IONOSPHERIC OBSERVER'S INSTRUCTION MANUAL

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DEFENCE RESEARCH TELECOMMUNICATIONS ESTABLISHMENT
RADIO PHYSICS LABORATORY

DEFENCE RESEARCH BOARD
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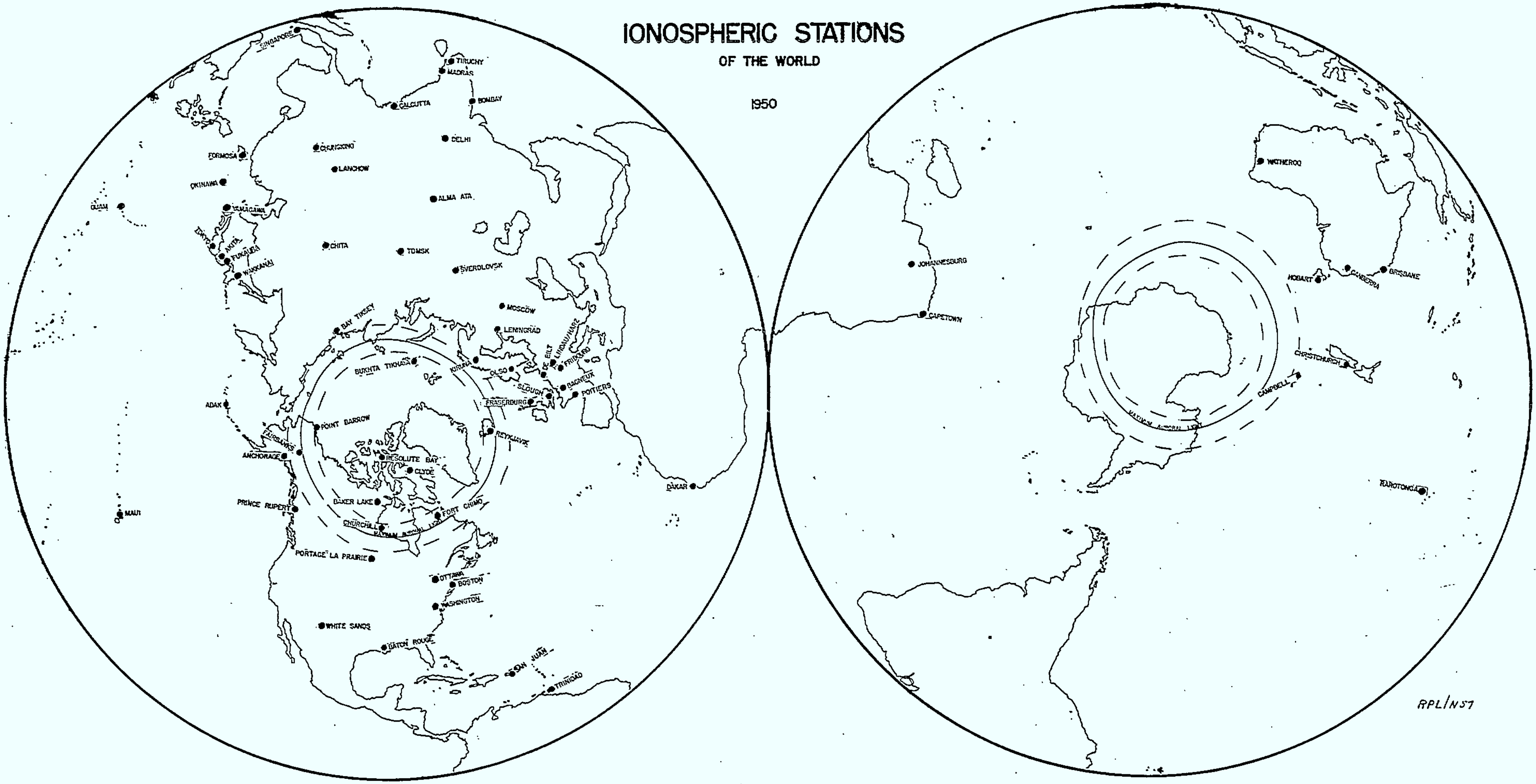
IONOSPHERIC OBSERVER'S HANDBOOK

IONOSPHERIC STATIONS
OF THE WORLD
1950



IONOSPHERIC OBSERVERS

INSTRUCTION MANUAL

SECTION 1

INTRODUCTION

A knowledge of the prevailing characteristics of the ionosphere is of considerable importance to all services using radio as a means of long distance communication. Since the characteristics of the ionosphere are by no means constant, regular radio measurements are made for the prediction of the characteristics and for purposes of study.

In order to obtain the basic information on the refracting regions of the ionosphere, measuring stations are being operated at a number of places throughout the world. The positions of these stations are shown in Figure 1.1. Since the auroral zones are closely related to disturbances in the ionospheric regions their normal position has been indicated on the chart by closed curves.

The data from all the ionosphere stations are collected and analysed at three laboratories:-

1) Central Radio Propagation Laboratory, Washington, D.C.

2) National Physical Laboratory, London, England

3) Ionospheric Prediction Service, Sydney, Australia

Each of these laboratories obtains records from the measuring stations and periodically issues summaries of the data received. In addition, each issues charts which may be used for predicting, in advance, the proper radio communication frequencies.

In this manual an attempt has been made to provide detailed instructions for scaling and tabulating the ionospheric observations made at Canadian stations. It is assumed that the user of this manual has some fundamental knowledge of both the ionosphere and the ionospheric sounding equipment.

Where applicable to the Canadian records, the recommendations adopted at the fifth meeting of the International Radio Consultive Committee (CCIR) Stockholm, 1948, have been followed.

It must be noted that this handbook is designed as an instruction manual. Brief explanations are given throughout the manual but in many cases there has been no attempt to provide complete explanations for the rules and procedures laid down.

SECTION 2

VERTICAL INCIDENCE PULSE MEASUREMENTS

2.1 General

If pulses of radio waves sent vertically upward from a radio transmitter are refracted in the ionosphere they may be received back and detected in a radio receiver a few milliseconds later. Assuming the speed of the radio waves to be constant the effective or 'virtual' height of the refracting region can be determined.

