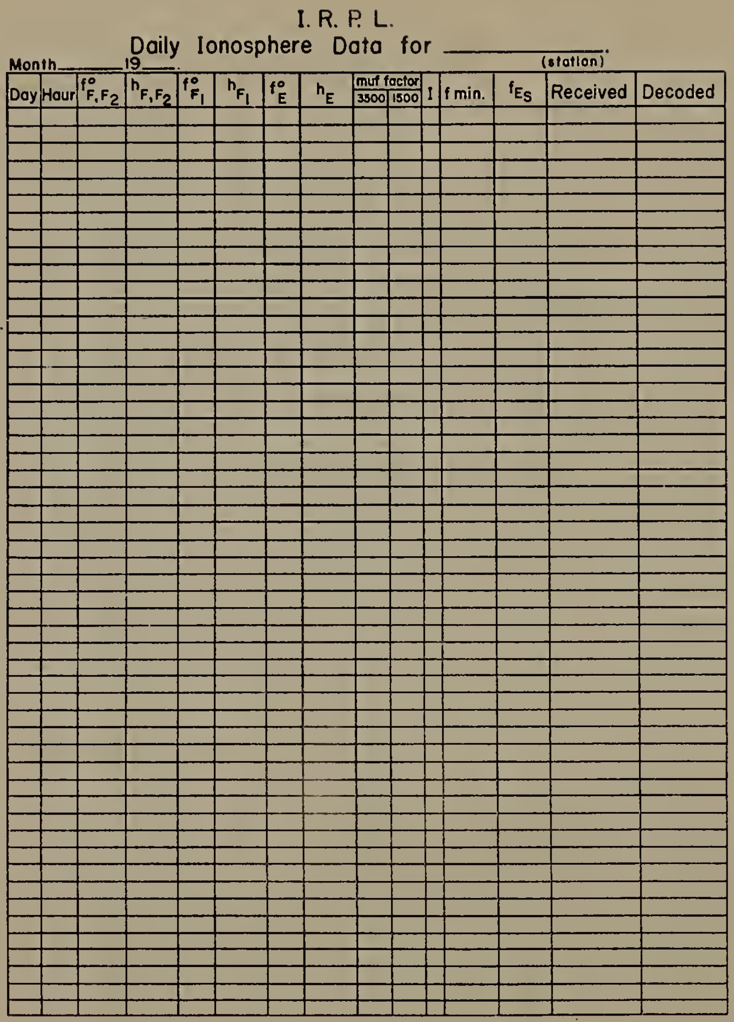
During the early days of ionospheric work at NBS, virtual heights of the layers were the only quantities measured, in terms of the delay time between the base signal (or ground pulse) and the return echo from the ionosphere. As sweep-frequency ionosondes were developed, the scaling of critical frequencies and MUF-factors became possible.

For the reduction of data from the ionograms, overlays were employed carrying scales of frequency, virtual height, and transmission curves either of maximum usable frequency or, for recent years, MUF-factors. With the paper ionograms of the early ionosondes, the overlay was superposed on the individual ionogram and the desired information scaled. With the advent of recording ionosonde sweeps on film, various methods of projection were used. At first a film-strip projector was employed and the image projected against an opaque overlay. With the development of the CRPL Model C-2 ionosonde a special type of scaling table was designed, in which the film was projected onto a mirror, thence to the underside of a ground-glass screen. A transparent overlay was then superposed on the image of the ionogram. With some modifications, this system is still used in the reduction of ionograms at CRPL stations and associated laboratories.

The scaled data are entered on two types of sheets. On the daily sheet, the hourly values of all characteristics for a given day are tabulated for each of the 24 hours. On the monthly sheet each separate characteristic is tabulated for the entire month and monthly median values prepared.

In 1955 a graphical representation of frequencies, termed the f-plot, was introduced as a useful accessory in the scaling of ionospheric data. On the f-plot are plotted, for each 15-minute sweep, the critical frequencies of all the regular layers, the minimum frequency of ionospheric reflection, and the blanketing frequency of sporadic E, together with the indication of the type of Es present.

Since considerable time is required for the manual tabulation and processing of data, machine processing has been applied to the determination of monthly median values, frequency distribution



I. R. P. L.

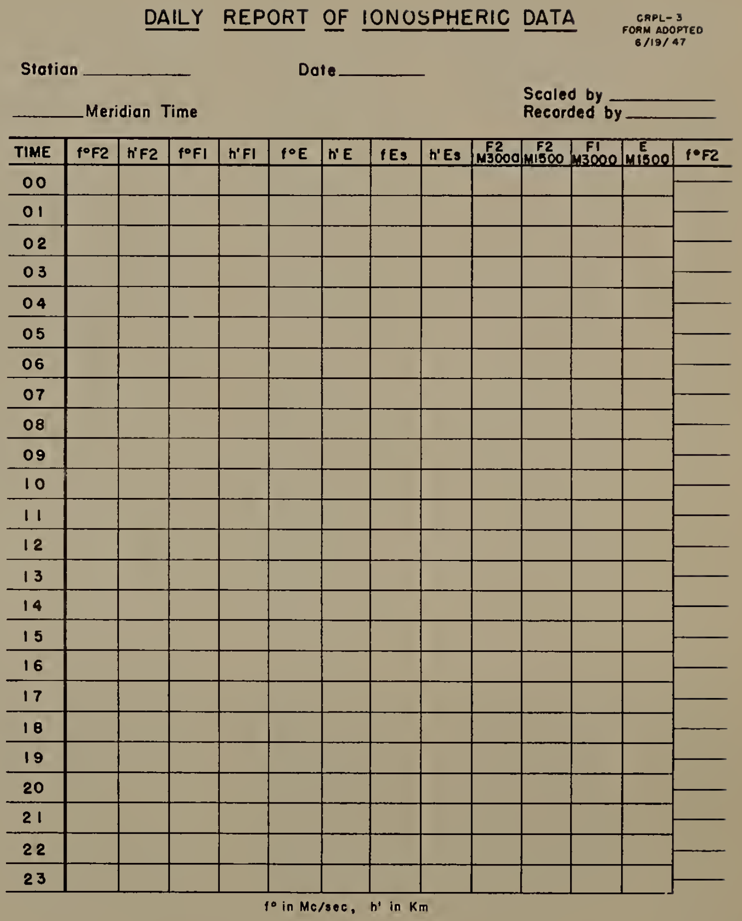
Daily Ionosphere Data for ____________.
(station)

Month________19____.

Day	Hour	f^{o}_{F,F_2}	h_{F,F_2}	$f^{o}_{F_1}$	h_{F_1}	f^{o}_{E}	h_E	muf factor		I	f min.	f_{E_S}	Received	Decoded
								3500	1500					

Figure 18

The IRPL daily ionosphere report sheet



DAILY REPORT OF IONOSPHERIC DATA

CRPL-3
FORM ADOPTED
6/19/47

Station ____________ Date ________

________Meridian Time

Scaled by ____________
Recorded by ____________

TIME	f°F2	h'F2	f°F1	h'F1	f°E	h'E	fEs	h'Es	F2 M3000	F2 M1500	F1 M3000	E M1500	f°F2
00													
01													
02													
03													
04													
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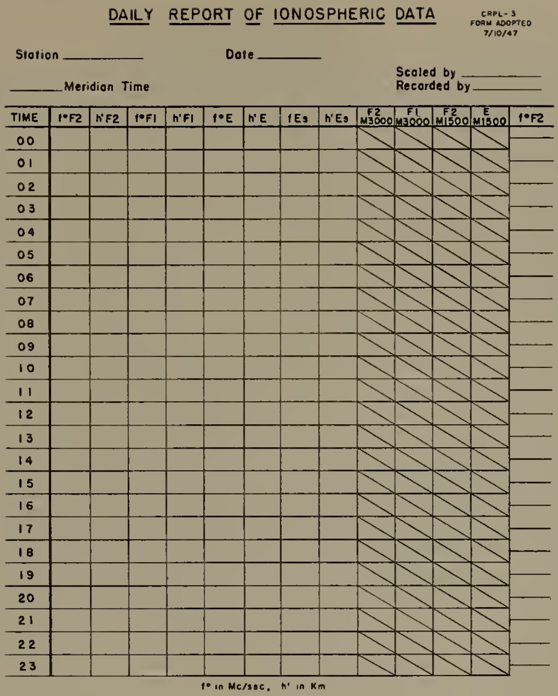
f° in Mc/sec, h' in Km

Figure 19

The first CRPL daily ionosphere data sheet



DAILY REPORT OF IONOSPHERIC DATA

CRPL-3
FORM ADOPTED
7/10/47

Station ________ Date ________

Scaled by ________
Recorded by ________

________ Meridian Time

TIME	f°F2	h'F2	f°F1	h'F1	f°E	h'E	fEs	h'Es	F2 M3000	F1 M3000	F2 M1500	E M1500	f°F2
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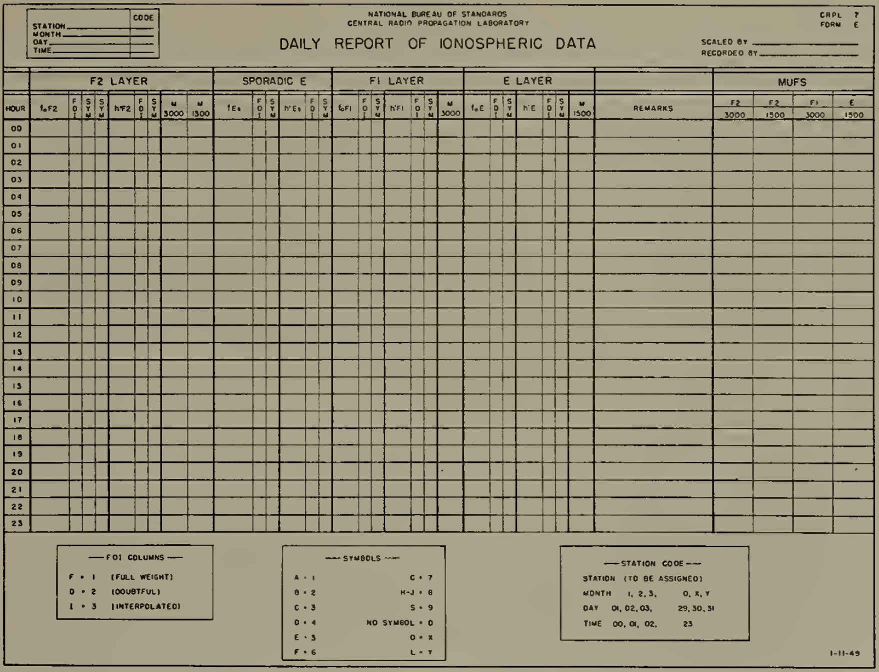
f° in Mc/sec, h' in Km

Figure 20

The modified Form CRPL-3



	CODE
STATION ________	
MONTH ________	
DAY ________	
TIME ________	

NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY

DAILY REPORT OF IONOSPHERIC DATA

CRPL 7
FORM E

SCALED BY ________
RECORDED BY ________

	F2 LAYER									SPORADIC E						F1 LAYER							E LAYER								MUFS			
HOUR	f°F2	FOI	SYM	SYM	h'F2	FOI	SYM	M 3000	M 1300	fEs	FOI	SYM	h'Es	FOI	SYM	f°F1	FOI	SYM	h'F1	FOI	SYM	M 3000	f°E	FOI	SYM	h'E	FOI	SYM	M 1500	REMARKS	F2 3000	F2 1500	F1 3000	E 1500
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— FOI COLUMNS —

F = 1 (FULL WEIGHT)
D = 2 (DOUBTFUL)
I = 3 (INTERPOLATED)

— SYMBOLS —

A = 1	C = 7
B = 2	H-J = 8
C = 3	S = 9
D = 4	NO SYMBOL = 0
E = 5	O = X
F = 6	L = Y

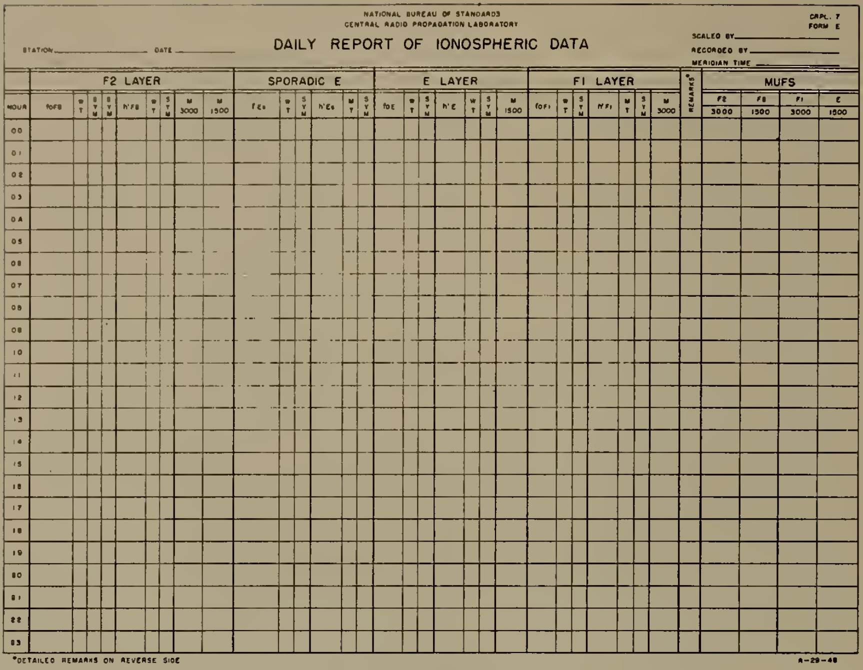
— STATION CODE —

STATION (TO BE ASSIGNED)
MONTH 1, 2, 3, 0, X, Y
DAY 01, 02, 03, 29, 30, 31
TIME 00, 01, 02, 23

1-11-49

Figure 21

The first form of CRPL 7-E



NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY

CRPL. 7
FORM E

DAILY REPORT OF IONOSPHERIC DATA

STATION __________ DATE __________

SCALED BY __________
RECORDED BY __________
MERIDIAN TIME __________

	F2 LAYER									SPORADIC E						E LAYER							F1 LAYER							REMARKS*	MUFS			
HOUR	foF2	W T	S Y M	S Y M	h'F2	W T	S Y M	M 3000	M 1500	fEs	W T	S Y M	h'Es	M T	S Y M	foE	W T	S Y M	h'E	W T	S Y M	M 1500	foF1	W T	S Y M	h'F1	M T	S Y M	M 3000		F2 3000	F2 1500	F1 3000	E 1500
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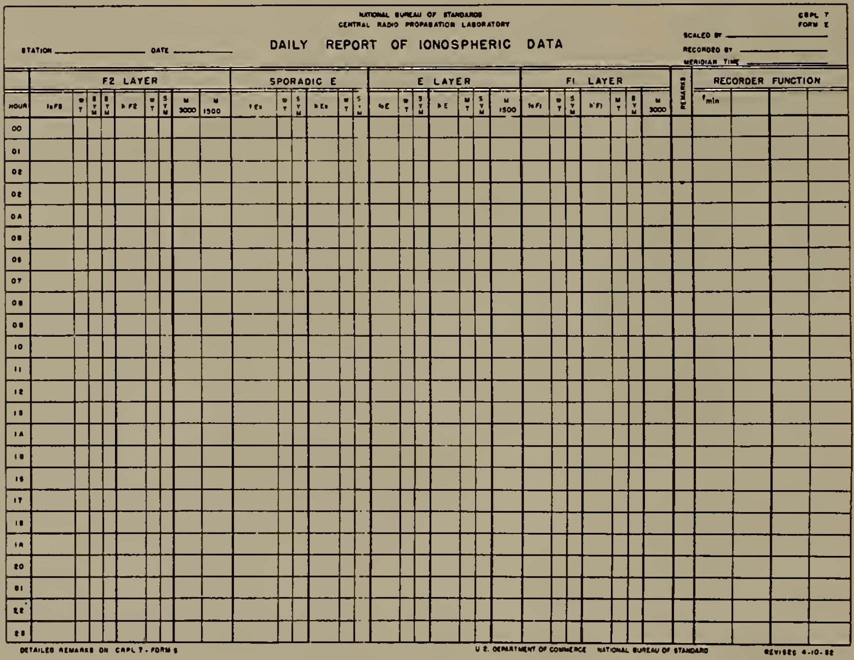
*DETAILED REMARKS ON REVERSE SIDE

A-29-48

Figure 22

Form CRPL 7-E as modified in August 1949



NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY

CRPL 7
FORM E

DAILY REPORT OF IONOSPHERIC DATA

STATION __________ DATE __________

SCALED BY __________
RECORDED BY __________
MERIDIAN TIME __________

	F2 LAYER									SPORADIC E						E LAYER							F1 LAYER							REMARKS	RECORDER FUNCTION			
HOUR	foF2	W T	S Y M	S Y M	h'F2	W T	S Y M	M 3000	M 1500	fEs	W T	S Y M	h'Es	W T	S Y M	foE	W T	S Y M	h'E	M T	S Y M	M 1500	foF1	W T	S Y M	h'F1	M T	S Y M	M 3000		f_{min}			
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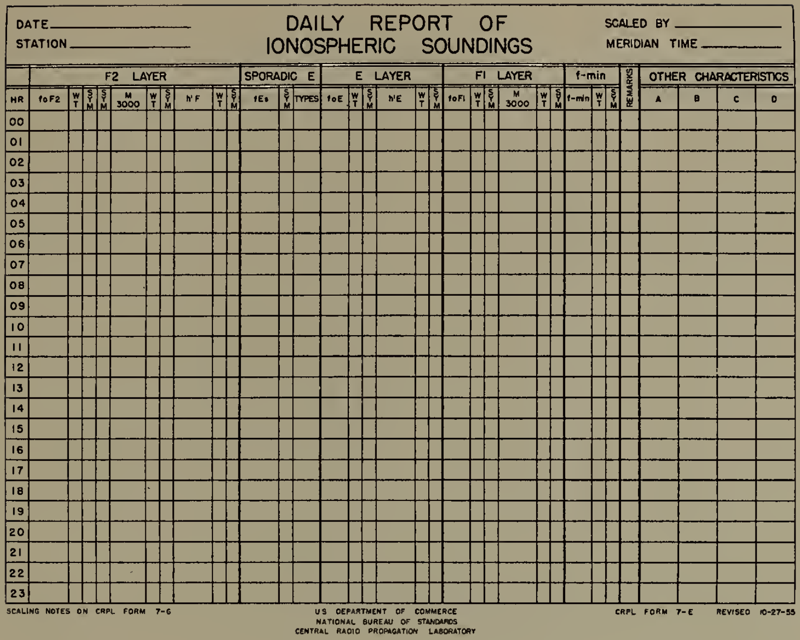
DETAILED REMARKS ON CRPL 7-FORM 6

U S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

REVISED 4-10-52

Figure 23

Form CRPL 7-E as modified in April 1952



DATE
STATION

DAILY REPORT OF
IONOSPHERIC SOUNDINGS

SCALED BY
MERIDIAN TIME

	F2 LAYER										SPORADIC E			E LAYER						F1 LAYER						f-min			REMARKS	OTHER CHARACTERISTICS			
HR	foF2	WT	SYM	SYM	M 3000	WT	SYM	h'F	WT	SYM	fEs	SYM	TYPES	foE	WT	SYM	h'E	WT	SYM	foF1	WT	SYM	M 3000	WT	SYM	f-min	WT	SYM		A	B	C	D
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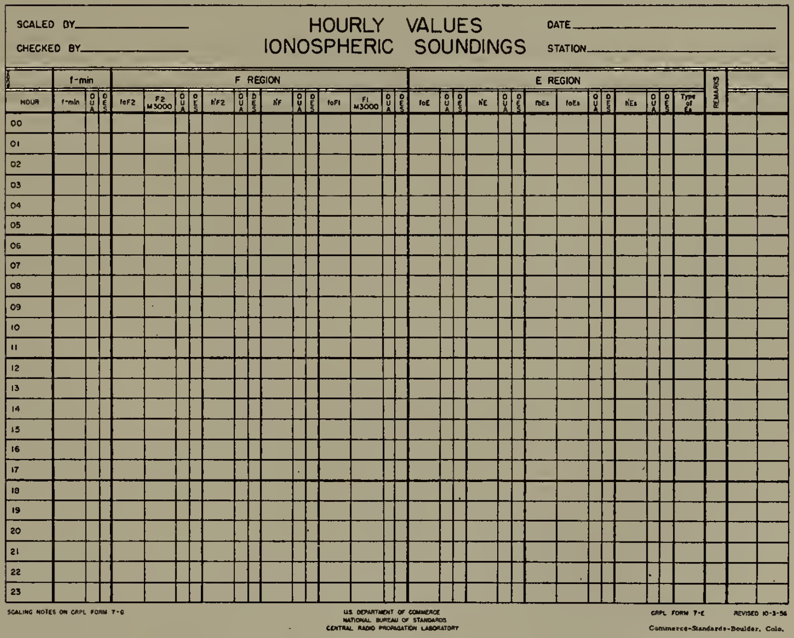
SCALING NOTES ON CRPL FORM 7-G

US DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY

CRPL FORM 7-E REVISED 10-27-55

Figure 24

Form CRPL 7-E as modified in October 1955



SCALED BY
CHECKED BY

HOURLY VALUES
IONOSPHERIC SOUNDINGS

DATE
STATION

	f-min			F REGION														E REGION														REMARKS		
HOUR	f-min	QUA	DES	foF2	F2 M3000	QUA	DES	h'F2	QUA	DES	h'F	QUA	DES	foF1	F1 M3000	QUA	DES	foE	QUA	DES	h'E	QUA	DES	fbEs	foEs	QUA	DES	h'Es	QUA	DES	Type of Es			
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SCALING NOTES ON CRPL FORM 7-G

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY

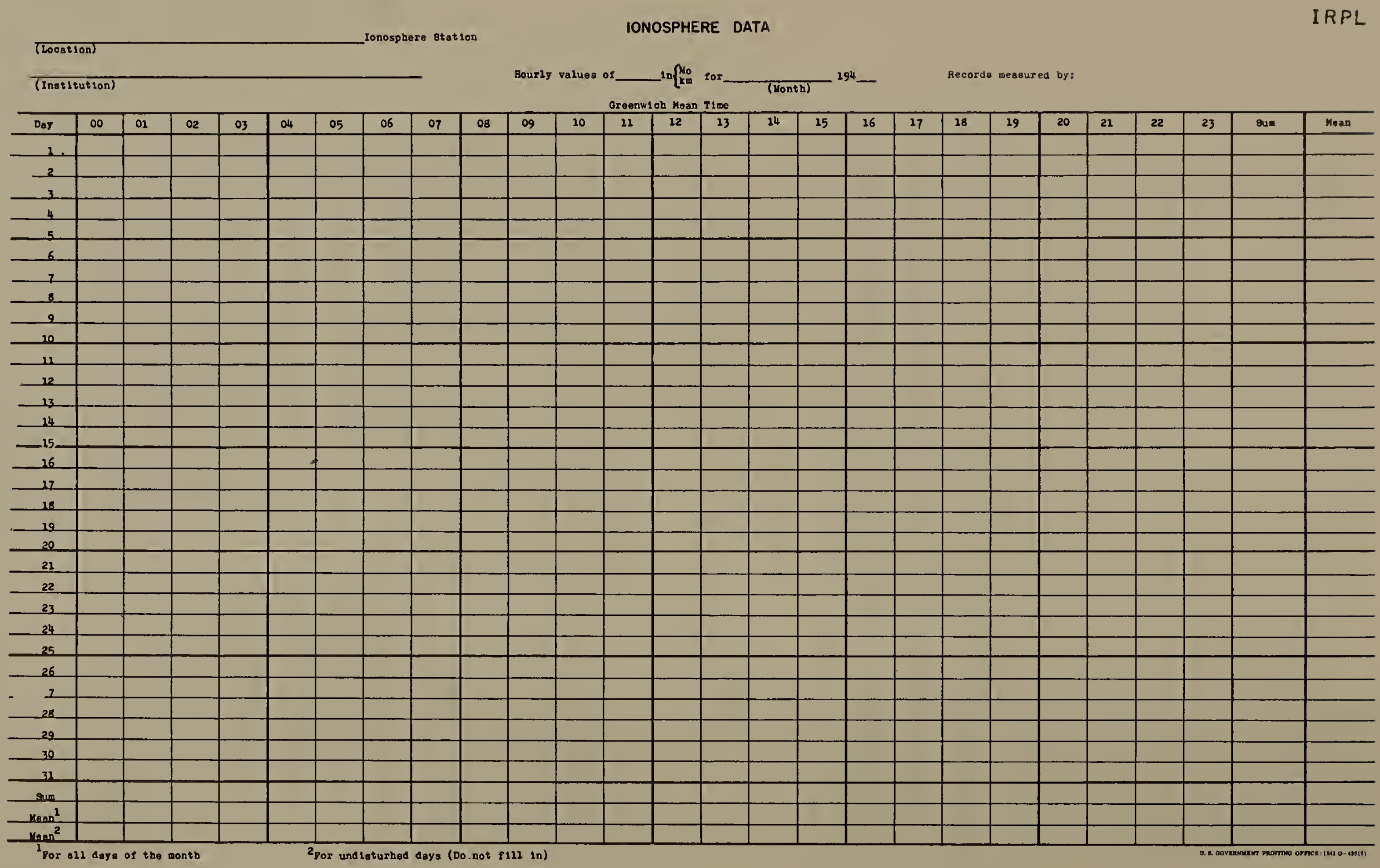
CRPL FORM 7-E REVISED 10-3-56

Commerce-Standards-Boulder, Colo.

Figure 25

Form CRPL 7-E as modified in October 1956

IRPL



IONOSPHERE DATA

______________________________ Ionosphere Station
(Location)

____
(Institution)

Hourly values of ______ in {Mc / km} for ____________ 194__
(Month)

Records measured by:

Greenwich Mean Time

Day	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Sum	Mean
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Sum																										
Mean[1]																										
Mean[2]																										

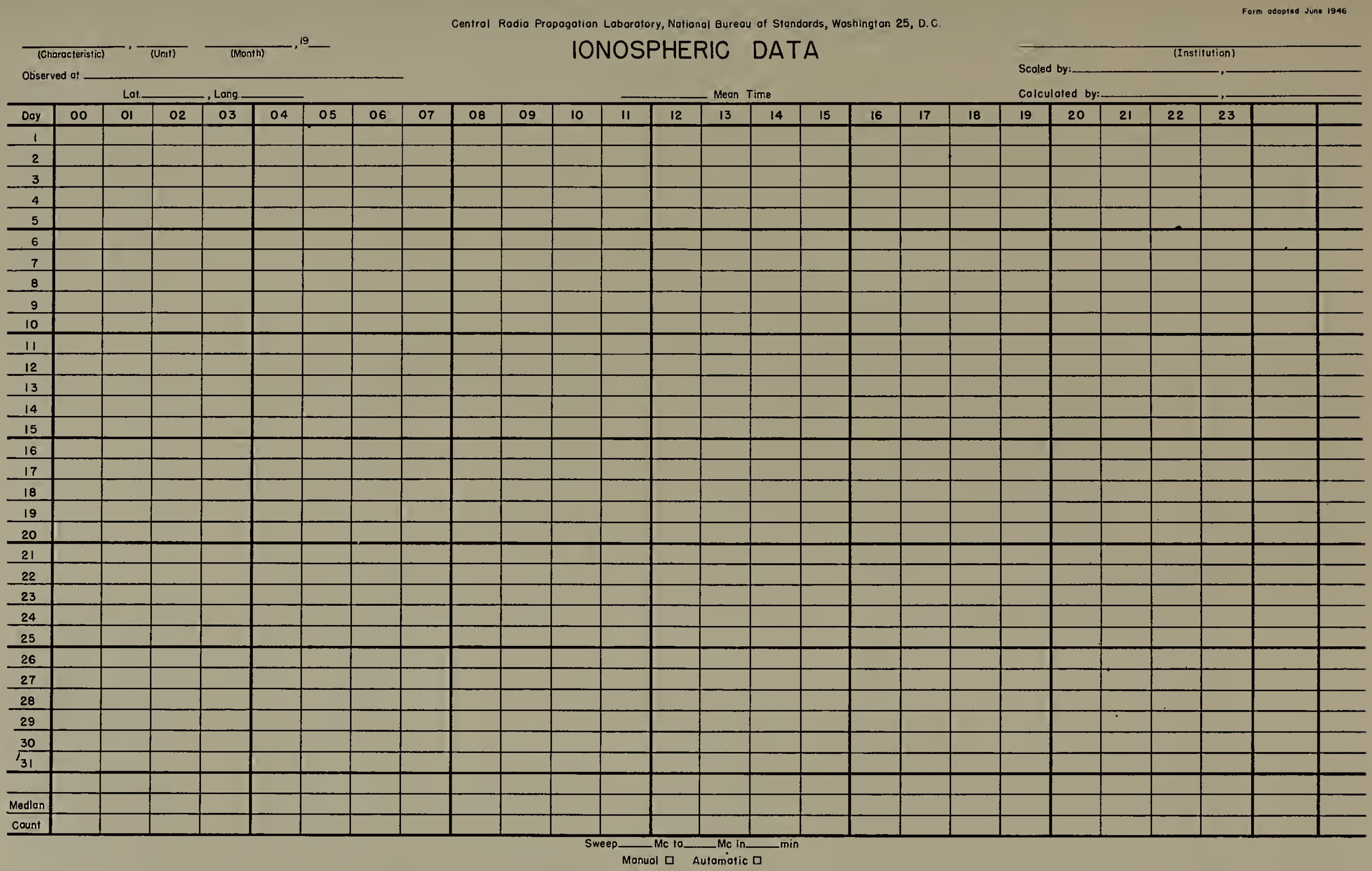
[1] For all days of the month

[2] For undisturbed days (Do not fill in)

U. S. GOVERNMENT PRINTING OFFICE: 1941 O-435151

Figure 26

Monthly summary sheet as used by IRPL



Form adopted June 1946

Central Radio Propagation Laboratory, National Bureau of Standards, Washington 25, D. C.

IONOSPHERIC DATA

______ (Characteristic), ______ (Unit) ______ (Month), 19___

Observed at ______

Lat.______, Long.______

______ Mean Time

______ (Institution)

Scaled by:______, ______

Calculated by:______, ______

Day	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23		
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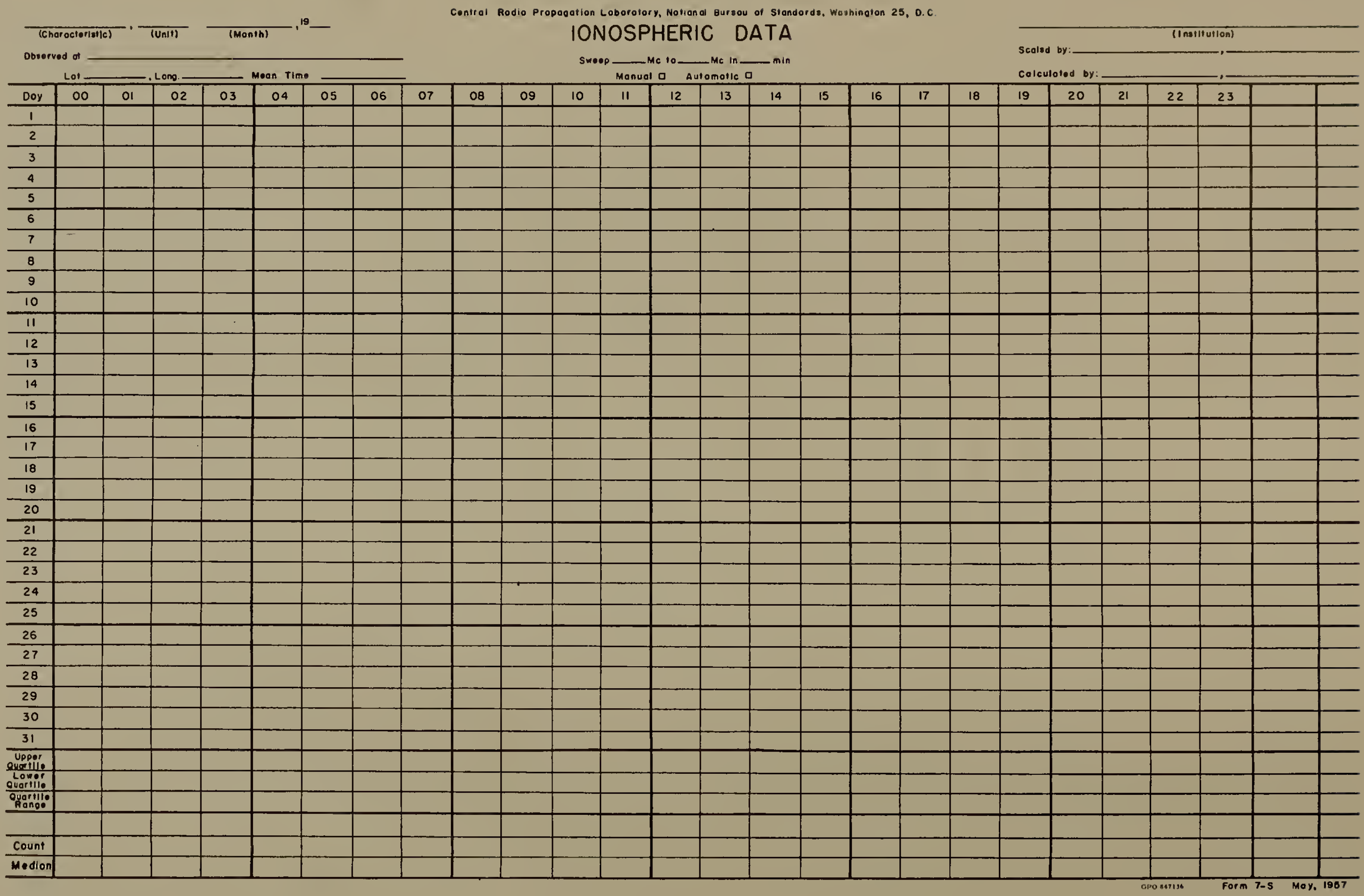
31																										
Median																										
Count																										

Sweep______Mc to______Mc in______min

Manual ☐ Automatic ☐

Figure 27

The first CRPL monthly summary sheet



Central Radio Propagation Laboratory, National Bureau of Standards, Washington 25, D.C.

IONOSPHERIC DATA

__________ , ______ ________ , 19___
(Characteristic) (Unit) (Month)

(Institution)

Observed at ____________________

Lat ______, Long. ______ Mean Time ______

Sweep ____ Mc to ____ Mc in ____ min

Manual ☐ Automatic ☐

Scaled by: __________ , __________

Calculated by: __________ , __________

Day	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23		
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Lower Quartile																										
Quartile Range																										
Count																										
Median																										

GPO 847134 Form 7-S May, 1957

Figure 28

CRPL monthly summary sheet as modified in May 1957 charts and the like. For this operation the hourly values of ionospheric characteristics are entered on punched cards, which are then handled in the desired manner by card machines.

6. Data inspection.

One of the important phases of the sounding program is the routine inspection of the ionospheric data obtained by the network of field stations, in order to insure uniformity of the data.

Prior to the time of CRPL, the only ionospheric data obtained systematically by NBS was that from the Washington field station. With the formation of CRPL in 1946 and the acquisition of six additional field stations and five associated laboratories, the need for regular inspection of the data became apparent. In the early days of CRPL, checking of the data was done only by the Regular Propagation Services Section. In January 1947, an expanded checking procedure was begun by Section 7, Regular Propagation Measurements, later known as the Field Operations Section. In May 1950 Section 7 was discontinued as such, and the work transferred to Section 1, Upper Atmosphere Research.

March 8, 1956 the Sun-Earth Relationships Section was formed at the Boulder Laboratories of NBS, and the program of data inspection transferred to it, along with the control of the field stations at Ft. Belvoir, Va. and Anchorage, Alaska, the sites of the North Atlantic and North Pacific Radio Warning Services.

The program of data inspection involves the continuing examination of ionograms and tabulated data from field stations in the light of existing procedures. These procedures are subject to modification as more information concerning the nature and behavior of the ionosphere is obtained.

Over the years many types of aids have been devised for the use of field stations so far as the station operation and interpretation of the ionograms were concerned. Memoranda describing new and improved procedures, atlases of typical ionograms, scaling aids of various sorts, - all these have been provided. The personnel at field stations have been encouraged to submit questions regarding the interpretation of difficult ionograms, and to call attention to unusual ionograms.

The results of the periodic examination of field station data are made available to the personnel at the stations through regular correspondence.

7. Improvement and extension of prediction methods.

During the existence of IRPL, the procedures for predicting ordinary-wave critical frequency and optimum working frequency were developed to a considerable degree. After the beginning of CRPL these methods were improved appreciably, principally because of the accumulation of data over a longer period of time.

During the interval July-September 1948 the FCC curves of predicted ordinary-wave critical frequency and optimum working frequency for a transmission distance of 4000 km by the F2 layer were revised by the Regular Propagation Services Section of CRPL. These predictions as originally computed by the former IRPL had become obsolete with the availability of additional data obtained during the high part of the then current sunspot cycle.

In 1949 a paper by White and Potter of CRPL indicated the usefulness of antipodal stations for the prediction of F2 critical frequencies. The authors used data from Watheroo, Western Australia and Baton Rouge, La. for the years 1944-1947 inclusive. It was found that the predicted values of F2 critical frequencies for all hours of the day for Baton Rouge, La. based on data from Watheroo, agreed with observed values almost as well as those predicted from Baton Rouge values. These two stations were located at almost antipodal points. Similar tests conducted for other stations in corresponding geographical latitudes, north and south, but not antipodally located showed poorer agreement.

In 1952 two other workers at CRPL, Ostrow and PoKempner, found that ionospheric data for the current sunspot cycle only should be used in preparing ionospheric radio propagation predictions. Using data from Washington, D. C. and Watheroo, Australia, and rescaling the original ionograms when necessary to conform to current scaling practices, it was found that small but real differences existed between sunspot cycles in the relationship between F2-layer critical frequencies and sunspot number.

Predictions of F2-layer critical frequencies and maximum usable communication frequencies have been published by NBS since September 1944 on a monthly basis for three months in advance. Since March 1945 these predictions have been revised on a semi-monthly basis. The monthly predictions are distributed on a subscription basis by the U. S. Government Printing Office, while the semi-monthly revisions may be obtained free of charge from CRPL, Boulder.

The monthly publication, CRPL-D Series, starting with the September 1947 issue, contains contour charts of F2-zero-MUF and F2-4000-MUF for each of the zones, West, Intermediate, and East, into which the world is divided for the purpose of taking into consideration the variation of the characteristics of the F2 layer with longitude; the world-wide contour chart of E-2000-MUF; the chart of median limiting frequency of Es; and a chart showing the percentage of time occurrence for Es-2000-MUF in excess of 15 Mc. Beginning with predictions for December 1958, there will be contour charts for two I-zones: I-zone (Afro-European) and I-zone (Pacific).

8. Radio warning services.

The predictions of the Regular Propagation Services Section are prepared for 3 months in advance of the applicable time. Radio communications systems require, in addition, more timely information as to possible disturbances in the ionosphere which might affect communication. Such forecasts are made possible by the close statistical relationships between solar activity and geomagnetic disturbances, which are, in turn, closely related to ionospheric disturbances.

Two headquarters for this service are presently in operation. One, serving the North Atlantic area for transatlantic radio paths, is located at Fort Belvoir, Va.; the other, serving the North Pacific area, is located at Anchorage, Alaska. The North Atlantic Radio Warning Service has been operating since about 1942, while the North Pacific Radio Warning Service was initiated in 1952. Both services are under the supervision of the Sun-Earth Relationships Section of CRPL. (1957)

In addition to special observations carried on at the respective headquarters, magnetic, ionospheric, and circuit-performance observations through the two service areas are reported promptly every day or oftener to the respective forecasting center.