Measurements are made over a range of frequencies from 500 Kc/s to 20 Mc/s. The range of frequencies which normally refract from a region can then be determined.

As the transmission frequency is raised a point is reached where radio waves of higher frequencies do not return from the ionospheric region. This limiting frequency is called the penetration or 'critical' frequency.

Modern multifrequency ionospheric equipment is designed so that a record of virtual height of reflection plotted against frequency of transmission is made photographically on either 16 mm or on 35 mm photographic film. An example is shown in Figure 2.1.

2.2 Virtual Height

If a radio frequency pulse is transmitted vertically into the ionosphere and an echo is received, the height at which refraction has taken place can be calculated, provided that the speed of propagation is known. Vertical incidence equipment is calibrated assuming that the wave travels at the speed of light (300,000 km per second) throughout its whole journey to the refracting region and the return. Actually the radio wave slows down as it passes through the ionized region. For this reason the true height attained is less than the measured height. The difference in the two heights is shown in Figure 2.2. The path of the wave has been drawn obliquely for ease in illustration.

2.3 Critical Frequency

When a radio wave enters an ionized gas it is refracted; the amount of refraction depending upon the frequency of the radio wave and the density of ionization. In an ionospheric region the ionization density increases with height so that a radio wave of a given frequency will penetrate the region to a point where the ionization density is sufficient to cause the wave to be refracted downward.

A definite electron density is required to cause reflection of radio waves of any given frequency; increased densities being required for increased transmitter frequencies.

The maximum ionization density in the region determines the highest frequency of a radio wave that will be refracted downwards by the region. This 'highest frequency' is called the critical frequency since radio waves of higher frequency will penetrate the region and pass beyond. Figure 2.3 illustrates this effect. The path has been drawn obliquely for ease in illustration although the cases referred to are defined in terms of radio waves incident on the region.

A TYPICAL DAYTIME IONOSPHERIC RECORD

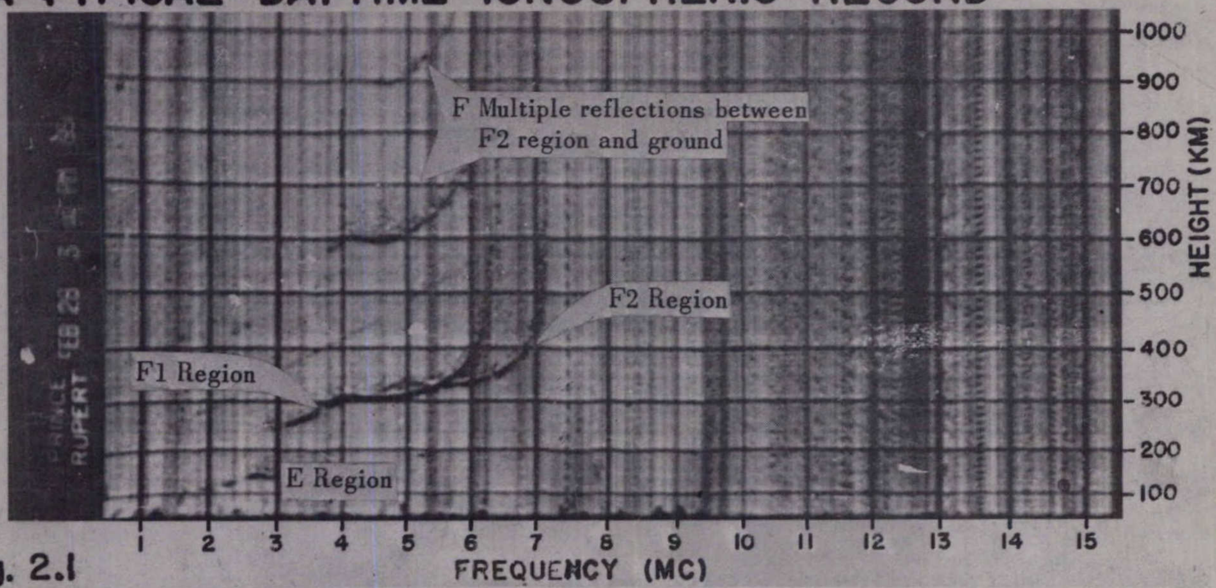


Fig. 2.1

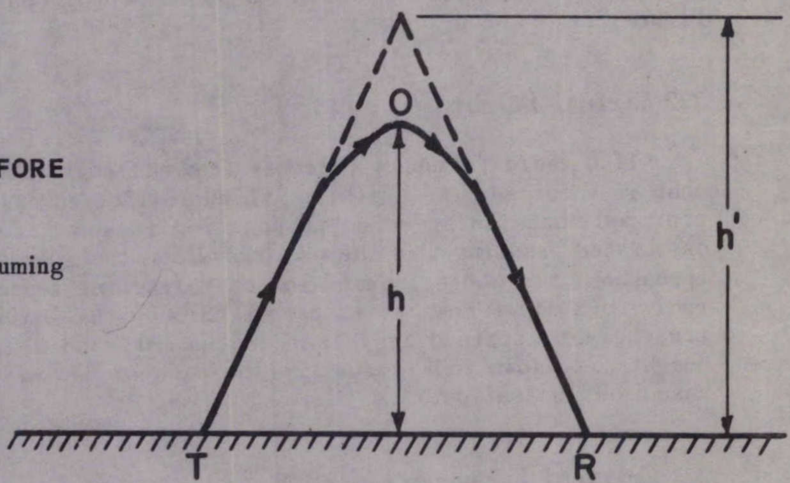


Fig. 2.2

Wave **TOR** is refracted at point **O. THEREFORE** **h** is the true height of reflection

h' is the virtual height measured assuming constant speed

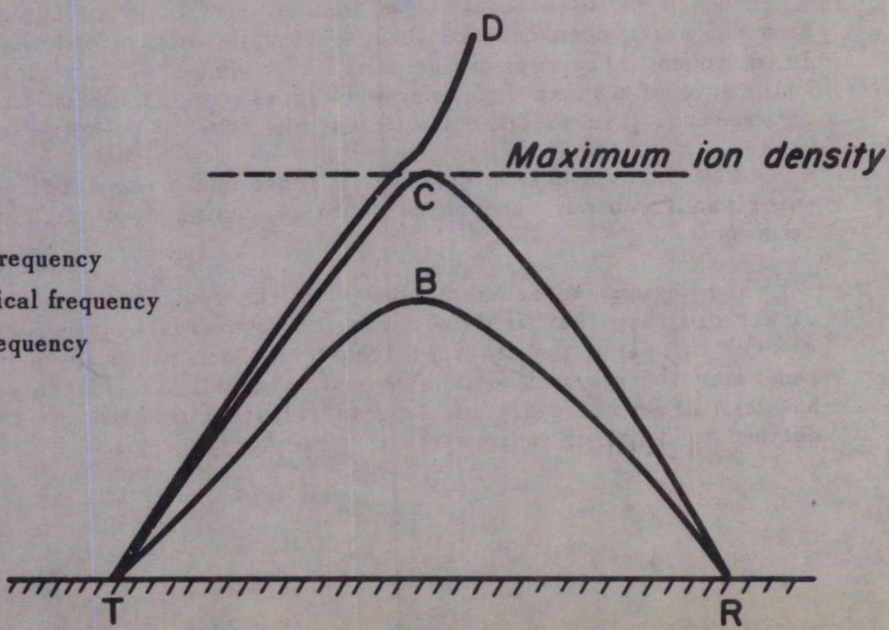


Fig. 2.3

Wave **TBR** is wave below critical frequency

Wave **TCR** is wave just below critical frequency

Wave **TD** is wave above critical frequency

2.4 Ionospheric Regions

A number of typical ionospheric records are reproduced throughout this manual and indicate the existence of regular ionized regions in the ionosphere. In this section each of the regions will be briefly discussed.

2.4.1 E Region -- 90 km to 140 km

This region is responsible for refraction at vertical incidence of radio waves of frequencies between approximately 1 Mc/s and 3 Mc/s.

The normal E region ionization is formed by ultra-violet radiation from the sun and the ionization density depends upon the elevation of the sun above the horizon. Accordingly the ionization density of this region, is greater in summer than in winter, rises to a maximum at local noon, and decreases with the decreasing solar elevation during the afternoon. In polar regions, however, several types of intense sporadic ionization occur in the E region during the dark hours and cannot, therefore, be directly due to ultra-violet radiation. A further discussion of these latter phenomena is included in section 4.

2.4.2. Fl Region - 180 km to 250 km

This region has similar characteristics to those of the E region but has greater ionization densities. This region refracts vertically incident radio waves of frequencies up to about 5 Mc/s in Canada. In the winter, however, the layer height is very close to that of the F2 region and it is not visible for the greater part of the day.

2.4.3 F2 Region - 250 to 400 km in summer day, 180 km to 400 km at night and 150 km to 300 km during winter months.

The diurnal and seasonal variations of the F2 region indicate that the solar ultra-violet light provides a considerable contribution to the ionization in this region. Sufficient irregularities exist to show that other causes of ionization exist in addition.

Maximum ionization is reached in mid-afternoon in the summer and about one hour after noon in the winter. The greatest ionization occurs in the winter rather than in the summer in contrast to the case of the E and Fl regions.

As with the other regions, the ionization density decreases after sunset due to recombination processes in the ionized region, but an appreciable amount of ionization is maintained in the F2 region throughout the night. Further discussion of the peculiarities of this region are included in Section 4.

2.4.4 D Region - 70 km to 90 km

This region does not normally support refraction of radio waves within the limits of our measuring equipment. Echoes are recorded occasionally and the observer should be aware of their existence.

The region is more important on frequencies above 1 Mc/s due to its absorbing effect upon waves of these frequencies passing through it. As in the case of E and Fl region the Solar ultra-violet light is responsible for its existence during the day. The greatest absorbing effects taking place near noon and in the summer.

2.5 Double Refraction in the Ionosphere

A radio wave passing through the ionized regions of the ionosphere is usually double refracted due to the effect of the earth's magnetic field. The resultant frequency vs. height sweep of the ionospheric echoes is a double trace (see Figure 2.1.). One trace, that due to the 'ordinary' wave, is not affected by the changes in the earth's magnetic field. The other trace, that due to the 'extra-ordinary' wave, is similar to the 'ordinary' trace in shape but displaced to higher frequencies by an amount depending upon the intensity of the earth's magnetic field at the level of the ionized region. Further discussion of this effect is given in section 4.7.

2.6 Vertical Incidence Observations

2.6.1. Automatic Equipment

Canadian Ionospheric stations are equipped with an automatic ionospheric equipment either Canadian type LG17 or American C.R.P.L. type C2. The frequency limits of the LG17 are .6 Mc/s to 20 Mc/s, of the C2 1.0 Mc/s to 25 Mc/s.

In addition to the automatic equipment each station has a standby manual ionospheric equipment covering approximately the range 1.7 Mc/s to 16 Mc/s.

The equipment at the stations is as follows:

Baker Lake	C2	and	manual	equipment
Churchill	LG17	"	"	"
Fort Chimo	C2	"	"	"
Ottawa	C2	"	"	"
Prince Rupert	LG17	and	manual	equipment
Resolute Bay	C2	"	"	"
St Johns	LG17	"	"	"
The Pas	manual			
Winnipeg	LG17	"	"	"

2.6.2. Control Settings for Automatic Equipment

The following are the normal settings for the controls of the C2 and LG17 automatic equipment. It may be necessary to vary these at some stations depending upon local conditions.

TYPE C2 EQUIPMENT

RECEIVER	SETTINGS
RF Gain control*	about ¼ to ½ turn from zero gain
Auto-Man. switch	Man.
Time constant	short

* The gain setting is important and should be adjusted to produce the maximum amount of information at all times.

MASTER CLOCK

Mains switch..on

Clutch switch..off

VARIABLE FREQUENCY OSCILLATOR

Frequency Sweep Time......................................15 seconds

35 MM CAMERA

Gear setting...15 seconds

MONITOR OSCILLOSCOPE

Selector switch...sweep

RECORDING OSCILLOSCOPE

Record...35 mm.