The NBS service makes available to operators of communication systems three sets of disturbance forecasts of the quality of radio propagation conditions. They are made rather specifically three or four times a day for 1 to 7 hours in advance (short term forecast), 24 hours in advance (medium term forecast), and 1 to 27 days in advance (advance forecast). Dissemination of the information is accomplished by telephone, telegraph, teletype, and letter; or, for the short term forecasts, by broadcasting over WWV and WWVH, the two standard-frequency and time transmitters of CRPL.

The communications operator receives the forecast in terms of "expected quality" of radio propagation conditions. Basically, however, the forecasts are of variations in the intensity and direction of the earth's magnetic field. These variations are closely associated with abnormal conditions in the ionosphere, which in turn affects the propagation of specific radio transmission.

Practical circuit "quality" includes many types of effects, but it is found that the indices of quality compare more closely with magnetic disturbance variations than with any single ionospheric characteristic. Therefore, the magnetic condition is given most weight in radio disturbance forecasting. The magnetically disturbed periods can often be forecast several days or weeks in advance from solar-terrestrial relationships or from the marked tendency (at sunspot minimum) for magnetic disturbances to recur at about 27-day intervals. Occasionally a forecast can be made a few hours in advance of the beginning of a severe disturbance, - if a very intense solar flare is observed, for instance.

9. Vertical sounding at low frequencies.

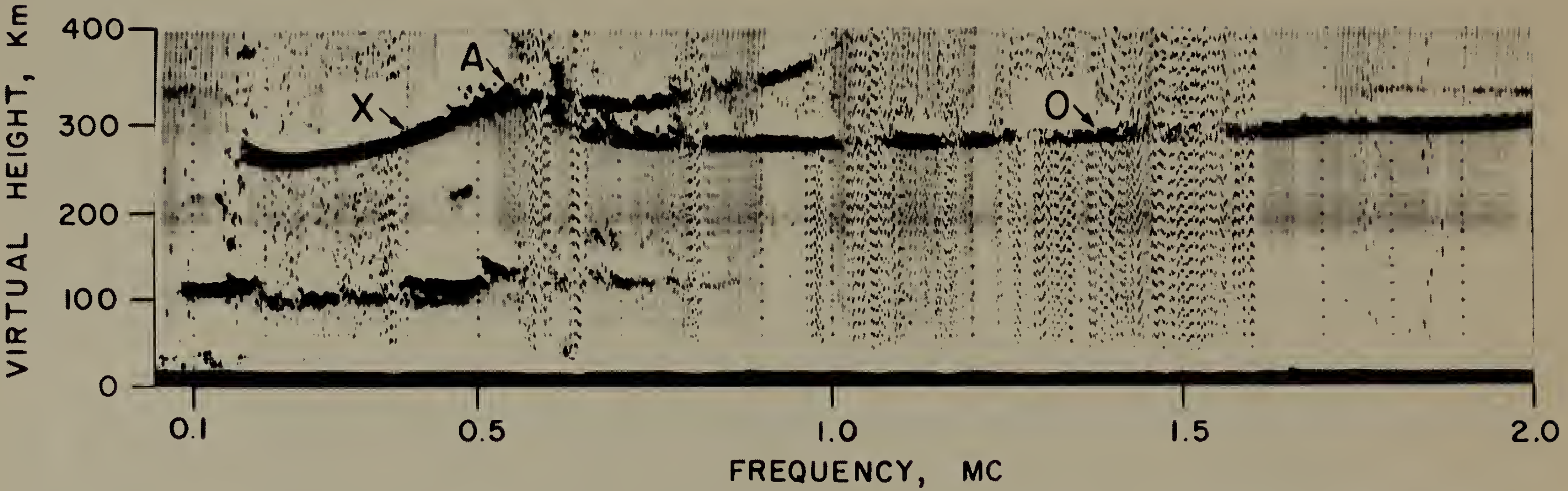
Prior to 1949, some work had been done at NBS on vertical-incidence ionosphere sounding on low frequencies, but only as an accessory to the routine probing at high frequencies.

In 1949 work was begun on a pulse transmitter which was completed by early 1950 and operated on a fixed frequency basis. The transmitter was of the master oscillator-power amplifier type, at first using four type 527 tubes in the output stage, and later six such tubes. It was capable of delivering pulses of over one megawatt power with a duration of about 100 microsec. As soon as it was available, a series of experiments was performed, at first on an exploratory basis. Vertical-incidence reflections were obtained at 37 kc, which is believed to be the lowest frequency at which such an experiment has been successful. Other frequencies were 50 kc, 100 kc, and 160 kc. However, the results were not of sufficient value to describe the relation between apparent reflection height and frequency, which is one of the important parameters used in ionospheric analysis.

Design and assembly of a sweep-frequency apparatus were begun in late 1950, and it was put into operation at the Sterling Va. field station in December 1951. The principles first used by Sulzer in 1946 for high frequency ionosphere recorders were adopted, since the advantages of mechanical simplicity and low cost were not to be ignored.

The transmitter consisted of a series of wide-band amplifiers fed by the output of a mixer. The mixer produced a beat frequency between two oscillators, one a continuous-wave oscillator variable in frequency from 2 Mc to 3.1 Mc, the other a pulsed oscillator at a fixed frequency of 2 Mc.

In some ways the design of the low frequency equipment was less difficult than the design of the high frequency equipment. The band width was only about 1 Mc compared to 25 Mc. Also the low frequencies permitted the use of ferromagnetic cores in all transmitter stages; therefore, push-pull operation with appreciable inductive coupling



LOW FREQUENCY IONOGRAM
MARCH 15, 1957, 04:45 MST

Figure 29

A typical ionogram obtained with the low frequency ionosonde

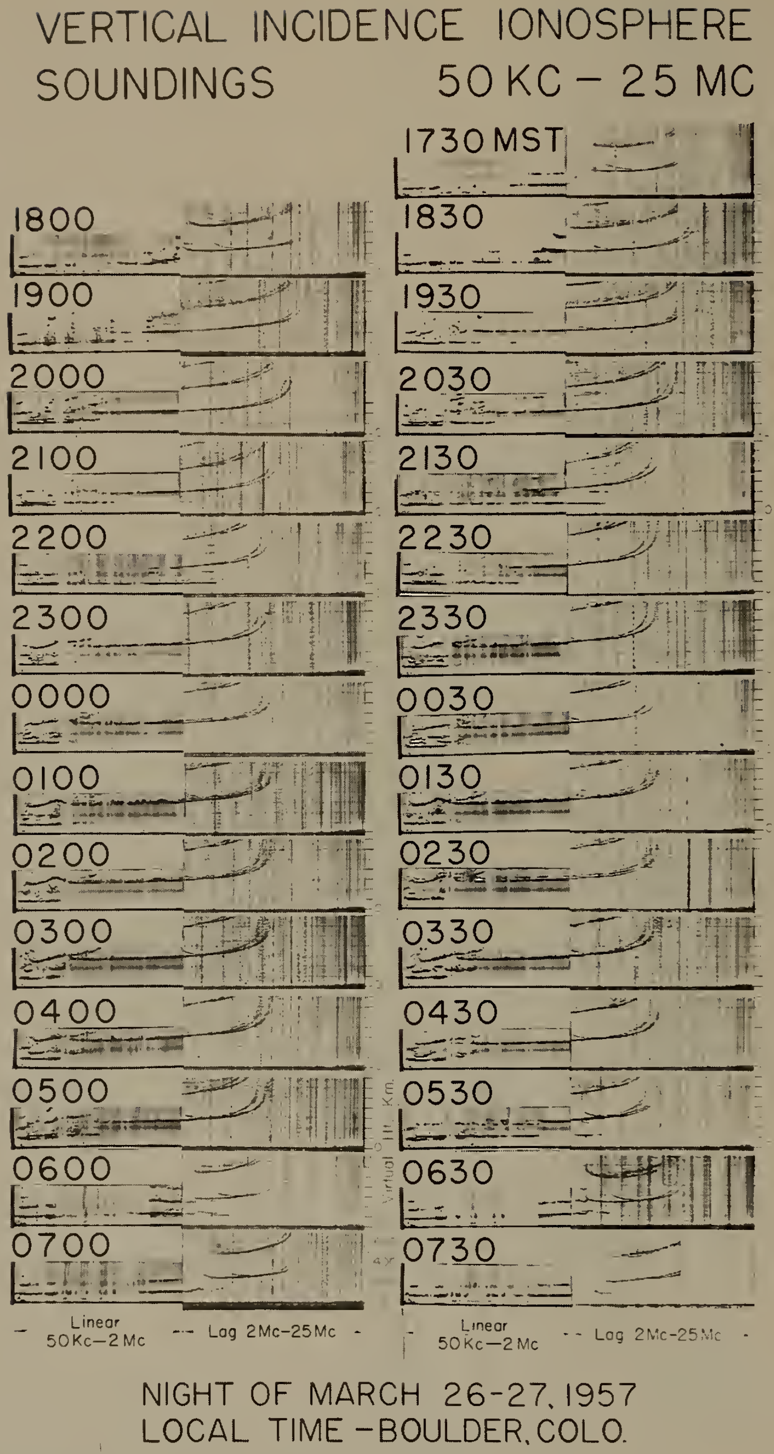


Figure 30

A composite ionogram made up of the sweeps from both the low-frequency and high-frequency ionosondes between the plate circuits was possible, which allowed the high power stages to operate as Class B amplifiers with reasonably good waveform.

At first a single loop antenna was used, which was approximately 350 ft. long and 150 ft. high. Measurement of peak-pulse antenna current at 100 kc indicated that the radiated power was probably of the order of five watts. In spite of the low radiated power, reflections at 100 kc were frequently obtained during the night hours. When the equipment was moved to Boulder, Colorado, a single wire triangular antenna was installed across the top of a mountain canyon, with a length of 3300 ft. per side. The frequency range of the transmitter was also extended to 2 Mc, thus overlapping appreciably the frequency range of the CRPL Model C-2, C-3 and C-4 ionosondes.

The record of apparent reflection height versus frequency was made in the conventional way by intensity modulation of an oscilloscope beam to which a line detection type of time base was applied. The line thus produced was photographed by a camera whose film moved in synchronism with the frequency-change motor of the transmitter and in a direction of travel perpendicular to the time base line.

10. Ionospheric research.

Since the early days of vertical-incidence soundings, scientists at NBS have studied those phenomena which directly or indirectly contribute to the behavior of the ionosphere. Investigations have been made of the complex motions which the ionosphere undergoes as a result of the heating by the sun and of the gravitational tidal forces exerted by the sun and moon. Another line of investigation has been the study of winds in the upper atmosphere, which have periodic variations and travel at speeds up to 300 miles per hour.

A thorough knowledge and understanding of the nature and cause of ionization in the ionosphere is vitally important to the operation of the CRPL prediction service. Progress has been made in gaining a better understanding of the physical characteristics and processes of the upper atmosphere.

An understanding of the physical and chemical processes which are responsible for ionospheric behavior is basic to an understanding of ionospheric radio propagation characteristics. Gross characteristics are relatively predictable with present knowledge, but many important new developments and applications involving radio propagation depend upon a knowledge of the fine details of ionospheric behavior which can only be gained through continued fundamental research.

The practical application of ionospheric and radio propagation science is seriously hampered by the great amount of labor involved in present manual methods. A new approach to this problem is being made with the increased use of machine methods of accumulating and processing new data.

Since solar radiation exerts a considerable effect on the earth, particularly on the ionosphere, it is necessary that a good understanding of the mechanisms by which it arises, is emitted, and is transferred to the earth, must be obtained. Special methods must be devised for the detection of the various solar effects on the earth's atmosphere. Close cooperation is maintained by CRPL with solar observatories all over the world.

The ionospheric film library of CRPL is the largest in the world and comprises a unique quantity of research material, the usefulness of which is being more appreciated by workers both in America and abroad.

It is beyond the scope of this history to discuss in detail all of the different types of ionospheric research pursued at CRPL. The list of pertinent references will serve as a guide to the type of work in this field.

VI. International Programs of Ionospheric Research

1. The Second International Polar Year.

The First International Meteorological Polar Year extended from August 1882 to August 1883. Ten nations were involved: Austria, Denmark, Finland, Germany, Great Britain, Holland, Norway, Russia, Sweden, and the United States. Each nation established one or more stations as near the Arctic Circle as practicable, at which continuous meteorological and magnetic observations were made.

Fifty years later the Second International Polar Year was initiated, from August 1932 to August 1933. As far as possible, the different nations reoccupied the stations occupied by them in 1882-83. Many new stations were opened, and the observational program was greatly expanded over that of 50 years previously. In addition to the usual meteorological and magnetic observations, studies of the heights of the ionospheric layers were included as part of the program.

Arrangements were made for ionospheric measurements by various expeditions and the Bureau on a cooperative basis. The pulse-method of sounding the ionosphere used by NBS was employed in cooperation with the Carnegie Institution of Washington to develop improved types of ionosondes.

At the Washington field station of NBS, measurement of layer heights was extended to include noon and midnight measurements each week, as well as two 24-hour runs on 4100 kc. These observations were made with the automatic recorder developed in 1931.

By April 1933 the automatic multifrequency ionosonde was in operation at NBS, and some of the soundings obtained with this equipment were incorporated with the other Polar Year measurements. Aside from the data obtained at the Washington station, NBS did no other ionospheric measurements during the Second Polar Year.

The United States participated in the program of the Second International Polar Year through the operation of two special stations, one designated as the College-Fairbanks station in Alaska, provided for by an act of Congress appropriating $30,000; and the second the station established at Point Barrow, Alaska, as a reoccupation of the station at that place occupied by the United States during the First International Polar Year of 1882-83.

The College-Fairbanks station (at the Alaska Agricultural College and School of Mines, later becoming the University of Alaska) was under the direction of the U. S. Coast and Geodetic Survey. The station at Point Barrow was established through the cooperation of the U. S. Weather Bureau, the Carnegie Institution of Washington through its Department of Terrestrial Magnetism, and the International Polar Year Committee.

One phase of the work at the College-Fairbanks Station dealt with the measurement of ionospheric layer heights. No work of an ionospheric nature was done at the Point Barrow station.

2. CRPL and the International Geophysical Year.

a. The general program.

During the International Geophysical Year, which began July 1, 1957 and will continue through December 31, 1958, several thousand scientists representing some sixty nations will make simultaneous worldwide observations of the earth and its immediate cosmic environment. The data gathered in this huge cooperative measurement program should help answer questions regarding the size and shape of the earth, the origins of earthquakes, the causes of radio blackouts, the sources of weather disturbances, and many other terrestrial phenomena.

The greatest part of the Bureau's effort during IGY will be concerned with variations in the ionosphere. Because of its extensive studies of the ionosphere as a factor in radio propagation, the Bureau has been given responsibility for operating the Western Hemisphere World Data Center for the ionospheric data program. In this program information will be collected from numerous laboratories making observations of the ionosphere and added to that of the Boulder Laboratories.

These data will be made available to all qualified research scientists, as well as to the other world data centers in Moscow, Tokyo and Slough, England.

During periods of intense ionospheric activity, IGY scientists hope to gather enough information about the ionosphere so that improved predictions of radio propagation conditions can be made. The ionospheric studies will consist mainly in soundings of the various layers of this region. The Bureau will be directly concerned with some 37 of the approximately 160 stations scattered throughout the world that will be making vertical soundings of the ionosphere. Simultaneous data gathered by all the stations will be plotted and analyzed to provide a global picture of the ionosphere and its properties.

The Bureau equipped 16 new stations, carefully located to fill important gaps in the world network. Five of these - the Antarctic sounding stations - are operated by NBS and the others will be closely guided in their work by Bureau staff members. In addition the pre-IGY network of 7 NBS-operated and 11 associated stations will continue to provide ionospheric data through IGY.

The Bureau also played an important role in the international organization and coordination of the ionospheric soundings program. Members of the staff were authors of the 150-page IGY instruction manual and an extensive atlas of typical records, which will be invaluable in the attempt to obtain consistent and comparable observations from the world network.

As another part of the IGY program, the Bureau will intensify its study of sporadic E, operating carefully controlled circuits in the Far East, South America, the Caribbean, and the United States.

Scatter propagation, occurring when high-powered transmitters are beamed at the ionosphere and small but useful amounts of radio energy are returned to the earth, will form another aspect of NBS participation in the IGY program.

b. World Warning Agency.

The day-to-day coordination of a large part of IGY observations is accomplished through the most extensive communication network ever arranged for scientific research purposes. The designation of special days and intervals for special or intensified effort by IGY stations will help assure that the right kinds of observations are taken while the extensive IGY networks are in operation.

Focal point of the system is the Bureau's radio forecasting center near Washington, which has been selected as the IGY World Warning Agency by the International IGY Committee. From this nerve center of the whole IGY program, located at Fort Belvoir, Virginia, warnings are flashed to scientists throughout the world to redouble their observational efforts in anticipation of unusual activity in cosmic rays, aurora, earth magnetism, and ionospheric disturbances.

Warnings are of two kinds: Alerts and Special World Intervals. When reports justify it, the staff of the World Warning Agency issues an Alert, advising scientists that a Special World Interval may be called within a few days. If a strong disturbance appears likely within 24 hours, the Special World Interval is announced on 8-hours notice. During the Special World Interval IGY programs in ionospheric physics, geomagnetism, solar activity, cosmic rays, and aurora are intensified.

The international communication net involves the radio teletype network supervised by the World Meteorological Organization, virtually all of the commercial communications facilities throughout the world, government facilities (such as military channels, and in the United States, the Civil Aeronautics Administration), and special messages broadcast by stations WWV and WWVH (on the NBS radio propagation forecast channels) and their counterparts in other countries.

c. World Data Centers.

In order to make the best use of data obtained during the IGY, data centers were established in various countries. Their functions were to serve as collection and distribution agencies for all IGY data, and to make the data available for scientists doing research in the particular fields.

Data centers for all disciplines were established in the United States and in the U.S.S.R. Additional data centers for certain disciplines of IGY were also established in other countries. The total number of data centers for each discipline is usually 3 or 4. For each discipline, data centers were established in the United States at institutions interested in the particular field and able to provide the necessary facilities.

At the Boulder Laboratories of the National Bureau of Standards a World Data Center (WDC-A) handles the data from two disciplines - Airglow and Ionosphere. Data for these two disciplines are received either in original form or as copies, from observatories in the area assigned to World Data Center A. It is the responsibility of each data center to provide copies of pertinent data to all the other data centers in return for copies of data from their areas.

Facilities are provided at the NBS Data Center for visiting scientists to work with the data in the World Data Center files. Copies of data are made available at the cost of reproduction to any one desiring them.

d. Data processing.

Much of the IGY program at the Boulder Laboratories will be greatly aided by high-speed techniques developed chiefly during the past 10 years. Without them, scientists could scarcely hope to keep up with the processing of the billions of geophysical measurements to be recorded during the extent of the IGY.

The IGY program will increase from 5 to 10 times the normal volume of data handled by the Boulder Laboratories. Equipment has been installed to make the computation of IGY data largely automatic, eliminating hand-processing wherever possible.

A great deal of the IGY information forwarded to Boulder will be recorded on punched cards and stored in permanent archives. To process the vast sea of scientific data that will come in from ionospheric stations in the Western Hemisphere and the Pacific area, the Boulder Laboratories will rely on a high-speed electronic computer.

Appendix I

Early NBS ionosondes

1. The first NBS automatic multifrequency ionosonde.

In 1933, the ionosonde used for fixed-frequency automatic height recording on 4100 kc was modified to cover a range of frequencies.

It was found that one set of receiver coils could be conveniently used between 2.5 and 4.4 Mc without modification, and the transmitter was designed to cover this range. Two cams were used to change the frequency continuously. The transmitter tuning condensers were actuated by one cam while the receiver tuning condensers were actuated by another. Both cams were attached to a single shaft driven by a synchronous motor through a reduction gear. The cam shapes were determined after the ionosonde had been assembled.

The transmitter was keyed with an interrupter driven by a synchronous motor. The antenna system of the transmitter consisted of four inverted L antennas of three-fourths wave length for 2.5, 3.0, 3.5 and 4.5 Mc, all permanently connected together at the base. The receiving antenna was a single inverted L of three-fourths wave length for about 4.0 Mc. Peak power was about 3.0 kw, and the pulse repetition frequency was 10 per sec.