PULSE GENERATOR

Height range...1000 km.

Pulse Zero adjustment....................Adjust so that ground-pulse blanks out first height marker.

Height marker...100 km.

Pulse length.......................................50 microseconds

Pulse rate.............................About 60 cycles per second

CONTROL PANEL

Interval-selector switch................................15 minutes

Auto-Man switch..Auto

Continuous sweep switch..off

TYPE LG 17 EQUIPMENT

RECEIVER

RF Gain control........................about ¾ turn from zero gain (adjusted for best picture).

MASTER CLOCK

Charging rate..............................High with resistor shorted (unless operated from battery supply).

VARIABLE FREQUENCY OSCILLATOR

Frequency sweep time......................................16 seconds

35 MM CAMERA

Flexible drive-shaft connected

Gear setting...No. 2

R.H. OSCILLISCOPE

35-16 mm switch..16 mm.

L.H. OSCILLISCOPE

35-16 mm switch..35 mm.

PULSE GENERATOR

Height range switch..1200 km.

Height marker switch...100 km.

Pulse length switch..50 microseconds

Pulse rate switch..60 cycles per Sec.

CONTROL

Interval-selector switch...15 minutes

2.6.3. Routine Observations

At stations having automatic equipment, 35 mm photographic records are made every 15 minutes but only the records on each hour are scaled. Records are made on the manual equipment once each shift (three a day) and each hour when the automatic equipment shows no echoes.

At stations having manual equipment only, and at other stations, when the automatic equipment is inoperative, sweeps are made once each hour.

2.6.4. 16 mm Records

The automatic equipments are capable of making records on 16 mm film. When records are made at short intervals and then run through on a standard motion picture projector, the changes of the ionosphere are speeded up and can be studied very conveniently.

16 mm records at 15 second intervals are made at stations having automatic equipment on the first and third Wednesday of each month starting at 0001 GMT and running for 24 hours.

When taking continuous 16 mm sweeps the height and frequency markers should be eliminated except for a five minute period each hour. Before starting the sweeps short lines ¼ inch long should be marked in ink on the face of the cathode ray tube along the top of the sweep and corresponding to the frequency markers.

2.6.5. Manual Vertical Incidence Equipment

The manual vertical incidence equipment must be tuned by hand through the available range. At each frequency the transmitter is tuned to the receiver and the virtual heights of all echoes seen are plotted directly on semi-logarithmic graph paper.

Figure 2.6.5. (a) represents the sweep line on the cathode ray tube. The position of the blank spot is controlled by a dial which is calibrated in equivalent height of reflection.

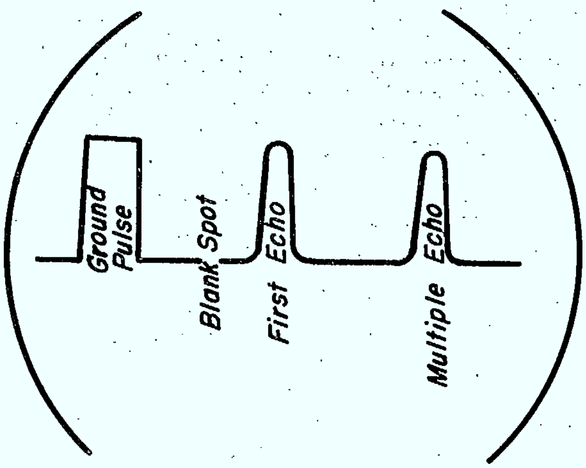


Fig. 2·6·5(a)