Sensitized photographic paper four inches wide was used for recording. The oscillograph of the receiver was provided with a revolving mirror driven by a synchronous motor connected to the same power system as used for the transmitter. The photographic paper was moved over the pulse pattern in a direction parallel to the axis of the revolving mirror. Frequency-wise, the paper was 1-1/4 inches long for the 2.5 to 4.4 Mc sweep.

The first ionograms obtained with this ionosonde were made on April 20, 1933, 9.5 min. being required for the sweep. No markers for frequency or virtual height were present on the ionogram, a special scaling overlay being required. The time was registered automatically once an hour, but the date had to be marked manually on each ionogram.

Normally, automatic sweeps were made each hour or half-hour. It was possible to make about six sweeps per hour if manual switching was performed at the end of each sweep.

This ionosonde was used at the Beltsville field site until about May 1935. At that time it was moved to Meadows, Md. (now the site of Andrews Air Force Base), where it was operated until the fall of 1941.

Figure 31

The first NBS automatic multifrequency ionosonde.

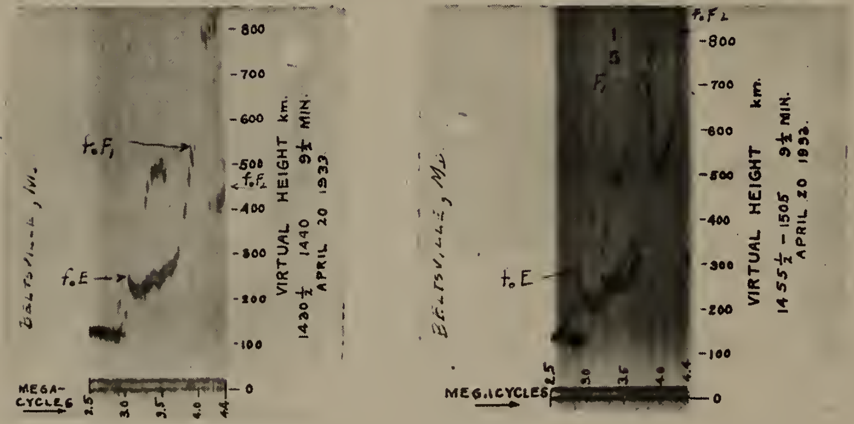


Figure 32

The first and second ionograms made with the original
NBS automatic multifrequency ionosonde.
(Original ionograms from which photograph was made were supplied
by T. R. Gilliland)

From May 1933 through October 1941, the ionospheric data obtained with this equipment, supplemented at times by other ionosondes, was published in the Proceedings of the Institute of Radio Engineers. The data for the frequencies 2.5 to 4.4 Mc were obtained with this automatic ionosonde, while that for the frequencies from 1.6 to 2.5 Mc and above 4.4 Mc were taken manually with the 1.6 to 25.0 Mc pulse transmitter at Beltsville.

2. Model A ionosonde.

In 1940, a new type of ionosonde was designed and put into use by NBS. It consisted of a pulsed transmitter linked to a receiver by a beat-frequency system. The output of a variable-frequency oscillator was mixed with the output of an oscillator operating at the intermediate frequency of the receiver. The difference of these two frequencies was selected and amplified in the transmitter. Signals to be received were mixed with the output of the variable oscillator, the frequency difference then being the receiver intermediate frequency which was amplified and detected in the usual manner. This is the basic idea for interlocking radio transmitter and receiver in modern multi-frequency apparatus.

The variable oscillator, converter and power amplifier were tracked by means of cams. The frequency range was divided into four bands, with the frequencies spaced logarithmically. Band 1 went from 0.79 to 1.62 Mc; band 2, from 1.62 to 3.34 Mc; band 3, from 3.34 to 6.73 Mc; and band 4, from 6.73 to 14.0 Mc. Switching from one band to another was accomplished by relays. Each band required three cams for operating the tuning condensers.

The pulse width was 500 microsec, with a pulse repetition rate of 20 per sec. The approximate peak power was 2 kw. The time required for one frequency sweep was one min.

With the first model, four L-type antennas were used, each antenna serving for two different frequency ranges, being used first in the 1/4-wavelength range, and later in the 3/4-wavelength range. A later model employed two single wire delta antennas, fed at the bottom and terminated with 600 ohms.

The ionograms were made on 35-mm film, with the recorded trace being a photograph of a light beam reflected from the mirror of a string galvanometer. To indicate the time at which the sweep was made, the image of a drum-dial synchronous clock was exposed on the film for each ionogram by a solenoid-operated shutter. The time mark followed the ionogram to which it applied. The date had to be marked on the film manually.

Figure 33

The Model A ionosonde in a trailer

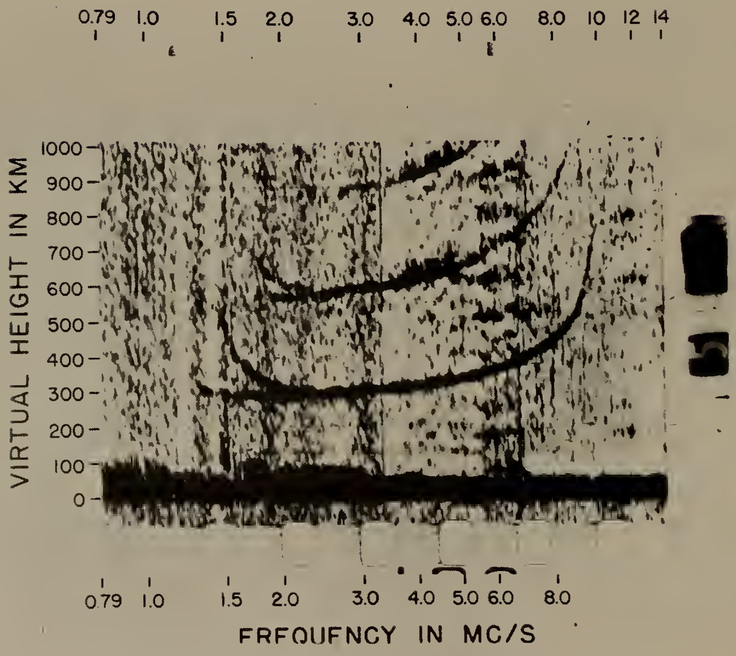


Figure 34

Sample ionogram made with CRPL Model A ionosonde at Patos, Brazil

The complete ionogram with associated time mark occupied two standard motion picture frames; i.e., 1 x $1\frac{1}{2}$ inches. The frequency scale from 0.79 to 14.0 Mc covered about 1-3/8 inches and the time mark about 1/8 inch. Virtual heights of somewhat more than 1000 km could be recorded across the width of the film. Frequency marks indicated the limits of the four bands, but height markers did not appear on the ionograms.

This ionosonde was installed in a trailer and taken to Fort Clark, Texas, to observe the annular eclipse of the sun on April 7, 1940. The expedition was made in cooperation with the National Geographic Society.

On the return trip, the sounder was operated at Keokuk, Iowa to determine the critical frequency there at the time of failure of oblique-frequency transmission from San Francisco to Washington. The critical frequencies at Keokuk and the maximum usable frequency at the time of failure were compared. Examination of the ionograms indicated that on undisturbed nights the best transmission from San Francisco to Washington was by two hops and that the vertical-incidence critical frequency at Keokuk at the time of failure was consistent with the maximum usable frequency computed by the Bureau. On disturbed nights the best transmission was by one hop because of the increased height of the F layer.

This same ionosonde was used by Gilliland to study the total solar eclipse of October 1, 1940 at Patos, Brazil, 240 miles from the coastal city of Pernambuco.

On June 11, 1941 the Louise A. Boyd Arctic Expedition sailed from Washington, D. C. on the auxiliary schooner Effie M. Morrissey. The ionosonde was included with other types of equipment used by the expedition. Miss Boyd had been made a Consulting Expert of the Bureau, and was in charge. The route of the expedition was via Brigus, Newfoundland, thence up the west coast of Greenland to latitude 78°20' N. From that point the route was westward into Lancaster Sound to longitude 86°20' W. The return was along Baffin Island and the Labrador coast, thence to Brigus and New York, arriving there on November 3. The ionograms obtained during the trip added considerably to the knowledge of the ionosphere.

Until the first quarter of 1946, this ionosonde was designated as the portable ionosphere recorder. At that time it received the new designation of the CRPL Model A ionosphere recorder. The present procedure is to call all such devices ionosondes rather than recorders.

The Model A ionosonde was used for a time (1941-43) at the NBS field station at Meadows, Md. In August 1943 it was moved to the new field site at Sterling, Va. where it was used until May 1946, when it was sent to the White Sands Proving Ground in New Mexico to assist in rocket experiments. When the White Sands ionosphere station was activated in July 1947, the Model A ionosonde served as the principal equipment until February 1951, when a CRPL Model C-3 ionosonde was installed. Thereafter the Model A was used as standby equipment until December 1954.

3. Model B ionosonde.

The transmitter installed at Meadows, Md. in October 1934 had a frequency range of 500 to 2500 kc, and was designed to probe the ionosphere through the broadcast range of frequencies. An externally connected chopper served to produce pulses in the transmitter signals.

By May 1940 this ionosonde had been modified for automatic operation from 2500 to 10,500 kc, and beginning June 5 it was making records at half-hour intervals. The ionograms were made on photographic paper, $3\frac{1}{2}$ inches wide, using an accessory recording unit. Several inverted-L antennas were used. These were employed over broad frequency bands for which the antenna was around 1/4-wavelength or 3/4-wavelength, but avoided the frequency bands for which the antenna was $\frac{1}{2}$ or one wavelength. The switching and tuning was done by a rotating motor-driven switch.

Since the magazines for photographic paper used with the recorder held only 75 feet, a five-day supply, new magazines holding 200 feet of paper were installed by August 1940.

In March 1943 the ionosonde was moved to the Beltsville, Md. field station, and in September 1943 to the Sterling field station.

By 1944 the ionosonde had been modified to cover the frequency range from 0.75 to 11.5 Mc in 4 bands, with a fifth band being added in October 1946 which increased the upper frequency limit to 16 Mc.

The approximate peak power was 5 kw. The time for one frequency sweep was 3.4 min., with a pulse recurrence frequency of 8 per sec. A vertical rhombic antenna was used. There were no scales of frequency or height on the ionogram, and the date and time had to be added manually. The height range was approximately 1000 km. Photographic paper was used during the operation of the ionosonde at Sterling.

On January 30, 1947 the Model B ionosonde (so designated in the early part of 1946) was destroyed by fire at the Sterling field station. The fire was believed to have started by a flashover of an rf choke and augmented by the rf coil insulation.

Appendix II

Types of ionosondes used by stations affiliated with IRPL

a. Types developed by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

1. Automatic multifrequency equipment.

This was a pulse-type ionosonde developed about 1936. It had a frequency range of from 16.0 Mc to 0.516 Mc in 6 bands (Band 1 went from 16.0 Mc to 11.924 Mc; band 2, from 11.924 Mc to 8.446 Mc; band 3, from 8.446 Mc to 5.566 Mc; band 4, from 5.566 Mc to 3.284 Mc; band 5, from 3.284 Mc to 1.610 Mc; and band 6, from 1.610 Mc to 0.516 Mc). The approximate peak power was between 300 and 400 watts. The pulse recurrence frequency was 10 per sec, with a pulse width of about 100 microsec, and the time for one frequency sweep was 15 min. Each band required 142.5 sec to traverse, with 7.5 sec between bands for switching. During the switching period no pulses were emitted.

The height range of the sweeps was 1200 km. At the upper portion of the ionogram, space was provided (0-500 km) for probing with a fixed frequency, usually 3.5 Mc.

Photosensitized paper 12 cm wide was used to record the sweeps. Both the frequency and height sweeps were linear, but without a scale of either appearing on the ionogram. A vertical resolution of about 0.66 cm/100 km was ordinarily used.

The antenna system consisted of two horizontal doublets with 550-ohm transmission lines connected to the centers. One doublet was used for Bands 1 to 4 (16.0 to 3.284 Mc), and was 30 meters long. The other was used for Bands 5 and 6 (3.284 to 0.516 Mc), and was 125 meters long.

This ionosonde was used at Huancayo, Peru from 1937 to 1951; at Watheroo, Australia, starting about 1938; and at the Geophysical Institute of the University of Alaska, from 1941 to 1951. The stations at Huancayo and the University of Alaska later became associated with the NBS program of vertical-incidence sounding.

2. Manual ionosphere recorder Model 1.

This was a sounder developed by DTM to implement the expanded U. S. program of ionospheric research, as a result of the establishment of IRPL at the National Bureau of Standards in 1942.

Figure 35

The automatic multifrequency ionosonde developed by DTM, CIW
(Photograph supplied through courtesy of DTM, CIW)

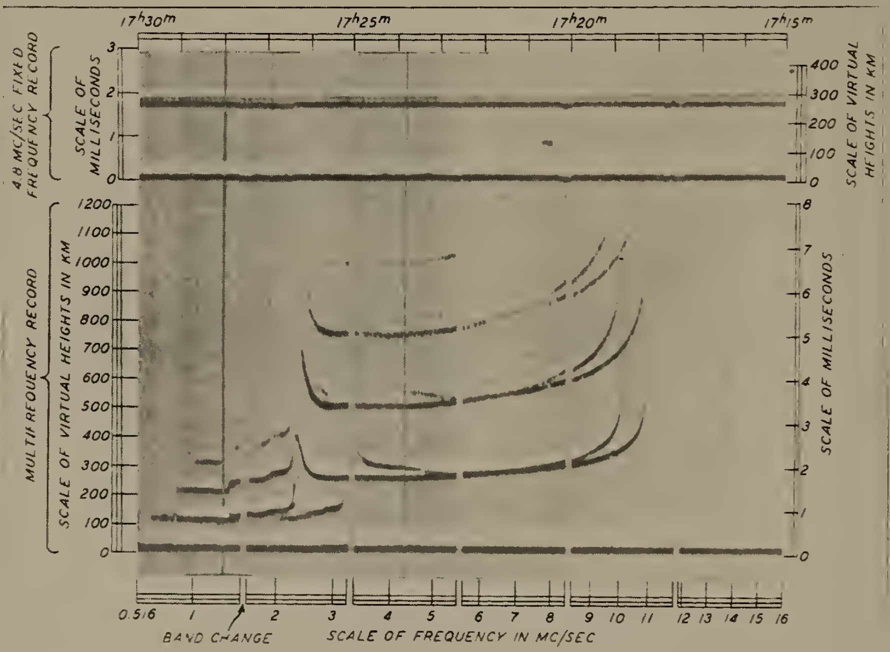


Figure 36

Typical ionogram obtained with the DTM automatic multifrequency ionosonde. (Photograph courtesy of DTM, CIW)

Manual sweeps were made through a frequency range of 1.2 to 13.2 Mc in four bands (Band 1, from 1.2 Mc to 2.4 Mc; band 2, from 2.4 Mc to 4.8 Mc; band 3, from 4.6 to 8.6 Mc; band 4, from 7.6 Mc to 13.2 Mc). The approximate peak power of the transmitter was estimated to be between 0.5 and 1.0 kw, depending on the operating frequency. The ionosonde unit consisted of the transmitter and a 3-inch oscilloscope tube for the indicator, plus a modified NC-200 superheterodyne receiver. Two vertical rhombic antennas were used, one for transmitting and the other for receiving. The pulse recurrence frequency was 15 per sec.

A special scale for height and frequency was superimposed on the face of the oscilloscope tube. The time required to plot the information for one sweep varied from 12 to 15 min.

This type of ionosonde was used as supplementary equipment at Maui, T. H. for a time, and at Palmyra Island from 1946 to 1949.

3. Manual ionosphere recorder, modified Model 1.

This was the original manual recorder developed by DTM, but modified to use a 12-inch cathode-ray tube in place of the original 3-inch tube. The modifications were made in 1945.

The frequency range was from 1.25 Mc to 18.0 Mc, and the height range was either 500 km or 1000 km. A special scale was superimposed on the face of the oscilloscope tube for scaling the sweep.

The pulse recurrence frequency was 30 per sec, with a pulse width of 60 microsec. The approximate time required to plot the information for one sweep was between 12 and 15 min. The approximate peak power was 500 watts.

This recorder was used at Guam Island from 1945 to 1947, and at Okinawa Island from 1946 to 1949.

Sometimes this recorder was designated as DTM Model 2.

4. Manual ionosphere recorder Model 3.

This sounder was constructed in 1945. It consisted of a transmitter and 3-inch oscilloscope, with a separate standard communications receiver having its band-pass interval increased to about 20 kc.

The frequency range of the transmitter was from 1.2 Mc to about 19.5 Mc in five bands (Band 1 went from 1.2 Mc to 2.3 Mc; band 2, from 2.4 Mc to 4.3 Mc; band 3, from 4.4 Mc to 7.2 Mc; band 4, from 7.1 Mc to 11.0 Mc; and band 5, from 11.8 Mc to about 19.5 Mc). The actual frequency range differed between individual sets.

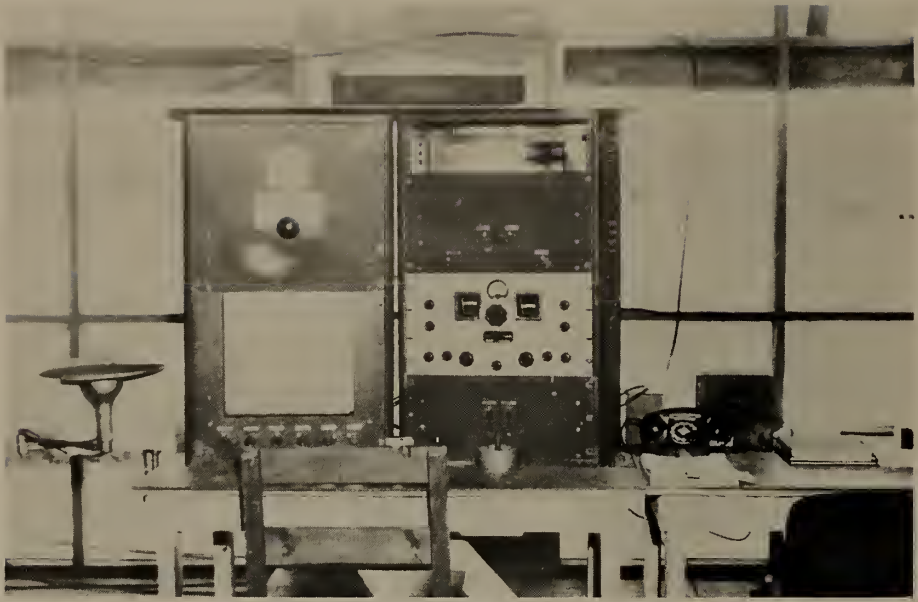
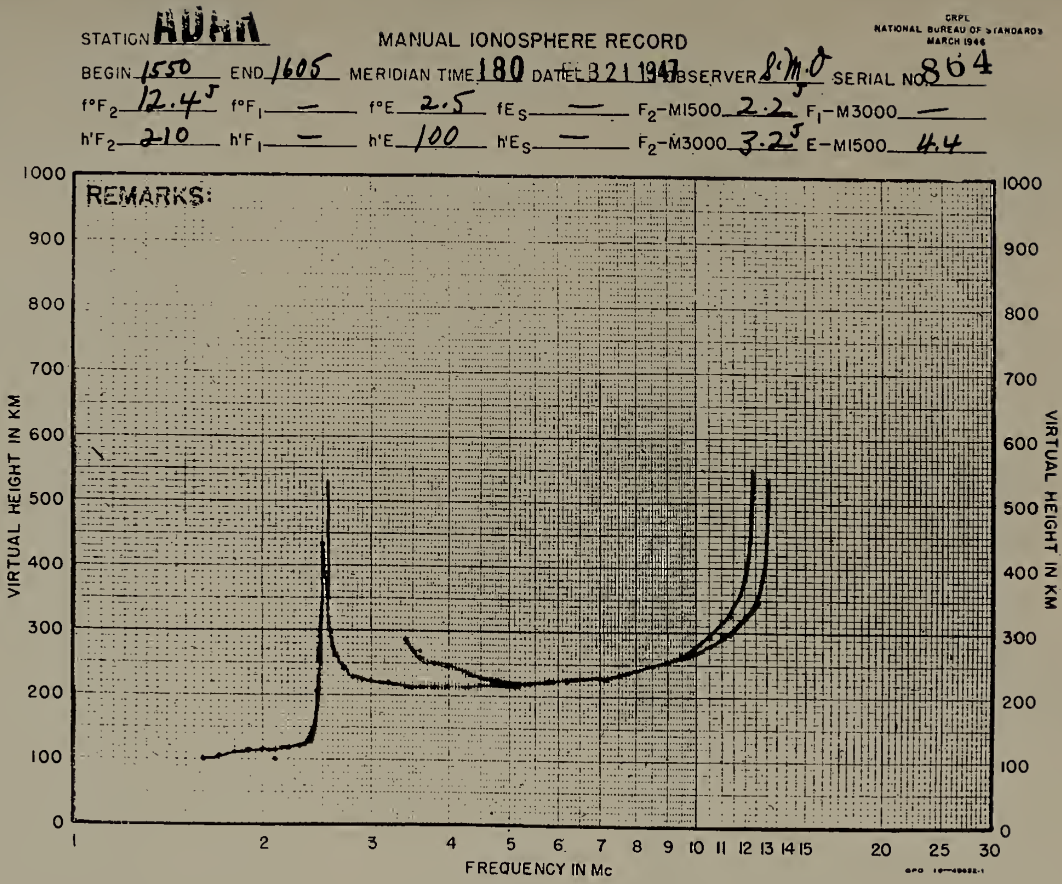


Figure 37

The modified DTM Model 1 manual recorder

Figure 38

DTM Model 3 manual ionosphere recorder



STATION ADAK MANUAL IONOSPHERE RECORD

CRPL NATIONAL BUREAU OF STANDARDS MARCH 1946

BEGIN 1550 END 1605 MERIDIAN TIME 180 DATE FEB 21 1947 OBSERVER S.M.O SERIAL NO. 864

f°F₂ 12.4⁵ f°F₁ — f°E 2.5 fEₛ — F₂-M1500 2.2 F₁-M3000 —

h'F₂ 210 h'F₁ — h'E 100 h'Eₛ — F₂-M3000 3.2⁵ E-M1500 4.4

REMARKS:

Figure 39

A typical plot made with the Model 3 manual recorder. Plots made with the Model 1 and modified Model 1 were similar to this.