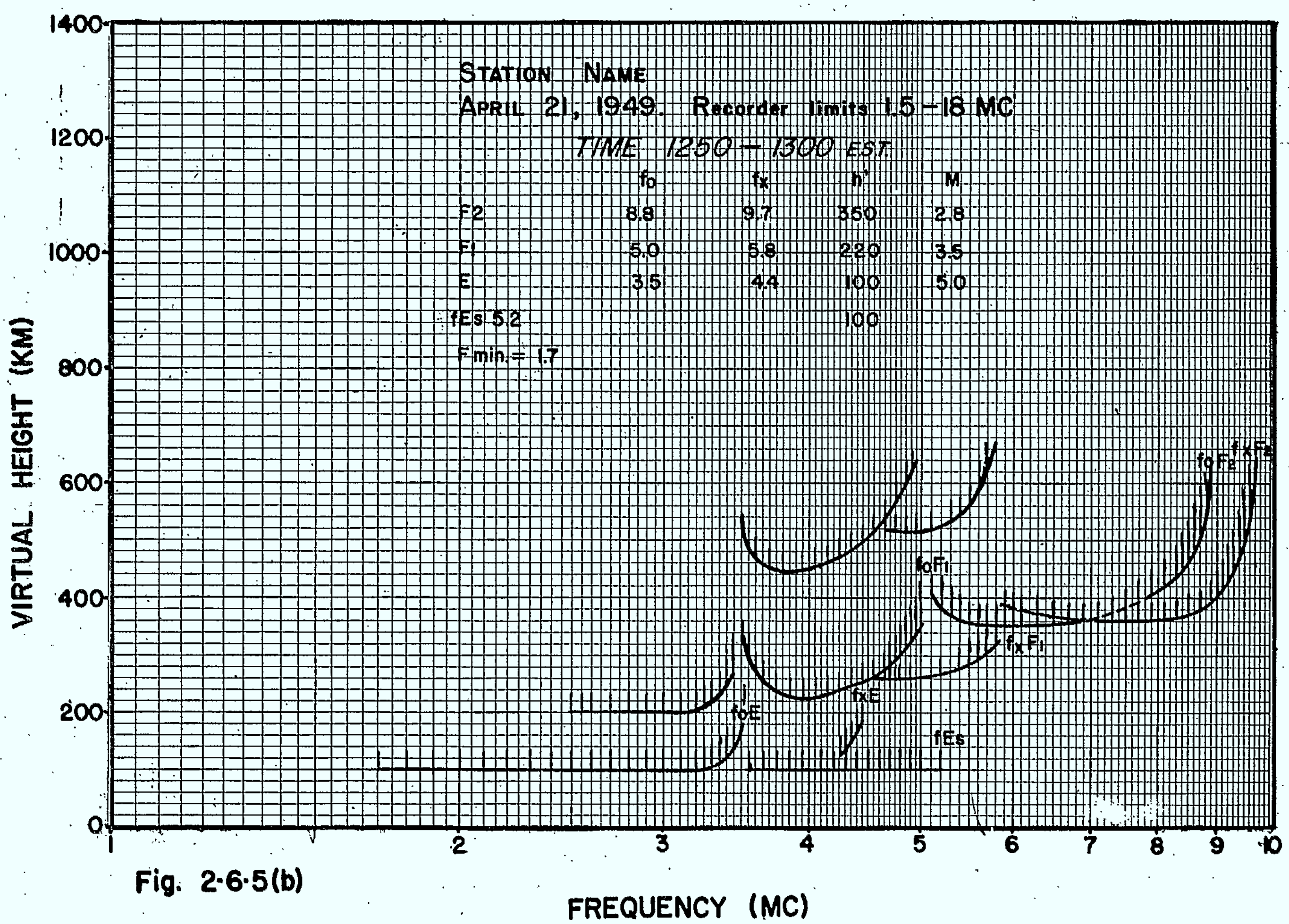


Fig. 2·6·5(b)

To measure the virtual height of an echo the blank spot is moved halfway up the left hand side of the echo pulse and the height dial is read. A similar reading is made on the right hand side of the echo. A line is plotted on the graph paper representing this range of heights.

On occasions the echo is very variable and may extend over some hundreds of km. Such an echo should be plotted as a wavy line.

When an echo shows a definite split with two peaks, a short horizontal line is drawn to show the mutual height of the minimum. When the minimum extends down to the sweep line the two peaks are plotted as separate echoes.

A manual sweep takes 10 to 15 minutes for an experienced operator and in order that the tabulated values may be comparable with those made on the automatic equipment, it should be arranged that the frequencies near the ordinary ray critical of the F2 region are measured as near as possible to the hour.

For a complete sweep, the measurements are made at each 0.1 Mc/s interval starting at the lowest frequency available. At frequencies above 5.0 Mc/s, intervals of 0.2 Mc/s are sufficient, except near critical frequencies. Figure 2.6.5. (b) shows a typical manual sweep.

A single cycle semi-logarithmic paper is normally used to plot sweeps. When echoes are observed above 10.0 Mc/s they should be plotted between 1 Mc/s and 2 Mc/s relabelling this range 10 Mc/s to 20 Mc/s.

SECTION 3

SYMBOLS

3.1. Basic Symbols

The following are basic symbols. Their use in scaling ionospheric records is given more fully in later paragraphs.

In all cases frequency is expressed in Megacycles per second ... Mc/s., heights or distances in Kilometers .... km.

3.1.1.	f	frequency
3.1.2.	fo	critical frequency of the ordinary wave
3.1.3.	fx	critical frequency of the extra-ordinary wave corresponding to the highest frequency branch of a three component h'f curve.
3.1.4.	fz	critical frequency of the longitudinal wave corresponding to the lowest frequency branch of a three component h'f curve.
3.1.5.	h'	virtual height or equivalent height (frequently used to denote minimum virtual height).
3.1.6.	hp	virtual height measured on the ordinary wave branch at a frequency equal to 0.834 times fo.
3.1.7.	MUF	maximum usable frequency
3.1.8.	d-MUF	maximum usable frequency over a given path of some specified or standard length d. e.g. 3000-MUF
3.1.9.	FOT	optimum traffic frequency. This is the recommended traffic frequency over a given path which will be good for communications 90% of the time. This optimum frequency is considered to be 15% below the MUF for the same given path.
3.1.10.	LUF	lowest useful *high frequency* over a given path. This frequency is determined by the amount of attenuation of the radio wave. It is directly dependent upon ionospheric absorption, power output of the transmitter, characteristics of antenna, receiver sensitivity and characteristics of receiver location such as local interference, and thunderstorm areas.
3.1.11.	Md	maximum usable frequency *factor* over a given path of some specified length d., via some particular layer or region e.g. (M3000) F2.
3.1.12.	h'f	a multifrequency observation of ionospheric echoes displaying the virtual height h' as a function of frequency f.
3.1.13.	h't	a fixed frequency observation of ionospheric echoes, displaying the virtual height h' as a function of time t.

3.1.14. F2 — The F2 region. This is the uppermost refracting region of the ionosphere which is regularly observed. It exists between 150 km and 450 km above the surface of the earth. Its height and thickness are variable and depend upon the time of day and season of the year.

3.1.15. F1 — The F1 region is visible as a lower stratification of the F region. It is visible during daylight hours and is most clearly defined during the summer months.

3.1.16. E — The E region. This is the refracting region observed during the daylight hours between 90 km and 150 km above the surface of the earth. Its vertical thickness is small compared to the F region and it may justifiably be called a 'layer'. This region was formerly referred to as the Kennelly-Heaviside layer.

3.1.17. E2 — The E2 region is an upper stratification of the E region. It is most often seen during the hours near sunrise. It is not observed regularly at all ionospheric stations.

3.1.18. Es — All echoes from the E region which are not attributed to the regular effect of solar ultra-violet radiation are called E-sporadic (Es). At stations in the auroral zone (Churchill and Fort Chimo) Es occurs regularly during the night hours.

3.1.19. D — The D region exists between 70 and 80 km above the earth's surface. It is responsible for absorption of medium and high frequencies but acts as a reflecting or refracting region at low frequencies.

3.2 Combinations of Symbols Representing Ionospheric Characteristics

The *correct* terminology for ionospheric characteristics is given below. On monthly report sheets this nomenclature should be entered under 'VALUES OF'.

3.2.1. foE — critical frequency for E layer, ordinary wave (o) branch

3.2.2. foF1 — critical frequency for F1 region, ordinary wave (o) branch

3.2.3. foF2 — critical frequency for F2 region, ordinary wave (o) branch

3.2.4. fxE — critical frequency for the E layer, extra-ordinary wave (x) branch, corresponding to the highest frequency branch of a three component h'f curve.