The height range of the sweep was either 500 km or 1000 km, with the latter range starting at 50 km. The pulse width was between 40 and 100 microsec, and the approximate peak power was 2 kw. The approximate time required to plot the information for one sweep was between 10 and 15 min. A folded doublet antenna was used.

For plotting, a special scale for frequency and height was superimposed on the face of the oscilloscope tube.

This sounder was used at Adak, Alaska from 1945 to 1950; at Manila, P. I. from 1946 to 1947; at Maui, T. H. from 1947 to 1949; and at Trinidad, B. W. I., from 1946 to 1951. In 1945 the first three units of the Model 3 were sent to Adak, Trinidad, and to a site in China. The one sent to Manila had been used for training at the NBS field station at Sterling, Va.

b. British frequency-modulation type 249.

In 1943, the British Admiralty allocated to DTM four Type 249 sounders (designed by the National Physical Laboratory) of the frequency-modulation design, as compared to the pulse type sounders developed in the United States.

In this sounder, the transmitter was tuned rapidly by a motor-driven rotating capacitor through the frequency on which the receiver was operating. The receiver was therefore subjected to a pulse whose shape and duration depended on the bandwidth of the receiver and the rate of change of the transmitter frequency. The portion of the energy in the pass band of the receiver which was radiated and returned to the installation by the ionosphere was recorded as a pulse.

The frequency modulation method as employed in this equipment was inefficient as compared to pulse methods, since the transmitter had to operate continuously and only a portion of the total received energy was utilized by the receiver. Another disadvantage of the system was the fact that the effective pulse width was in general not constant, since the rate of change of the transmitter frequency was not maintained at a uniform level over the frequency range. As a result, the height resolution of the equipment varied over the frequency band employed.

The four Type 249 ionosondes were modified by DTM and had the following characteristics after modification:-

The frequency range was from 2.2 Mc to 16.0 Mc in two bands (Band 1 went from 2.2 Mc to 7.0 Mc; and band 2, from 7.0 Mc to 16.0 Mc). The height range started at 100 km and went to 850 km, with height markers spaced at 50 km intervals. The time for one sweep was 1 min, and the approximate peak power was 4 kw.

Figure 40

The NPL Type 249 frequency-modulation ionosonde

Figure 41

Type of ionogram obtained with the NPL Type 249 ionosonde

A row of dots on the upper edge of the 35-mm film used for the ionograms represented 0.2 Mc intervals of frequency, with the first dot on the extreme left corresponding to 2.2 Mc. The dots were not uniformly spaced. The first twenty-five dots occurred at regular intervals, followed by a second group of forty-six dots, also equally spaced, but at shorter intervals, though still representing 0.2 Mc increments in frequency. The two groups of 25 and 46 dots occupied equal lengths of film. The twenty-fifth and twenty-sixth dots were more closely spaced than any of the others, and were thus easily distinguishable; both represented a frequency of 7.0 Mc.

In the original design, the film record was 7½ inches long, but this was changed to 4 inches by the DTM modifications. For the antenna system, 4 rhombic antennas were arranged in a vertical plane and used both for transmission and reception.

The time was indicated by the photograph of a clock face. A number on a counter below the clock image indicated the day of the year; i.e., January 30 would be 030. The year had to be added manually. The date-time preceded the ionogram to which it applied.

The modified Type 249 ionosonde was used at Clyde, Baffin Island from 1944 to 1948; at Reykjavik, Iceland in 1944; at Trinidad B.W.I. from 1944 to 1945; and at Maui, T. H. from 1944 to 1949. Of these stations, only Maui was under NBS supervision during the time of use of the Type 249 ionosonde.

c. Australian automatic multifrequency ionosonde. (Model Mark V)

This sounder was designed and built about 1945 by the Commonwealth Scientific and Industrial Research Organization of Australia for the Australian Radio-Wave Propagation Committee at the Radiophysics Laboratory, University of Sydney.

It was a pulse-type sounder, having a pulse recurrence frequency of 60 per sec, and a pulse width of 140 microsec. The frequency range was from 1.0 Mc to 13.0 Mc in four bands (Band 1 went from 1.0 Mc to 2.1 Mc; band 2, from 2.1 Mc to 4.4 Mc; band 3, from 4.4 Mc to 7.6 Mc; and band 4, from 7.6 Mc to 13.0 Mc). The time for one frequency sweep was 1.6 min. The frequency scale was logarithmic, and was calibrated in 0.5 Mc intervals. The height range was 1000 km, in 50 km intervals.

To record the sweeps, 35-mm film was used, each sweep requiring about 1½ inches of film. The time of each sweep was recorded photographically on the film. Two vertical delta antennas were used with the ionosonde, set at right angles to each other. One antenna was used for the transmitter and the other for the receiver, each antenna being terminated by a 1200-ohm resistor.

Figure 42

Interior of Palmyra field station, showing the Australian type ionosonde on the left and the DTM Model 1 manual recorder on the right

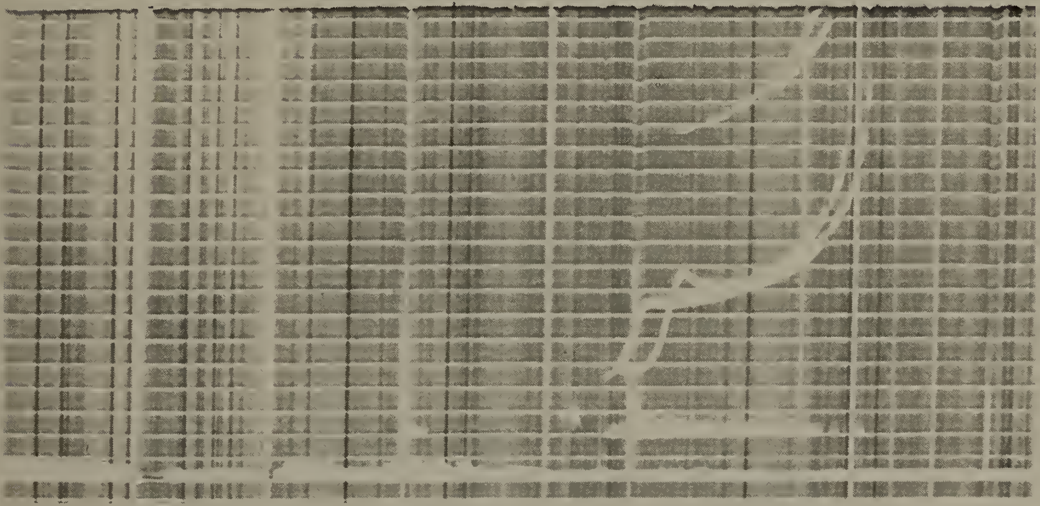


Figure 43

Type of ionogram obtained with the Australian type ionosonde

This ionosonde was used at Palmyra Island from 1946 to 1949. The same ionosonde had been previously used at Christmas Island by personnel of DTM.

d. Ionosondes developed by various laboratories associated with NBS.

1. Harvard University

This ionosonde was developed about 1945 and was used by Cruft Laboratory of Harvard University during the period 1945-1951. It was a pulse type sounder, with a frequency range of from 0.79 Mc to 14.0 Mc in four bands (Band 1 went from 0.79 Mc to 1.62 Mc; band 2, from 1.62 Mc to 3.34 Mc; band 3, from 3.39 Mc to 6.73 Mc; and band 4, from 6.73 Mc to 14.0 Mc). Its approximate peak power was 300 watts and the time for one frequency sweep was one min.

The records were made on photosensitized paper, three inches wide. There were no scales of frequency or height on the ionogram, and the date had to be added manually. The height range was approximately 800 km.

For the antenna system, four inverted "L" antennas were used, each of which resonated at 1/4-wavelength for one transmitter band and 3/4-wavelength for another transmitter band.

A system of chain drives was used to switch from one frequency band to another.

2. Leland Stanford University

This sounder was developed about 1946 and used until May 1951 when it was replaced by the CRPL Model C-3 automatic multifrequency ionosonde.

The frequency range was from 1.3 Mc to 18.0 Mc in three bands (Band 1 went from 1.3 Mc to 3.8 Mc; band 2, from 3.7 Mc to 8.2 Mc; and band 3, from 8.2 Mc to 18.0 Mc). The approximate peak power was 500 watts. The pulse recurrence frequency was 30 per sec, with a pulse width of 100 microsec. Photographic paper 3-5/8 inches wide was used for the ionograms. There were no scales of frequency or height on the ionogram, and both the date and time had to be added manually. The time for one frequency sweep was 4 min. 30 sec, with sweeps made on the hour and half-hour.

The antenna system consisted of two vertical rhombics, used both for transmitting and receiving, one for the frequency range 1.5 to 8 Mc, and the other for the range 8 to 18 Mc. Each antenna was terminated at the top by a 600-ohm resistor. An open wire transmission

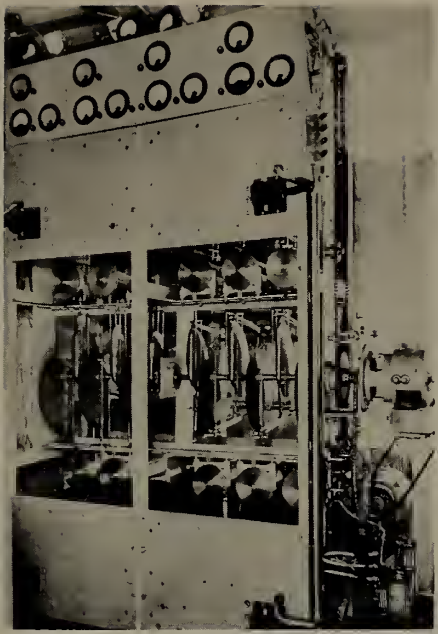


Figure 44

The automatic multifrequency ionosonde developed by Cruft Laboratory of Harvard University

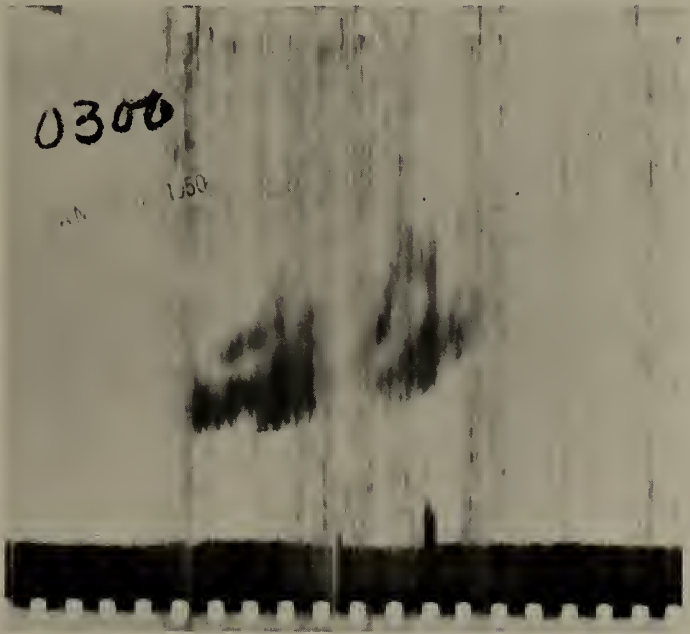


Figure 45

Example of ionogram obtained with the Harvard ionosonde

Figure 46

Automatic multifrequency ionosonde developed
by Leland Stanford University

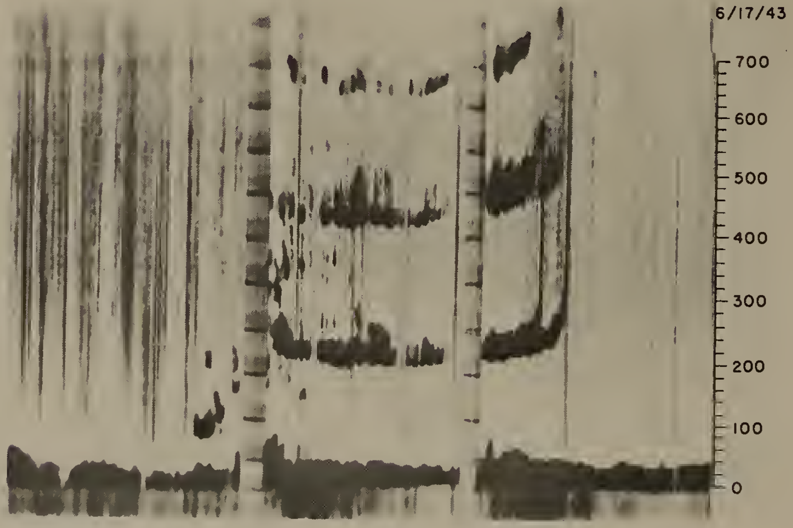


Figure 47

Typical ionogram obtained with the Stanford ionosonde

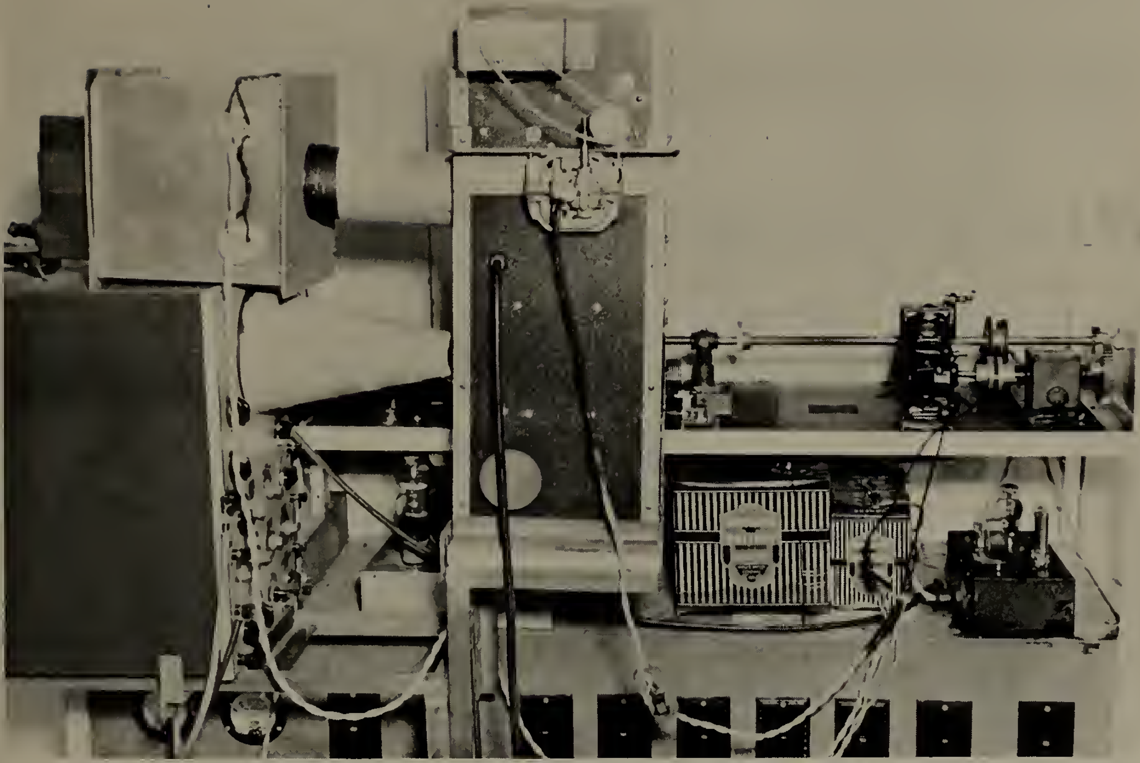


Figure 48

Automatic multifrequency ionosonde
developed at Louisiana State University

Figure 49

The Signal Corps AN/CPQ-7 (XE-1), to left of CRPL Model C-2 automatic multifrequency ionosonde line approximately 300 feet long, 8 feet above the ground, and with a surge impedance of 600 ohms was extended to each antenna.

3. Louisiana State University

This ionosonde was developed about 1946 and was used until May 1951, when it was replaced with a CRPL Model C-3 automatic multifrequency ionosonde.

The sounder had a frequency range of from 2.62 Mc to 15.68 Mc in three bands (Band 1 went from 2.62 Mc to 4.75 Mc; band 2, from 4.65 Mc to 8.50 Mc; and band 3, from 8.20 Mc to 15.68 Mc). The height range was 1250 km, and the approximate peak power was 500 watts. The time for one frequency sweep was 10 minutes. Sensitized photographic paper, four inches wide, was used for the ionograms.

The antenna system was a conventional delta with base legs 90 feet long, and the tilted legs 110 feet long. Each terminating resistor was 1200 ohms. The operating frequency of the antenna was from 2.15 Mc to 18.5 Mc.

4. Signal Corps Type AN/CPQ-7 (XE-1)

This ionosonde was developed about 1949. It was an automatic multifrequency ionosonde, with a frequency range of 1 to 24 Mc. Three height ranges were provided, for 500, 1000, and 3000 km. The approximate peak power was 7.5 kw. The pulse recurrence frequency was 30 per sec, and the pulse width could be 10, 50 or 100 microsec. The time for one frequency sweep was one minute. Sensitized photographic paper, $4\frac{1}{2}$ inches wide, was used for the ionograms. The height scale was linear, but the frequency scale depended on the type and shape of the main tuning condenser. A delta antenna, 90 feet high, was used.

Both a frequency and height scale appeared on each ionogram. The date and time were represented by numbered wheels. The number of the day of the year was indicated by three digits, the hour by two digits, the minute by two digits, and the year by one digit.

This ionosonde was used at Adak, Alaska (June 1950 - January 1951), and at Okinawa Island (November 1949 - March 1950). Three are still (1957) in use after modifications, one at Cornell University, one at Massachusetts Institute of Technology, and one at Pennsylvania State University.

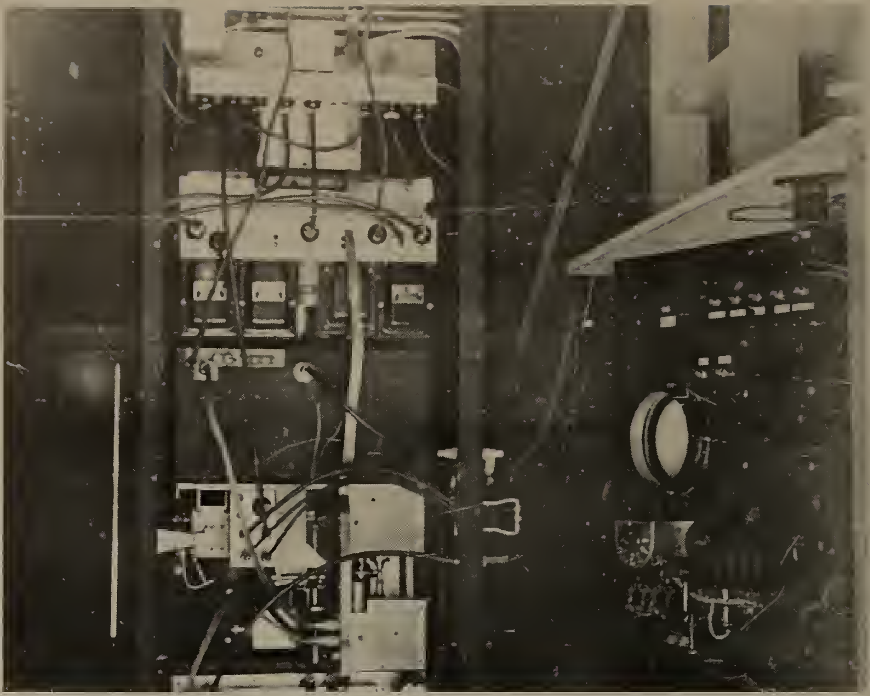


Figure 50

One stage in the development of the CRPL Model C-1 ionosonde

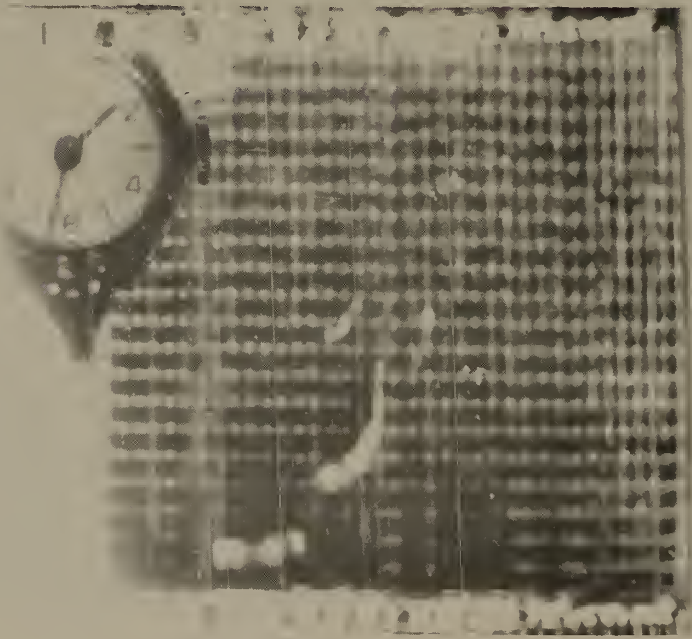


Figure 51

A typical ionogram made with the CRPL Model C-1 ionosonde

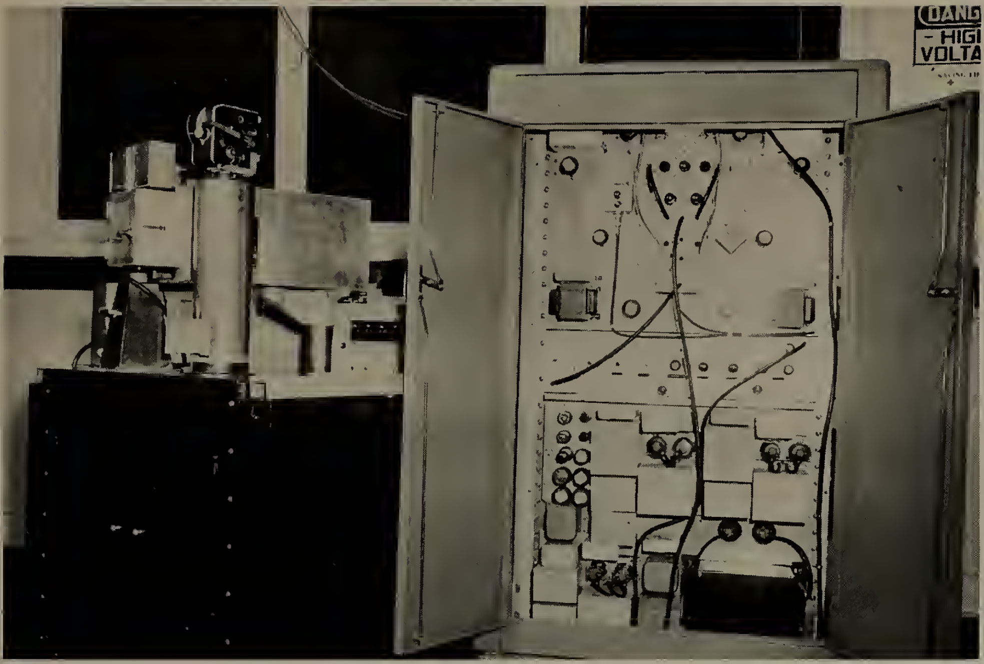


Figure 52

The prototype CRPL Model C-2 automatic multifrequency ionosonde

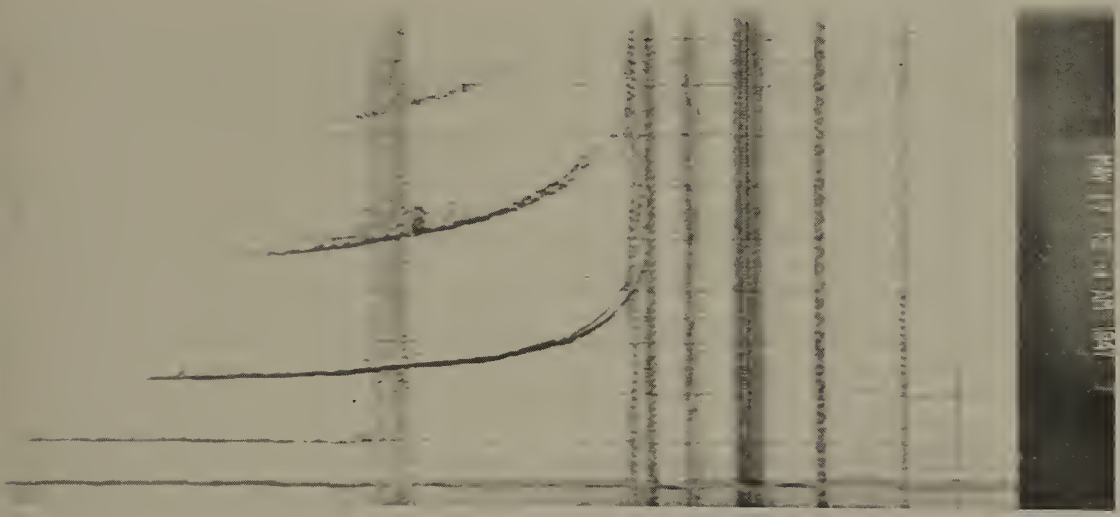


Figure 53

Typical ionogram obtained with the prototype CRPL Model C-2 ionosonde

Appendix III

Development of the CRPL Model C Ionosonde

1. The Model C-1

This was an ionosonde which employed a heterodyne method similar to that used in the NBS Model A ionosonde, in that the receiver and transmitter were linked to a beat-frequency arrangement. It was designed by Sulzer and incorporated his idea of untuned receiver input and transmitter circuits.

It had a frequency range from 1.0 to 20.0 Mc, and an approximate peak power of 2 kw. Ionograms were made on 35-mm film, but there was no scale of frequency or height on the ionogram. The time of a sweep was obtained by photographing a lady's wrist watch along with the sweep record. The date had to be added manually.

This ionosonde was installed aboard the U.S.S. Canisteo in the fall of 1946 for use by the U. S. Navy in the Byrd Antarctic Expedition "High Jump". A delta-type antenna was set up on board the ship, in its final form composed of legs 355-ft. long. Soundings were made at 15-minute intervals from December 28, 1946 to March 9, 1947 as the ship changed position during the trip.

In May 1947 the ionosonde was returned to the NBS field station at Sterling, Va., where it was reassembled and used in place of manual equipment which had replaced the Model B ionosonde destroyed by fire in January 1947.

In August 1947 the Model C-1 ionosonde was again lent to the U. S. Navy for use on an Arctic expedition, and was returned in September of that year.

2. The Model C-2

The experience gained in the development of the CRPL Model C-1 ionosonde was used in the design of an improved model, the CRPL Model C-2. The prototype C-2 was completed in time to be used in the Army Air Forces-National Geographic Society Eclipse Expedition to Bocayuva, Brazil, to study the solar eclipse of May 20, 1947.

It was the first completely automatic ionosonde to use, in continuous heavy duty, the heterodyne pulse transmitter arrangement described by Sulzer. The transmitter consisted of a series of wide-band amplifiers fed by the output of a mixer. The mixer produced a beat frequency between two oscillators, one a continuous-wave oscillator variable in frequency from 31 to 54 Mc, the other a pulsed oscillator at a fixed frequency of 30 Mc.

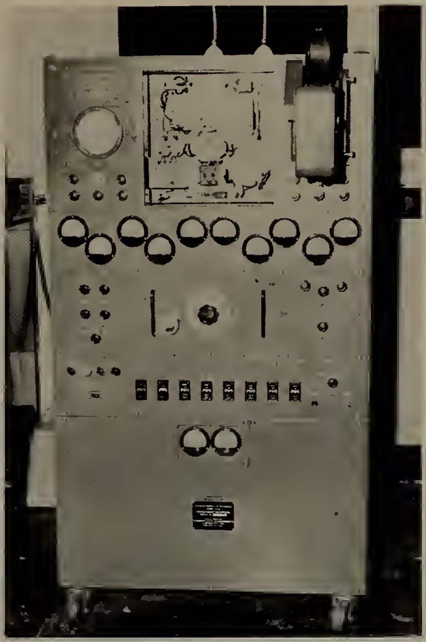


Figure 54

Production model of the CRPL Model C-2 ionosonde
Voltage regulator not shown

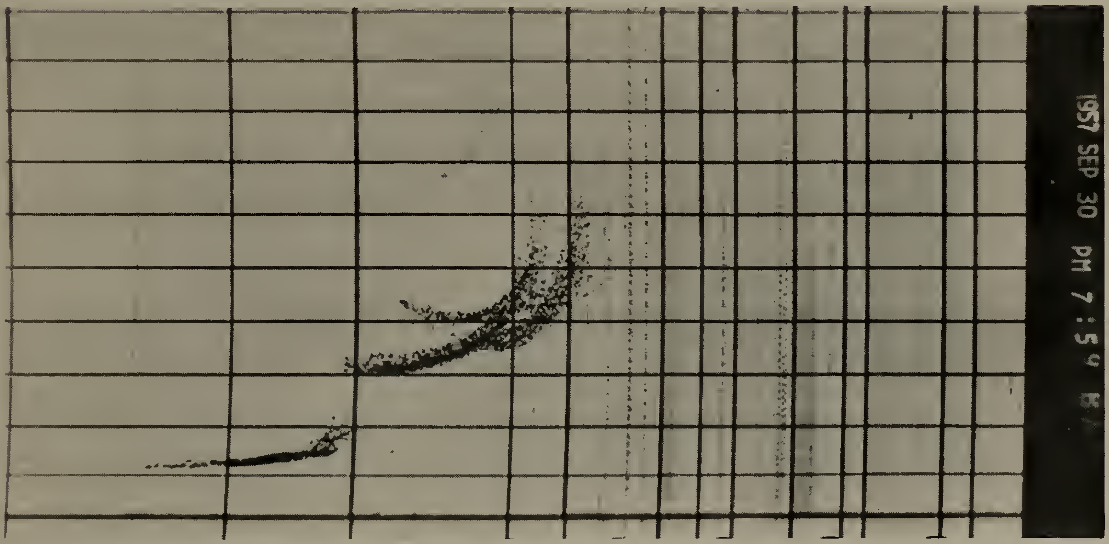


Figure 55

Typical ionogram obtained with the production model
of the CRPL Model C-2 ionosonde

The entire frequency range of 1 to 24 Mc was covered continuously without switching bands, through an arrangement of cams. The receiver was tuned with the transmitter throughout its frequency range. The time for one frequency sweep was $7\frac{1}{2}$, 15, or 30 sec, with pulse widths of 50 or 100 microsec, and a pulse recurrence frequency of 30 to 120 per sec.

A special 35-mm camera, driven by the motor that operated the transmitter oscillator made a continuous film record of the indications of the recording oscilloscope. As the image of the sweep line was oriented at right angles to the direction of film travel, the graph of height reflection (time delay) versus frequency was recorded on height scales of 500, 1000, or 4000 km. Both height and frequency markers were present on each film record, as well as the date and time of each sweep.

A standard 16-mm motion picture camera was provided to photograph the monitoring oscilloscope. A series of such film records, made at $7\frac{1}{2}$ or 15-sec intervals, over a long period of time, provides a striking accelerated version of the changes taking place in the ionosphere.

The main cabinet of the ionosonde had no moving parts, but enclosed the transmitter mixer, transmitter wide-band amplifier, receiver mixer, receiver intermediate frequency unit with detector and video stages, pulsing and keying circuits for the transmitter, the transmitter fixed frequency unit, and all the power supplies for these units.

A smaller cabinet on rollers contained the recording and monitoring oscilloscopes, the recording 35-mm camera, the variable-frequency oscillator, the camera and oscillator drive motor, switches and their associated controls, time-base and sweep-generator circuits, and the necessary power supplies.

Other features of the C-2 ionosonde were: a pulse receiver having large dynamic range and a differentiating circuit to minimize interference by CW and broadcast stations, provision for automatic operation by a clock completely independent of power-line frequency, the use of hermetically sealed units to insure reliable operation in many climates, and regulation of every important direct-current voltage.

After use in the study of the solar eclipse at Bocayuva, Brazil, the prototype C-2 was returned to the NBS field station at Sterling, Va., where it was placed in operation in July 1947.

The satisfactory performance of the prototype CRPL Model C-2 ionosonde caused the Bureau to place it in production through a commercial organization, the Communications Measurement Laboratory of

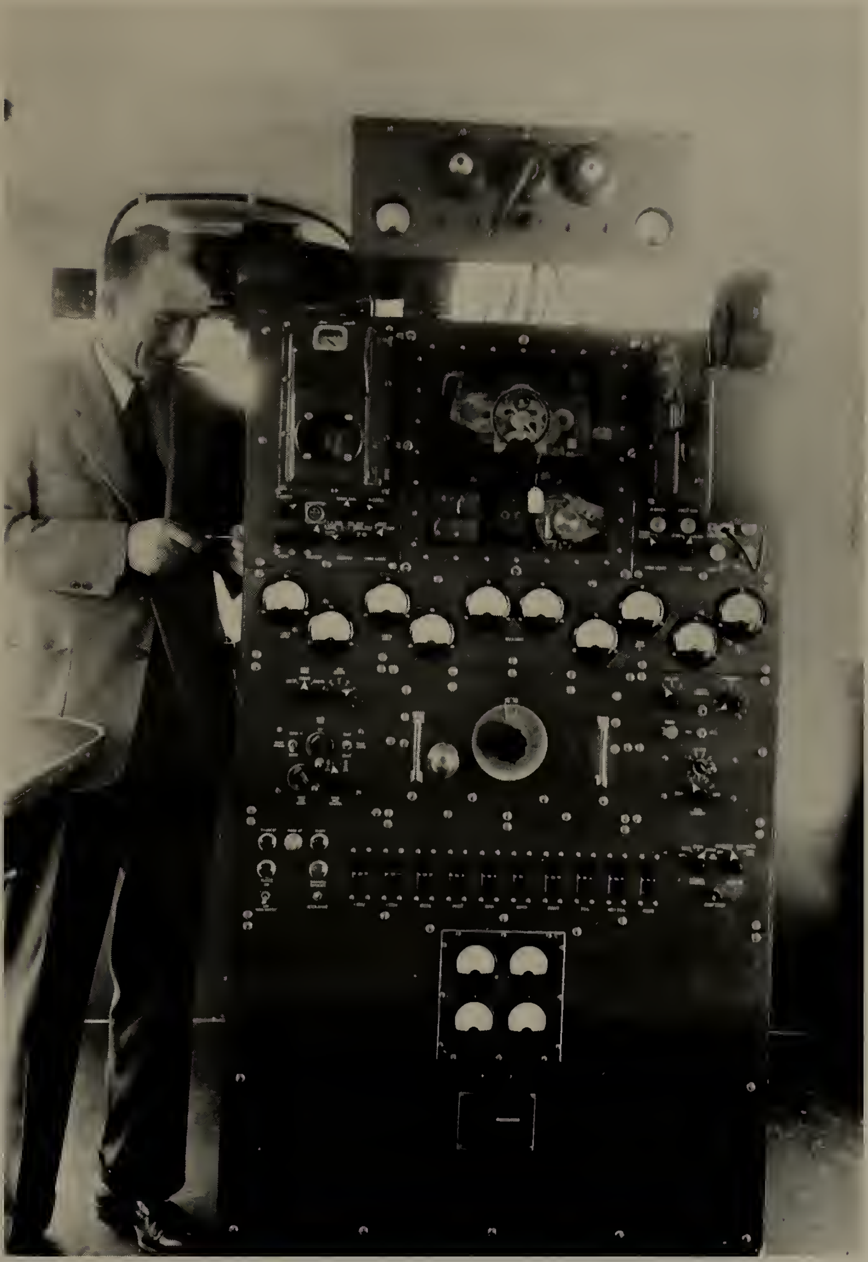


Figure 56

The CRPL Model C-3 automatic multifrequency ionosonde, installed in a trailer, with Rolfe H. Utz of the NBS staff making an adjustment.

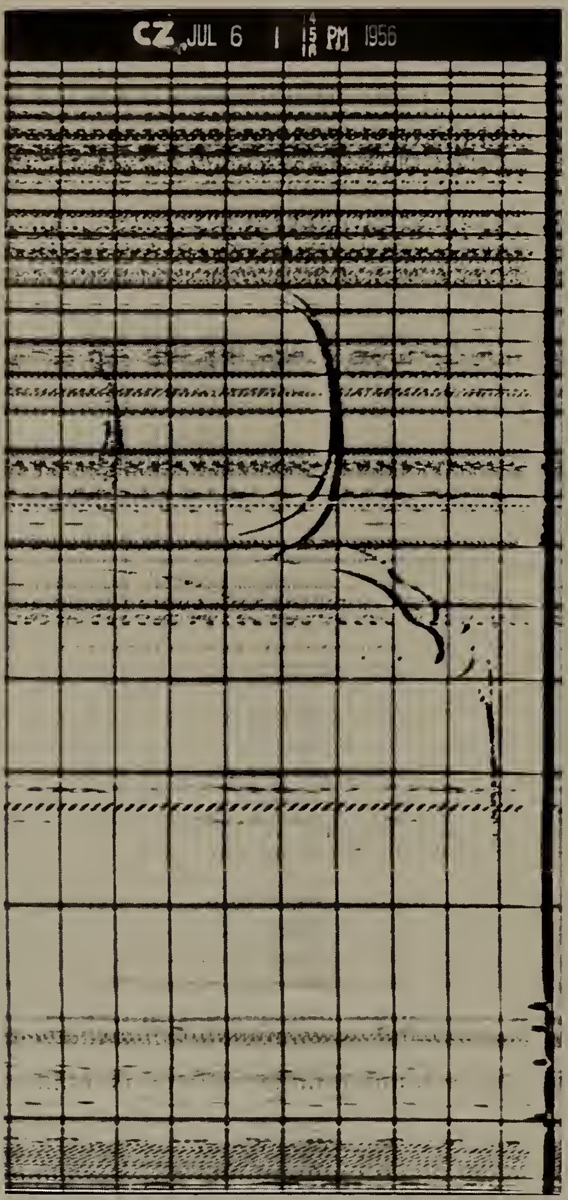


Figure 57

Typical ionogram obtained with the CRPL Model C-3 ionosonde

Whippany, N. J. By late October of 1948 the first production model of the C-2 was given acceptance tests at the Sterling, Va. station. Electrically the production model was similar to the prototype C-2, but with a single cabinet housing all parts except the voltage regulator. Also, the frequency range of the production model was extended to 25 Mc.