3.2.5. fxF1 — critical frequency for F1 region, extra-ordinary wave (x) branch

3.2.6. fxF2 — critical frequency for F2 region, extra-ordinary wave (x) branch

3.2.7. fzE — critical frequency for E layer, longitudinal wave (z) branch

3.2.8. fzF1 — critical frequency for F1 region, longitudinal wave (z) branch

3.2.9. fzF2 — critical frequency for F2 region, longitudinal wave (z) branch

3.2.10 fEs — highest frequency on which a continuous sporadic E trace is observed (see note 1. at the end of this subsection).

3.2.11.	fbEs	the lowest frequency at which F region echoes are observed through intense or blanketing type sporadic E.
3.2.12.	fmEs	the highest frequency of the first multiple reflection of E-sporadic.
3.2.13.	f-min	minimum frequency of echoes seen from any region.
3.2.14.	h'E	minimum virtual height or apparent height of E layer measured on the ordinary wave branch
3.2.15.	h'F1	minimum virtual height in the F1 region, corresponding to the lowest apparent height measured on the ordinary wave branch
3.2.16.	h'F2	minimum virtual height in the F2 region, corresponding to the lowest apparent height measured on the ordinary wave branch
3.2.17.	h'Es	minimum virtual height, corresponding to the lowest apparent height of sporadic echoes from E layer heights.
3.2.18.	hpF1	a virtual height in the F1 region measured on the ordinary-wave branch at a frequency equal to 0.834 times the foF1. This the true height of maximum ion density in the region assuming that the ionization of the region varies with height parabolically.
3.2.19.	hpF2	a virtual height in the F2 region measured on the ordinary wave branch at a frequency equal to 0.834 times the foF2.
3.2.20.	E-d-MUF	maximum usable frequency for transmission via E layer over a given oblique path of some specified or standard distance d. e.g. E-1500-MUF is the highest frequency which can be transmitted over 1500 km distance via the E layer.
3.2.21.	F1-d-MUF F2-d-MUF	maximum usable frequencies for transmission via their respective regions over a given oblique path of some specified or standard distance for d.
3.2.22.	(M1500)E	maximum usable frequency *factor* for E layer transmission over a given oblique path of 1500 km. This is the ratio of MUF to the critical frequency. i.e. MUF divided by fo.
3.2.23.	(M3000)F1	maximum usable frequency *factor* for F1 region transmission over a given oblique path of 3000 km.
3.2.24.	(M3000)F2	maximum usable frequency *factor* for F2 region transmission over a given oblique path of 3000 km.
	NOTE 1.	At the present time the mechanisms which produce E sporadic are not very well known. Analysis shows the existence of several types, one of which has retardation present near its top reflection frequency. For uniformity in measurement the top frequency which gives a continuous solid trace from either the lower frequency limit of the recorder or from the minimum frequency of reflections scaled, even though it may be the extra-ordinary wave, should be recorded.

NOTE 2. It should be remarked that all symbols in the above list, are to be typewritten on a straight line. No superscripts or subscripts are to be used. It should also be noticed that while layers or regions are written with capital letters (upper-case), characteristics of the region are written as small letters (lower-case).

3.3. Descriptive Symbols

Frequently the measurements of critical frequencies and virtual heights are approximate or doubtful. It is useful to indicate this when such values are entered on tabulation sheets. The following descriptive symbols are designed to describe such situations. Symbols have been provided for nearly every purpose including cases when the records are not measurable. It will be found that more than one symbol may describe a particular observation. When possible only one symbol should be used describing the most significant characteristic.

3.3.1. A — Characteristic not measurable because of blanketing by Es. (it may be logically tabulated on any height or critical frequency sheet, except of course for Es).

This may be used:-

(i) Instead of an observed numerical value.

(ii) As reason for doubtful numerical value when parentheses are used.

(iii) To describe a doubtful numerical value when parentheses are not used.

3.3.2. B — Characteristic not measurable because of partial or complete absorption. (Absorption is generally greatest on the lower frequencies and decreases with increasing frequency. Therefore it affects the high frequency portion of the sweep less than the lower frequencies. Symbol B should not be used for foF2 except in case of total blackout).

Symbol B should be used:-

(i) Instead of an observed numerical value.

(ii) For fEs, use B only in case of total blackout. (When computing f min median, count B as higher than the median).

3.3.3. C — Characteristic not observed because of equipment failure or
Characteristic not observed because of some failure or ommission on the part of the operator or
Loss or destruction of successful observations. (The latter two reasons were previously covered by symbols M and T. This symbol may be used logically on any of the tabulations).

This may be used:-

(i) Instead of an observed numerical value.

(ii) As a condition for which interpolations may be used.

3.3.4. D Characteristic at a frequency higher than the upper frequency limit of the recorder.

This may be used:-

(i) Instead of a numerical value of *critical frequency* and in the median-count as having a higher value than the median.

3.3.5. E Characteristic equal to or less than the lower frequency limit of the recorder.

Symbol E should be used:-

(i) Instead of a numerical value for fo and h'. In computing the median on critical frequency sheets, symbol E is counted as being equal to or less than the median.

(ii) As a qualifying symbol for fEs when Es and E layer is missing except in case of total blackout. Example: E 2.0 Mc/s. In this case, f min is 2.0 Mc/s. Hence fEs in the above example is equal to or less than 2.0 Mc/s.

3.3.6. F Spread echoes present (this may occur in any region including E layer, although it is far more common in the F region. Scaling of spread echoes is further discussed in detail in a later chapter).

This may be used:-

(i) Instead of an observed numerical value.

(ii) To qualify an observed numerical value.

(iii) As a reason for a doubtful numerical value when parentheses are used.

3.3.7. G (a) F2 region critical frequency equal to or less than F1 region critical frequency. This condition occurs when the ion-density of the F2 region falls below the ion-density of the F1 region. Therefore after the critical frequency of the F1 region is reached no echoes are visible from the F2 region. This condition might not be recognized until F2 region begins to reappear at great virtual heights as this phenomenon most often occurs during the first few hours of daylight. It might also be recognized by checking foF2 and foF1 the previous day.