Height markers and frequency markers were present on the ionograms, made on 35-mm film for the routine soundings. The height markers were spaced 50 or 100 km apart, depending on the height range used. Frequency markers were present for each megacycle, from 1.0 to 25.0 Mc. At the end of each sweep appeared the so-called print time information, consisting of the station designation, the date and the time of the sweep. Although the peak power of this ionosonde varied with the frequency it was rated approximately at 10 kw. A multiple-wire delta antenna was employed.

3. The Model C-3

In the latter part of 1950, the CRPL Model C-3 ionosonde was developed. While it had the same fundamental features as the Model C-2, a number of basic improvements were incorporated:

a. Time delays were added for voltage stabilization, which resulted in more uniform ionograms.

b. The safety features of the control and protective circuits were improved.

c. A heavy duty, rugged, automatic voltage regulator auxiliary unit was added for use with varying power line voltages.

d. The pulse generator was modified for better linearity of the height markers and vernier control of the pulse rate frequencies (PRF).

e. The VFO (variable frequency oscillator) was redesigned so that the frequency unit was isolated from the transmitter. The AFM output (automatic frequency marker) was taken from the oscillator stage, while the transmitter was driven from a 2E26 amplifier stage.

f. The receiver was given front panel controls for varying the time constant of the differentiating circuit in five steps, from approximately 10 microsec to 1000 microsec.

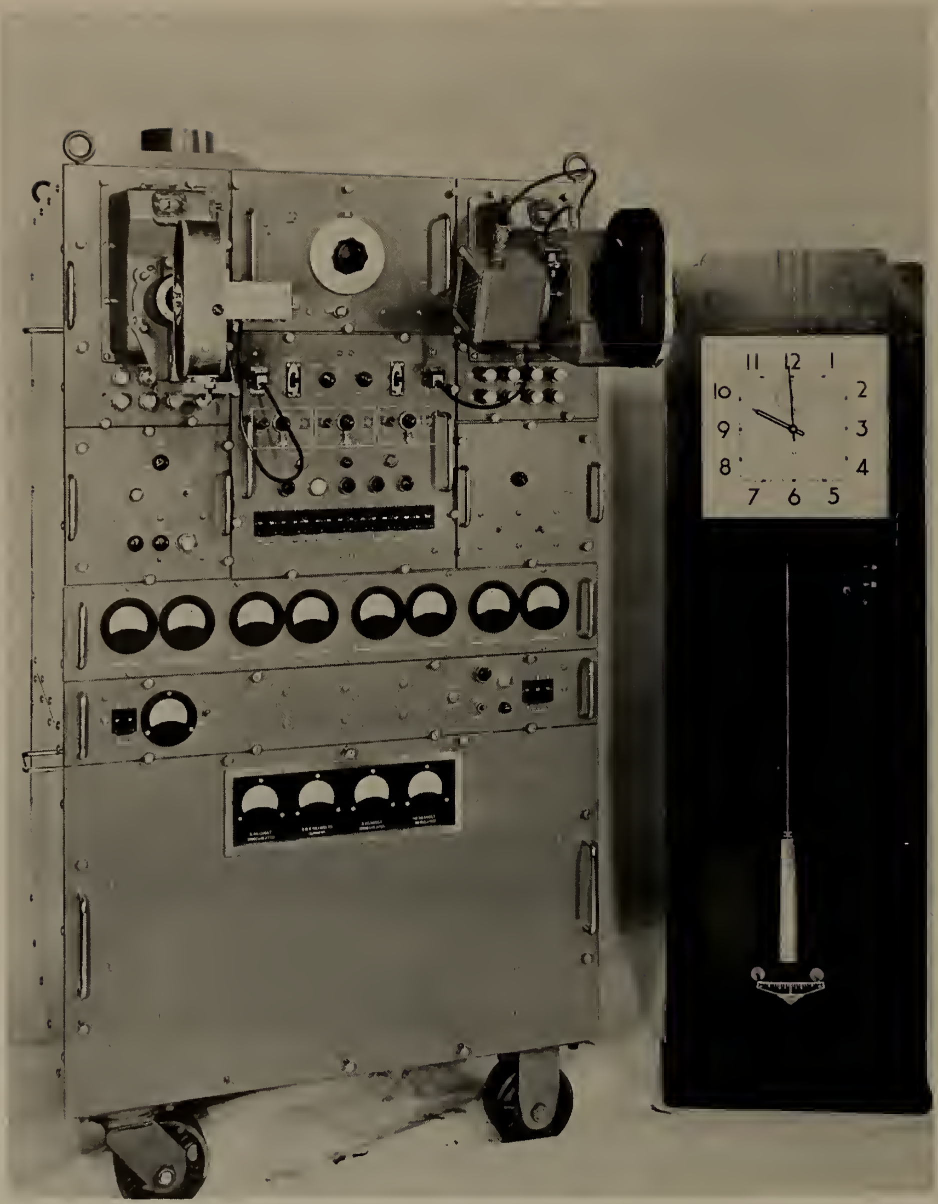


Figure 58

The CRPL Model C-4 automatic multifrequency ionosonde
(Photograph courtesy of Barker and Williamson)

g. The transmitter, ATX, was modified for more efficient operation by decreasing the final plate voltage from +8 kv to +5 kv, while the screen voltage on the three high power ATX stages was increased from +600 v to +1000 v.

h. The automatic print time assembly was modified and greatly improved for reliability of operation, ease of adjustment and instant identification of date time without opening the camera assembly.

4. The Model C-4

The need for additional ionosondes for proposed IGY stations provided the stimulus for the design of an improved Model C ionosonde called the CRPL Model C-4 ionosonde.

The major changes in the C-4 design as compared to the Model C-3 were:

a. Electrostatic deflection instead of magnetic deflection, as in the C-2 and C-3, was used with the oscilloscope tubes for improved linearity of the oscilloscope presentation.

b. The height marker oscillator was made crystal-controlled for maximum accuracy.

c. The receiver had higher gain and improved noise characteristics.

d. The transmitter was simpler and provided greater power output.

e. Most of the individual sub-units were mounted on roller slides so that they could be removed easily to facilitate maintenance.

f. The control and sweep circuits were consolidated into one unit and designed for greater flexibility in program selection and automatic receiver gain programming.

g. The Model C-4 ionosonde was one complete package, whereas Models C-2 and C-3 consisted of two units.

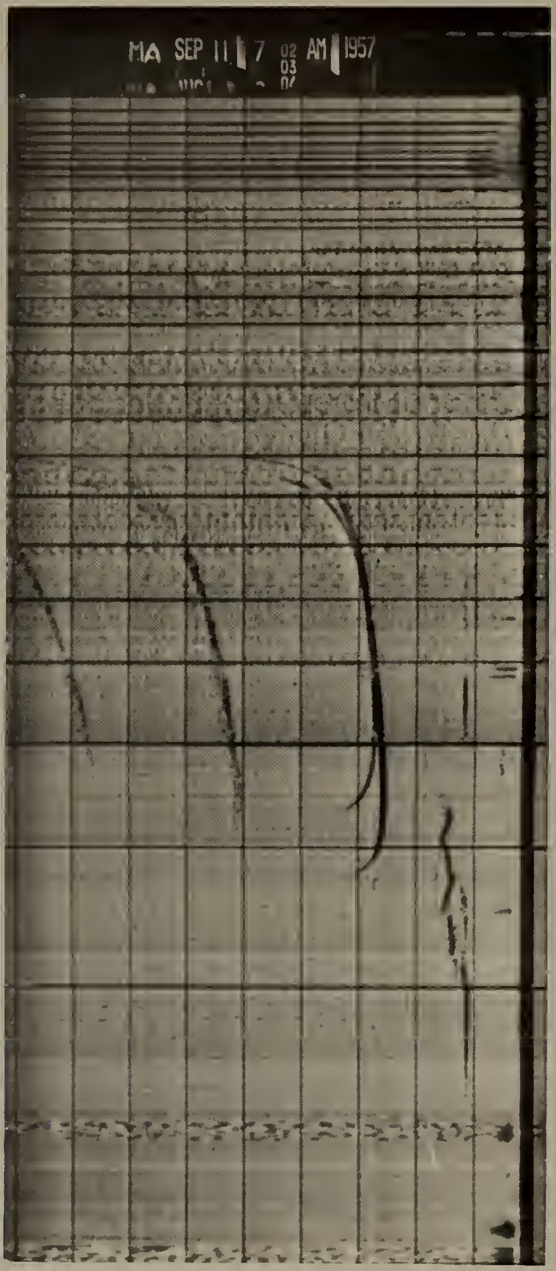


Figure 59

Typical ionogram obtained with the CRPL Model C-4 ionosonde

Appendix IV

Details of Operation of Field Station

ADAK, ALASKA

Operations began at this station October 8, 1945, under the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. In July 1946 CRPL took over the operation of the station. In the early part of November 1947, the U. S. Army Signal Corps assumed operation of the Adak station. Since January 8, 1954, this station has been operated under the direction of the United States Army Signal Radio Propagation Agency at Fort Monmouth, New Jersey.

Equipment used:

From October 1945 through April 1950, DTM Model 3 manual recorder.

From May 1950 through January 1951, Signal Corps automatic multifrequency ionosonde Model AN/CPQ-7 (XE-1), with DTM manual recorder as supplementary equipment.

Since February 1951, CRPL Model C-3 automatic multifrequency ionosonde.

NBS Personnel in charge:

Alton O. Crawley, July 1946 to November 1946.
Sidney M. Ostrow, November 1946 to June 1947.
Lloyd A. Lohr, June 1947 to November 1947.

ANCHORAGE, ALASKA

This station was activated in March 1949 and has always been operated by CRPL. The first complete tabulations of data from Anchorage were for April 1949.

Equipment used:

From March 1949 to March 1951, CRPL Model C-2 automatic multifrequency ionosonde.

Since March 1951, CRPL Model C-3 automatic multifrequency ionosonde.

Figure 60

The Adak, Alaska field station
(U. S. Army photograph)

Figure 61

The Anchorage, Alaska field station

NBS Personnel in charge:

Vernon H. Goerke, March 1949 to March 1950.
Joseph H. DeGregorio, March 1950 to May 1950.
Alton O. Crawley, May 1950 to February 1954.
Robert W. Knecht, February 1954 to September 1954.
Stephen S. Barnes, September 1954 to July 1957.
Martin E. Nason, since July 1957.

BAGUIO, PHILIPPINE ISLANDS

Operations began at this station March 5, 1952. It is operated by the Manila Observatory, and is regarded as an associated laboratory of the National Bureau of Standards.

Equipment used:

Since the start of operations, a CRPL Model C-2 automatic multi-frequency ionosonde, with C-3 auxiliary power unit.

BARROW, ALASKA

This station was activated by CRPL in November 1949, and has always been operated by CRPL.

Equipment used:

Since the start of operations, a CRPL Model C-2 automatic multi-frequency ionosonde.

NBS Personnel in charge:

Lloyd A. Lohr, November 1949 to December 1950.
Joseph H. DeGregorio, December 1950 to June 1951.
Robert W. Knecht, June 1951 to August 1951.
Joseph H. DeGregorio, August 1951 to December 1952.
Albert D. Krall, December 1952.
Wesley H. Daniels, December 1952 to September 1953.
Bernard Wieder, September 1953 to October 1954.
Donald M. Waters, October 1954 to February 1956.
William C. Wanbaugh, February 1956 to July 1957.
Harry E. Petrie, since July 1957.

Figure 62

The Baguio field station

Figure 63

The Barrow, Alaska field station

BATON ROUGE, LOUISIANA (Louisiana State University)

Operations began at this station in July 1943 and ceased September 1, 1953. From May 1946 to September 1953 it was operated by personnel of Louisiana State University as an associated laboratory of the National Bureau of Standards. Prior to this time the operation was carried on as part of the Department of Electrical Engineering of the University.

Equipment used:

From July 1943 to about December 1946, a locally assembled ionosonde, with a frequency range of 1.9 to 9.8 Mc.

From December 1946 to May 1951, a locally assembled ionosonde, with frequency range from 2.6 to 15.7 Mc.

From May 1951 to September 1953, a CRPL Model C-3 automatic multifrequency ionosonde.

BOSTON, MASSACHUSETTS (Harvard University)

Operations began at this station about March 1945 by the Cruft Laboratory of Harvard University. Until June 1951 it was operated as an associated laboratory of the National Bureau of Standards.

Equipment used:

Locally assembled automatic multifrequency ionosonde, with a frequency range of 0.79 to 14.0 Mc.

COCOA, FLORIDA

Operations began at this station in January 1952 and ceased the latter part of September 1952. It was operated by the U. S. Army Air Force at Patrick Air Force Base. A station was reestablished in this general location (Cape Canaveral) in late 1957 by the U. S. Signal Corps.

Equipment used:

CRPL Model C-3 automatic multifrequency ionosonde.

Figure 64

The Louisiana State University field station

Figure 65

The Harvard University field station

FAIRBANKS, ALASKA (Geophysical Institute of the University of Alaska)

While ionospheric research had been carried on at this location during the Second International Polar Year in 1932-33, The Department of Terrestrial Magnetism, Carnegie Institution of Washington entered on a regular program of ionospheric soundings in April 1941. On July 1, 1946 the station operation was transferred to the University of Alaska, at which time it also became an associated laboratory of the National Bureau of Standards.

Equipment used:

From July 1941 to March 1951, DTM automatic multifrequency ionosonde.

Since March 1951, CRPL Model C-3 automatic multifrequency ionosonde.

GODHAVN, GREENLAND

Regular operation of this station began November 1, 1951. It is under the control of the Danish URSI Commission and is considered an associated laboratory of the National Bureau of Standards.

Equipment used:

Since the start of operations, a CRPL Model C-3 automatic multifrequency ionosonde.

GUAM, MARIANA ISLANDS

This station was installed under the supervision of the U. S. Navy. Operations were begun in December 1945 by the U. S. Army Signals Corps. On June 6, 1946, Harold N. Cones was designated by CRPL as engineer-in-charge of the station. The station was deactivated April 30, 1956 and the ionosonde moved to Maui, T. H.

Equipment used:

From December 1945 through December 1947, DTM Model 2 (Modified Model 1) manual recorder.

From January 1948 to close of operations, CRPL Model C-2 automatic multifrequency ionosonde.

Figure 66

The Fairbanks, Alaska field station

Figure 67

The Godhavn, Greenland field station

NBS Personnel in charge:

Harold N. Cones, June 1946 to October 1946.
Harry G. Sellery, October 1946 to January 1948.
Lloyd A. Lohr, January 1948 to December 1949.
H. O. Wehner, December 1949 to February 1950.
H. C. Carmichael, February 1950 to November 1950.
W. J. Christian, December 1950 to January 1951.
Stephen S. Barnes, January 1951 to April 1951.
Lloyd A. Lohr, April 1951 to December 1952.
Stephen S. Barnes, January 1953 to May 1954.
John J. Pitts, June 1954.
Alton O. Crawley, July 1954 to April 1956.

HUANCAYO, PERU

Operations began at this station in November 1937. Through October 1947 the station was operated by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. Since November 1947 the Geophysical Institute of Huancayo has operated the station as an associated laboratory of the National Bureau of Standards.

Equipment used:

From November 1937 to December 1951, DTM automatic multifrequency ionosonde.

Since December 1951, CRPL Model C-3 automatic multifrequency ionosonde.

MANILA, PHILIPPINE ISLANDS

This station started operations in August 1946 and was inactivated August 15, 1947. It was operated by NBS personnel.

Equipment used:

DTM Model 3 manual recorder.

NBS Personnel in charge:

Mrs. M. L. Phillips, August 1946 to November 1946.
J. J. Murray, November 1946 to May 1947.
The station was inoperative after May 1947.

Figure 68

The Guam field station

Figure 69

The Huancayo, Peru field station

MAUI, TERRITORY OF HAWAII

Operations began at this station in March 1944. Until July 1946 it was operated by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. At that time CRPL took over the operation of the station.

Equipment used:

From March 1944 through February 1947, National Physical Laboratory Type 249 automatic multifrequency ionosonde.

From March 1947 to August 15, 1947, DTM Model 3 manual recorder.

From August 15, 1947 through June 1949, National Physical Laboratory Type 249 automatic multifrequency ionosonde.

From June 1949 to February 1951, CRPL Model C-2 automatic multifrequency ionosonde. The use of the NPL Type 249 and the Model C-2 overlapped in June 1949.

From February 1951 through July 1956, CRPL Model C-3 automatic multifrequency ionosonde.

Since September 1957, CRPL Model C-4 automatic multifrequency ionosonde.

NBS Personnel in charge:

Lester E. Kendall, July 1946 to April 1947.
Leo W. Honea, since April 1947.

FORT MONMOUTH, NEW JERSEY

Operations were initiated at this station by the U. S. Army Signal Corps at Belmar, N. J., July 1, 1950. The station was moved to Fort Monmouth, N. J. about August 17, 1953, still under the supervision of the Signal Corps. In December 1957 the site was changed to Middletown, N. J. This station serves as the training center for ionospheric soundings of the U. S. Army Signal Corps. January 8, 1954 it was placed under the direction of the United States Army Signal Radio Propagation Agency.

Figure 70

The Maui ionosphere station

Figure 71

Fort Monmouth field station
(U. S. Army photograph)

Equipment used:

From July 1950 to June 1954, CRPL Model C-2 automatic multifrequency ionosonde.

Since July 1954, CRPL Model C-3 automatic multifrequency ionosonde.

Since January 1958, CRPL Model C-4 automatic multifrequency ionosonde.

NARSARSSUAK, GREENLAND

Operations began at this station in September 1950. Until May 10, 1957 it was operated by CRPL. In August 1957 the station was reactivated by the Danish URSI Commission as an associated laboratory of the National Bureau of Standards.

Equipment used:

CRPL Model C-3 automatic multifrequency ionosonde.

NBS Personnel in charge:

George S. Burkholder, July 1950 to September 1950.
Robert F. Biloon, September 1950 to March 1952.
Earl E. Ferguson, March 1952 to November 1953. Mr. Ferguson set up the station in 1950.
Leonard F. Marcus, November 1953 to December 1954.
Harry E. Petrie, December 1954 to May 1957.

OKINAWA ISLAND

Operations began at this station April 7, 1946. It was operated by the U. S. Army Signal Corps until January 8, 1954 when it was placed under the direction of the U. S. Signal Radio Propagation Agency at Fort Monmouth, N. J.

Equipment used:

From April 1946 through October 1949, DTM Model 2 (modified Model 1) manual recorder.

From November 1949 to March 1950, Signal Corps Model AN/CPQ-7 (XE-1) automatic multifrequency ionosonde, supplemented by the DTM Model 2 manual recorder.

Figure 72

The Narsarssuak, Greenland field station

Figure 73

The Okinawa field station
(U.S.Army photograph)

Since September 1950, CRPL Model C-3 automatic multifrequency ionosonde.

PALMYRA ISLAND

Operations began at this station in July 1946 and ceased November 25, 1949. The station was operated by CRPL.

Equipment used:

From November 1946 to November 1949, DTM Model 1 manual recorder.

From December 1946 to November 1949, Australian type automatic multifrequency ionosonde. The first film ionograms were made on December 24, 1946.

NBS Personnel in charge:

Leo W. Honea, July 1946 to April 1947.
Vernon H. Goerke, April 1947 to June 1948.
Stephen S. Barnes, June 1948 to September 1949.
James E. McMillan, September 1949 to December 1949.

PANAMA CANAL ZONE

Operations began at this station June 1, 1951. It has always been operated by CRPL. The station replaced the one at Trinidad, B.W.I.

Equipment used:

CRPL Model C-3 automatic multifrequency ionosonde.

NBS Personnel in charge:

Richard F. Carle, October 1950 to May 1956. Actual production of ionograms did not start until June 1951.
Alton O. Crawley, since May 1956.

Note: This station was closed on December 24, 1958.

Figure 74

The Panama field station

Figure 75

The Puerto Rico field station

PUERTO RICO

Operations began at this station in February 1941. Through December 1950 it was operated by the University of Puerto Rico at Rio Piedras. In 1949 T. R. Gilliland of NBS was transferred to Puerto Rico from Washington to inspect and secure detailed information on the most favorable and available sites for the establishment of a radio propagation field station. By December 1950 suitable quarters had been completed at Ramey Air Force Base and the work of the University of Puerto Rico was terminated by the end of that month. The first ionograms made with a CRPL Model C-3 ionosonde were for January 1951. The University of Puerto Rico was considered an associated laboratory of the National Bureau of Standards.

Equipment used:

From January 1943 to June 1945, a manual recorder, locally built.

From July 1945 to October 1947, and from March 1946 to January 1951, an automatic multifrequency ionosonde, locally built.

Since January 1951, CRPL Model C-3 automatic multifrequency ionosonde.

NBS personnel in charge:

Theodore R. Gilliland, since August 1949.

REYKJAVIK, ICELAND

From February 1944 to the end of July 1945 the station was operated by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. On January 1, 1950 the station was reactivated and has been operated since that date by the Icelandic Post and Telegraph System as an associated laboratory of the National Bureau of Standards.

Equipment used:

February 1944 to July 1945, National Physical Laboratory Type 249 automatic multifrequency ionosonde.

Since January 1950, CRPL Model C-2 automatic multifrequency ionosonde, on 50-cycle power supply.

Figure 76

The Reykjavik, Iceland field station

Figure 77

The Stanford University field station

SAN FRANCISCO, CALIFORNIA (Leland Stanford University)

Operations began at this station in February 1942. Since May 1946 it has been an associated laboratory of the National Bureau of Standards.

Equipment used:

From February 1942 to November 1946, locally assembled ionosondes.

From December 1946 to May 1951, a locally assembled automatic multifrequency ionosonde.

Since May 1951, CRPL Model C-3 automatic multifrequency ionosonde.

ST. JOHNS, NEWFOUNDLAND

From May 1945 to July 1954 this station was operated by the Canadian Department of Transport for the Radio Physics Laboratory. In January 1957 the station was reactivated at a new site as a cooperative IGY project of Canada and the United States. The station is operated by the United States Army Signal Ionosphere Station, Newfoundland, under the direction of the United States Army Signal Radio Propagation Agency at Fort Monmouth, New Jersey.

Equipment used:

From May 1945 to July 1954, Canadian Type LG17 automatic multifrequency ionosonde.

From January 1957, CRPL Model C-3 automatic multifrequency ionosonde.

TALARA, PERU

Operations began at this station October 9, 1954. It is operated by the Geophysical Institute of Huancayo, Peru and is an associated laboratory of the National Bureau of Standards.

Equipment used:

Since start of operations, CRPL Model C-3 automatic multifrequency ionosonde.

Figure 78

The St. Johns, Newfoundland field station
(U. S. Army photograph)

Figure 79

The Talara, Peru field station

THULE, GREENLAND

Operations began at this station in February 1956. It is a cooperative IGY project of Denmark and the United States. The station is operated by the United States Army Signal Ionosphere Station, Thule, under the direction of the United States Army Signal Radio Propagation Agency at Fort Monmouth, New Jersey.

Equipment used:

From start of operations until April 3, 1957, CRPL Model C-2 automatic multifrequency ionosonde.

Since April 3, 1957, CRPL Model C-4 automatic multifrequency ionosonde.

TRINIDAD, B.W.I.

Operations began at this station in February 1944 and ceased June 21, 1951. Until July 1946, the station was operated by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. From that time until the close of operations, the work was under the supervision of CRPL.

Equipment used:

From February 1944 to December 1945, National Physical Laboratory Type 249 automatic multifrequency ionosonde.

From January 1946 to May 1951, DTM Model 3 manual recorder.

NBS personnel in charge:

Richard F. Carle, July 1946 to October 1950.
J. S. Noble, October 1950 to June 1951.

WASHINGTON, D. C.

This station has always been designated as the Washington field station, although the site has been at various times at Kensington, Md., Beltsville, Md., Meadows, Md., Sterling, Va. and Ft. Belvoir, Va. (See Section III 2) Work at the Washington station began with the measurement of virtual heights of the ionosphere near Kensington, Md. in 1929, with the pulse transmitter located at the Naval Research Laboratory, Bellevue, D. C. Details of the work at the various locations has been previously described.

Figure 80

The Thule, Greenland field station
(U. S. Army photograph)

Figure 81

The Sterling, Va. field station

Equipment used:

From December 1929 to June 1930, fixed frequency pulse transmitter at Naval Research Laboratory, Bellevue, D. C. and virtual height recorder near Kensington, Md.

From July 1930 to August 1932, variable frequency pulse transmitter of 500 watts power used for fixed frequency measurement of virtual heights, usually on 4045 kc, at Potomac Yards, north of Alexandria, Va. The receiver was located at the NBS field station near Kensington, Md.

From August 1932 to March 1933, fixed frequency transmitter (4100 kc) of 250 watts output used for measurement of virtual heights, with transmitter and receiver operated alongside in the same room for the first time. This combination was first used at the NBS station near Kensington, Md., and later at the NBS site near Beltsville, Md.

From March 1933 to September 1933, and intermittently thereafter, a variable frequency pulse transmitter, 1 kw output and with a frequency range of 1750 to 25,000 kc (later reduced to 1600 kc), operated manually at Beltsville. The recorder was operated at Meadows, Md.

From April 1933 to October 1941, the NBS first automatic multifrequency ionosonde (2.5 to 4.4 Mc range). It was operated at the Beltsville field site until about May 1935, and was then moved to the field site at Meadows, Md.

From October 1934 to January 1947, the NBS Model B ionosonde. First installed at Meadows, Md. with a frequency range of 500 to 2500 kc. Modified by May 1940 to have a frequency range of 2500 to 10,500 kc. Used at the Beltsville field station from March 1943 to September 1943, when it was moved to the Sterling field station. By 1944 the ionosonde had been modified to cover the frequency range from 0.75 to 11.5 Mc, and another modification in October 1946 which increased the upper frequency limit to 16 Mc. This ionosonde destroyed by fire at the Sterling field station on January 30, 1947.

From fall of 1941 to February 1943, NBS Model A automatic multifrequency ionosonde, used at Meadows site.

March 1943, NBS Model A automatic multifrequency ionosonde used at Beltsville site.

From August 1943 to May 1946, NBS Model A automatic multifrequency ionosonde used at Sterling site.

From February 1947 to June 11, 1947, DTM automatic multifrequency ionosonde, together with a manual recorder, used at Sterling site to replace the NBS Model B ionosonde destroyed by fire in January 1947.

From June 9, 1947 to August 1947, CRPL Model C-1 automatic multifrequency ionosonde used at Sterling site.

From June 12, 1947 to June 1950, CRPL Model C-2 automatic multifrequency ionosonde, first used at the Sterling site (1947-1949), then at the Fort Belvoir site (1949-1950).

From June 1950, CRPL Model C-3 automatic multifrequency ionosonde used at Fort Belvoir site. Use of the CRPL Models C-2 and C-3 overlapped in June 1950.

NBS personnel in charge:

Prior to 1943, the various stations were all generally under the direction of Dr. J. H. Dellinger. The Kensington station was established by Mr. T. Parkinson about 1926 or 1927. When Mr. Parkinson left NBS about 1930, S. S. Kirby directed the work of the Meadows and Beltsville stations, except for the standard frequency work under W. D. George. After Mr. Kirby's death in 1941, among those working part time at Meadows and Beltsville were Dr. Newbern Smith, Fred Gracely, S. E. Reymer, Elbert B. Judson and Archer S. Taylor. Mr. T. R. Gilliland was also associated with these stations.

Archer S. Taylor, from fall of 1941 to August 1943.
Edward J. Wiewara, August 1943 to June 1946.
Rolfe H. Utz, June 1946 to January 1947.
Edward J. Wiewara, January 1947 to April 1947.
M. L. Johnson, May 1947 to August 1947.
Edward J. Wiewara, August 1947 to December 1949.
David H. Sands, December 1949 to March 1950.
Alvin H. Morgan, April 1950 to July 1951.
Allan P. Stansbury, August 1951.
H. C. Carmichael, September 1951.
Edward J. Wiewara, since September 1951.

Figure 82

The Ft. Belvoir field station

Figure 83

The White Sands, New Mexico field station
(U. S. Army photograph)

WHITE SANDS, NEW MEXICO

In May 1946 the NBS Model A ionosonde was sent to White Sands Proving Grounds, New Mexico, to be used in the V-2 rocket tests conducted by the Army and Navy. The ionosonde was installed in a trailer, and occasional soundings were made until July 1947, when the station was activated as a CRPL field station. In June 1947 the ionosonde was shifted from the trailer to a building within the Post area. On September 1, 1951 the U S. Army Signal Corps took over the operation of the station. Since January 8, 1954 this station has been operated under the direction of the United States Army Signal Radio Propagation Agency at Fort Monmouth, New Jersey.

Equipment used:

From June 1946 to February 1951, NBS Model A automatic multifrequency ionosonde.

From March 1951 to December 1, 1951, NBS Model A ionosonde used as standby equipment.

Since March 1, 1951, CRPL Model C-3 automatic multifrequency ionosonde.

NBS personnel in charge:

Edward J. Wiewara set up the mobile station in June 1946.
Alton O. Crawley, December 1946 to May 1947.
Edward J. Wiewara, May 1947 to August 1947.
Allan P. Stansbury, August 1947 to July 1948.
Earl E. Ferguson, July 1948 to December 1949.
Edward J. Wiewara, December 1949 to September 1951.

Appendix V. Summary of station information for stations established before 1957.

TABLE 1

Station	Geographic		Geomagnetic		Approx. Dip Angle	Time Used
	Latitude	Longitude	Latitude	Longitude		
ADAK	51.9°N	176.6°W	48°N	240°E	64°N	180°W
ANCHORAGE	61.2°N	149.9°W	61°N	258°E	74°N	150°W
BAGUIO	16.4°N	120.6°E	5°N	189°E	18°N	120°E
BARROW	71.3°N	156.8°W	68°N	241°E	81°N	150°W
BATON ROUGE	30.5°N	91.2°W	41°N	335°E	63°N	90°W
BOSTON	42.4°N	71.2°W	53°N	358°E	73°N	75°W
CHRISTMAS ISLAND (before 6/45) (after 6/45)	2.0°N 1.9°N	157.0°W 157.3°W	2°N	271°E	5°N	150°W
COCOA	28.2°N	80.6°W	39°N	346°E	62°N	75°W
FAIRBANKS	64.9°N	147.8°W	64°N	256°E	77°N	150°W
GODHAVN (before 11/56) (after 11/56)	69.2°N 69.3°N	53.5°W 53.5°W	81°N 80°N	32°E 33°E	81°N 81°N	45°W 45°W
GUAM (before 9/47) (after 9/47)	13.5°N 13.6°N	144.8°E 144.9°E	4°N	213°E	14°N	150°E
HUANCAYO	12.0°S	75.3°W	1°S	354°E	2°N	75°W
MANILA	14.5°N	121.0°E	4°N	190°E	16°N	120°E
MAUI	20.8°N	156.5°W	21°N	268°E	40°N	150°W
FT. MONMOUTH (before 8/53) (8/53 - 12/57) (after 12/57)	40.2°N 40.3°N 40.4°N	74.1°W 74.1°W 74.2°W	51°N	354°E	72°N	75°W

Station	Geographic		Geomagnetic		Approx. Dip Angle	Time Used
	Lat.	Long.	Lat.	Long.		
NARSARSSUAK	61.2°N	45.4°W	71°N	37°E	78°N	45°W
OKINAWA	26.3°N	127.8°E	15°N	196°E	37°N	135°E (before 11/50) 127.5°E (11/50 through 6/55) 135°E (since 6/55)
PALMYRA	5.9°N	162.2°W	6°N	266°E	12°N	157.5°W
PANAMA	9.4°N	79.9°W	20°N	343°E	39°N	75°W
PUERTO RICO (before 1/51) (after 1/51)	18.4°N 18.5°N	66.1°W 67.2°W	29°N	3°E	53°N	60°W
REYKJAVIK	64.1°N	21.8°W	70°N	71°E	76°N	15°W
SAN FRANCISCO	37.4°N	122.2°W	44°N	298°E	62°N	120°W
ST. JOHNS	47.6°N	52.7°W	59°N	21°E	73°N	60°W (5/45 - 7/54) 52.5°W (1/20/57 to 4/18/57) 60°W (after 4/18/57)
TALARA	4.6°S	81.3°W	7°N	350°E	12°N	75°W
THULE	76.6°N	68.7°W	88°N	1°E	86°N	75°W
TRINIDAD (2/44 - 1/45) (2/45 - 7/46)	10.6°N 10.6°N	61.3°W 61.2°W	22°N	9°E	42°N	60°W
WASHINGTON (Meadows, Md.) (Beltsville, Md.) (Sterling, Va.) (Ft. Belvoir, Va.)	39.0°N 39.0°N 39.0°N 38.7°N	77.0°W 76.9°W 77.5°W 77.1°W	50°N	351°E	72°N	75°W
WHITE SANDS	32.3°N	106.5°W	41°N	318°E	60°N	105°W

TABLE 2

Station	Start	Stop	Ionosonde	Staffed by
ADAK	10/45	----	DTM Model 3 AN/CPQ-7 (XE-1) CRPL Model C-3	DTM CRPL Signal Corps
ANCHORAGE	3/49	----	CRPL Model C-2 CRPL Model C-3	CRPL
BAGUIO	3/52	----	CRPL Model C-2	Manila Observatory
BARROW	11/49	----	CRPL Model C-2	CRPL
BATON ROUGE	7/43	9/53	Locally assembled CRPL Model C-3	Dept. of E.E., LSU
BOSTON	3/45	6/51	Locally assembled	Cruft Lab., Harvard
CHRISTMAS ISLAND	12/44	6/46	DTM Model 3 Australian Mark V	DTM
COCOA	1/52	9/52	CRPL Model C-3	U. S. Army Air Force
FAIRBANKS	4/41	----	DTM Automatic CRPL Model C-3	DTM Geophys. Inst. U. A.
GODHAVN	11/51	----	CRPL Model C-3	Danish URSI Commission
GUAM	12/45	4/56	DTM Model 2 CRPL Model C-2	U. S. Navy, Signal Corps CRPL
HUANCAYO	11/37	----	DTM Automatic CRPL Model C-3 CRPL Model C-4	DTM Geophys. Inst. Huancayo

Station	Start	Stop	Ionosonde	Staffed by
MANILA	8/46	5/47	DTM Model 3	CRPL
MAUI	3/44	----	NPL Type 249 DTM Model 3	DTM
			CRPL Model C-2 CRPL Model C-3 CRPL Model C-4	CRPL
FT. MONMOUTH	7/50	----	CRPL Model C-2 CRPL Model C-3 CRPL Model C-4	Signal Corps
NARSARSSUAK	9/50	----	CRPL Model C-3	CRPL Danish URSI Commission
OKINAWA	4/46	----	DTM Model 2 AN/CPQ-7 (XE-1) CRPL Model C-3	Signal Corps
PALMYRA	7/46	11/49	DTM Model 1 Australian Mark V	CRPL
PANAMA	6/51	12/58	CRPL Model C-3	CRPL
PUERTO RICO	4/40	----	Locally assembled	Univ. of Puerto Rico
			CRPL Model C-3	CRPL
REYKJAVIK	2/44	7/45	NPL Type 249	DTM
	1/50	----	CRPL Model C-2	Icelandic Post & Tel.
SAN FRANCISCO	2/42	----	Locally assembled CRPL Model C-3	Radio Prop. Lab. Stanford U

Station	Start	Stop	Ionosonde	Staffed by
ST. JOHNS	5/45	7/54	Model LG17	Radio Phys. Lab. Canada
	1/57	----	CRPL Model C-3	Signal Corps
TALARA	10/54	----	CRPL Model C-3	Geophys. Inst. Huancayo
THULE	2/56	----	CRPL Model C-2	Signal Corps
			CRPL Model C-4	
TRINIDAD	2/44	7/46	NPL Type 249	DTM
			DTM Model 3	CRPL
WASHINGTON	12/29	----	Locally assembled	NBS
			NBS Model A	CRPL
			NBS Model B	
			DTM Automatic	
			CRPL Model C-1	
			CRPL Model C-2	
			CRPL Model C-3	
WHITE SANDS	6/46	----	NBS Model A	U. S. Navy
			CRPL Model C-3	CRPL
				Signal Corps

Prior to January 8, 1954 the U. S. Army Signal Corps operated those stations listed as being sponsored by the Signal Corps. After that date these stations were operated by the U. S. Army Signal Radio Propagation Agency.

Appendix VI. Summary of station information for stations established in 1957 and 1958.

TABLE 1

Station	Geographic Latitude	Geographic Longitude	Geomagnetic Latitude	Geomagnetic Longitude	Approx. Dip Angle	Time Used
BOGOTA	4.5°N	74.2°W	16°N	354°E	32°N	75°W
BYRD	80.0°S	120.0°W	71°S	336°E	75°S	120°W
CAPE CANAVERAL	28.4°N	80.6°W	39°W	348°E	62°N	75°W
CHICLAYO	6.8°S	79.8°W	5°N	349°E	10°N	75°W
CHIMBOTE	9.1°S	78.6°W	2°N	350°E	7°N	75°W
CONCEPCION	36.6°S	73.0°W	25°S	356°E	35°S	75°W
ELLSWORTH	77.7°S	41.1°W	67°S	15°E	70°S	45°W
GRAND BAHAMA IS.	26.7°N	78.4°W	38°N	349°E	60°N	75°W
HAIFA	32.8°N	35.0°E	35°N	275°E	47°N	30°E
ICE ISLAND B (Fletcher's Is.) (as of 1/58)	80.3°N	113.0°W	81°N	240°E	89°N	75°W
LA PAZ	16.5°S	68.1°W	5°S	1°E	5°S	60°W
LITTLE AMERICA	78.3°N	162.5°W	74°S	312°E	81°S	165°W
NATAL	5.4°S	35.1°W	4°N	34°E	2°S	37.5°W (until 3/58) 30°W (after 3/58)
SOUTH POLE (Amundsen Scott)	90.0°S	--	79°S	0°	75°S	GMT
WILKES	66.2°S	110.4°E	78°S	179°E	81°S	105°E

TABLE 2

Station	Start	Stop	Ionosonde	Staffed by
BOGOTA	7/57	----	CRPL Model C-4	Geophys. Inst. Los Andes, Col.
BYRD	7/57	----	CRPL Model C-3	CRPL
CAPE CANAVERAL	3/58	----	CRPL Model C-4	USA Sig. Rad. Prop. Agency
CHICLAYO	7/57	----	CRPL Model C-3	CRPL Geophys. Inst. Huancayo
CHIMBOTE	7/57	----	CRPL Model C-4	CRPL Geophys. Inst. Huancayo
CONCEPCION	8/57	----	CRPL Model C-4	Univ. of Concepcion
ELLSWORTH	7/57	----	CRPL Model C-4	CRPL
GRAND BAHAMA IS.	6/57	----	CRPL Model C-4	USA Sig. Rad. Prop. Agency
HAIFA	----	----	CRPL Model C-2	Israel Inst. of Technology
ICE ISLAND B (Fletcher's Is.)	6/57	12/58	CRPL Model C-2	USA Sig. Rad. Prop. Agency
LA PAZ	10/57	----	CRPL Model C-4	Lab. Cosmic Physics, Chacaltaya
LITTLE AMERICA	7/57	12/58	CRPL Model C-4	CRPL
NATAL	11/57	----	CRPL Model C-4	Brazilian Navy
SOUTH POLE (Amundsen Scott)	6/57	----	CRPL Model C-3	CRPL
WILKES	7/57	----	CRPL Model C-4	CRPL

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Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.


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