Symbol G should be used:-

(i) Instead of a numerical value for foF2. When computing foF2 median, count G as equal to or less than foF1 for the same hour.

(b) When Es is missing but E layers present, fEs is assumed to be equal to or less than foE.

Symbol G should be used:-

(i) Instead of a numerical value for fEs. When computing fEs median, count G as equal to or less than foE for the same hour.

3.3.8. H Stratification observed within the layer or region. Stratification appears as a leveling off in the trace followed by a rise. In some cases this rise may be enough to appear as another distinct critical frequency within the layer or region. This condition may occur in any region or layer but quite often occurs within the E layer. When this latter condition appears, it is referred to as E2 and tabulated separately.

This may be used:-

(i) To qualify an observed numerical value when parentheses are not used.

(ii) As a reason for doubtful numerical value when parentheses are used.

3.3.9. J Ordinary-wave characteristic determined from measuring extra-ordinary wave characteristic. In some cases, especially in the northern latitude stations, fo may be spread into fx or fz branches, making it impossible to determine the fo. Under some conditions, fo may become absorbed when fx or fz are quite visible or fo may be lost due to equipment trouble. When these or similar conditions occur, it is possible to determine the fo by subtracting a given quantity of frequency from the fx, or adding a given quantity to the fz. These amounts vary depending on the total magnetic force at different stations. These quantities for Canadian stations are tabulated in Section 4.7.

This may be used:-

(i) To qualify an observed numerical value.

3.3.10. L (a) F1 region visible but critical frequency for F1 region omitted because no definite or abrupt change in the slope of the h'f curve is observed either for the first reflection or any of the multiples.

(b) Minimum virtual height for F2 region omitted because the F2 region trace has no point of zero slope and is continuous with F1 region trace.

This may be used:-

(i) Instead of an observed numerical value.

3.3.11. M (This symbol is no longer used. Refer symbol C.)

3.3.12. N Unable to make logical interpretation. (This symbol should be used very cautiously and only when no numerical value or other symbol logically applies).

This may be used:-

(i) Instead of an observed numerical value.

3.3.13. P Trace extrapolated to a critical frequency. This is the case when the upturn or retarded part of the trace becomes absorbed before it reaches vertical. Critical frequency should not be estimated unless the slope of the curve reaches at least 60 degrees to the horizontal in the F2 region.

This may be used:-

(i) To qualify an observed numerical value.

3.3.14. Q F1 region not present (This symbol is to indicate when F1 region is expected to occur as a distinct stratification in the F region but no evidence of it appears. Such situations occur near sunrise and sunset as well as when conditions at Canadian stations are entering or leaving the winter season).

This is used:-

(i) Instead of an observed numerical value.

3.3.15. S Characteristic obscured by external interference. (This symbol is to be used where a virtual height or critical frequency can not be scaled due to obliteration of the trace by strong interfering stations, thunder storms, general noise or other type of interference. This symbol should be used as little as possible).

This may be used:-

(i) Instead of an observed numerical value.

(ii) To qualify an observed numerical value.

(iii) As reason for doubtful numerical value when parentheses are used.

3.3.16. T (This symbol is no longer used. Refer symbol C).

3.3.17. V Trace forked near the critical frequency. (In some instances the F2 region critical frequency splits up into two separate critical frequencies not having the correct separation to be fx or fz. Usually this forking appears in both the ordinary and extra-ordinary traces. In this case the highest fork on the ordinary trace is scaled as fo).

This may be used:-

(i) To qualify an observed numerical value of *critical frequency*.

(ii) As a reason for doubtful numerical value when parentheses are used.

3.3.18. W Characteristic at a virtual height greater than the normal upper height limit of the recorder.

This is used:-

(i) Instead of an observed numerical value.

3.3.19. Y Es trace intermittent in frequency range. (This is to indicate that the sporadic E is broken up into several short traces, all being the same virtual height and the highest frequency of the continuous trace scaled as fEs).

This is to be used:-

(i) To qualify an observed numerical value.

(ii) Instead of an observed numerical value.

3.4. Symbols Qualifying Ionospheric Characteristics

These symbols indicate accuracy of the values tabulated where measurements are doubtful.

3.4.1. ( ) Values enclosed in parentheses indicate the degree of doubtfulness. If a value of frequency can be estimated only within plus or minus 0.5 Mcs., enclose it in parentheses, reason for doubt to be specified by *one* of the appropriate DESCRIPTIVE SYMBOLS entered immediately before the first bracket. If a value of frequency can be estimated within plus or minus 0.2 Mcs. it is tabulated with only *one* of the DESCRIPTIVE SYMBOLS where necessary.

3.4.2. ( ) Values enclosed between oblique-strokes represent interpolated values rather than observed values, that is, the average of the value before and after the one concerned.

In hourly tabulations of ionospheric characteristics a single missing value should be interpolated provided that the value is missing due to non-ionospheric reasons. If two or more consecutive hours of values are missing, interpolation is not performed.

3.4.3. > or D Either symbol when standing before a number means greater than.

< or E Either symbol when standing before a number means less than.

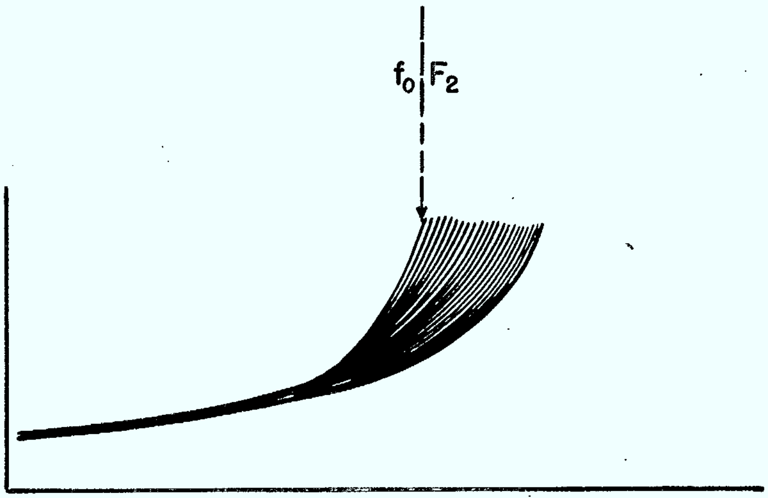


Fig. 4·1·1

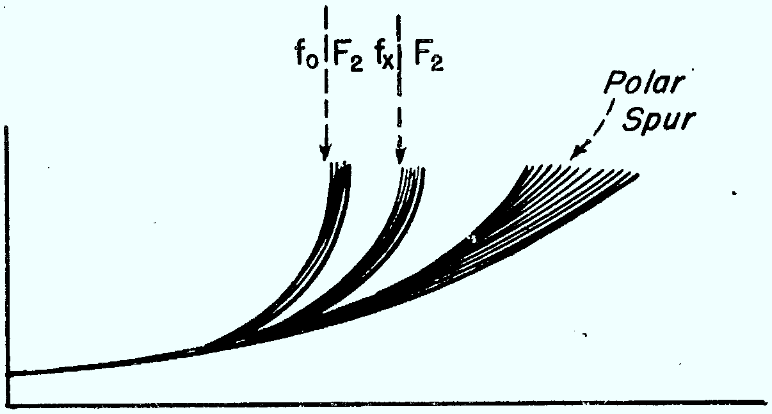


Fig. 4·1·2

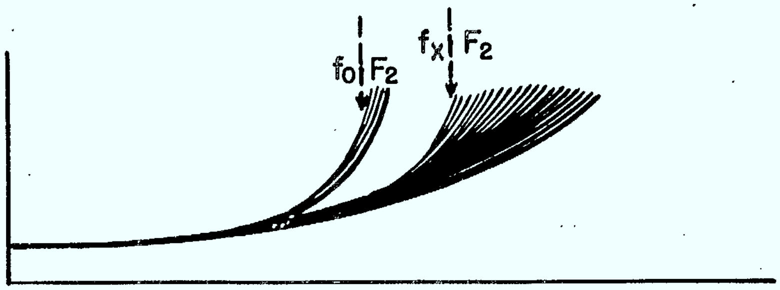


Fig. 4·1·3

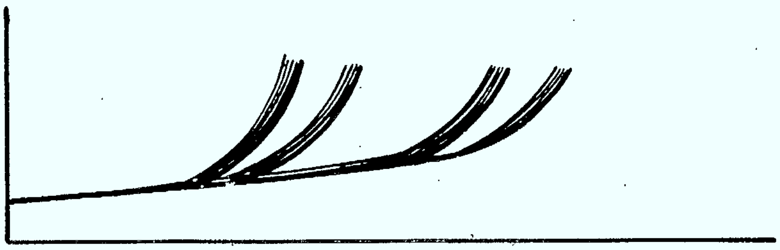


Fig. 4·1·4

SECTION 4

INTERPRETATION AND SCALING OF IONOSPHERIC RECORDS

4.1. Scaling the F2 Critical Frequency

This is the frequency on a vertical-incidence record at the point where the trace in the F2 region turns upwards and becomes almost vertical. The ordinary branch critical frequency (foF2) corresponds to the maximum electron density in the F2 region. The fxF2 and fzF2 depend upon the total force of the earth's magnetic field. At times these components become very complicated, especially at the more northerly stations, making scaling extremely difficult. In the following paragraphs a number of sweeps are described with explanations regarding how each may be produced and the manner in which each should be scaled for tabulations. The illustration numbers are correlated to the corresponding paragraphs.

4.1.1. **Spread Echo** - The fo and fx branches are often indistinguishable from one another. When the inside (lowest frequency) edge is clear it is scaled as the fo branch. Occasionally the spread is extended a megacycle or more. If the inside edge can be scaled within plus or minus 0.2 of a mc it is tabulated with 'Descriptive symbol' F. When it is possible to estimate it only with plus or minus 0.5 of a mc the value is enclosed in parentheses with 'Descriptive symbol' F. If the spread extends to the lower frequency limit of the equipment, no value should be tabulated but 'Descriptive symbols' either E or F are used, depending upon whether the observer believes the critical frequency is definitely below the limit of the equipment or not. In measuring MUF's, M factor etc., allowance should be made for the width of the pulse. In order to do this accurately with the manual equipment, it is necessary to plot the echo lengths carefully.

There are two possible explanations for the existence of spread echoes, either one or both may be correct. When the ionosphere becomes turbulent, the lower edge becomes very irregular. In this case many non-vertical reflections may occur over a considerable area of the ionosphere. On the other hand the ionosphere may be stratified into many thin sections resulting in partial reflections and group-retardation.

4.1.2. **Polar-Spur** - This is most often seen at the more northerly Canadian stations, and is probably a type of oblique reflection, the echoes coming from oblique angles as well as from overhead. As we wish only to measure critical frequencies from directly overhead, the lowest critical frequency should be recorded. These records may or may not be spread. Sometimes the polar-spur is more spread than the 'o' and 'x' traces and at other times it may be difficult to separate the polar-spur from these traces.

4.1.3. Occasionally sweeps are seen where two branches are present which have the usual frequency separation between the lower frequency branch and the inside edge of the upper frequency branch, with the upper branch spread over a megacycle or more. In such case the lower frequency branch is scaled as the foF2, the inside edge of the upper trace as fxF2, the remainder being polar-spur as that described in 2.

4.1.4. This type of sweep is seen quite frequently during the early morning hours before sunrise. There are two complete sets of traces with both ordinary and extraordinary branches with approximately the same minimum virtual height. Successive

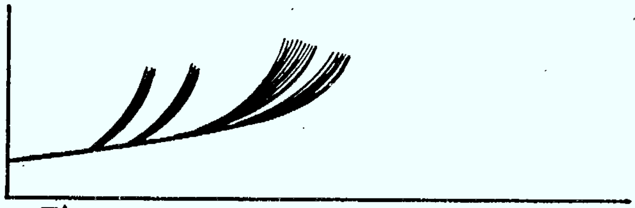


Fig. 4·1·5

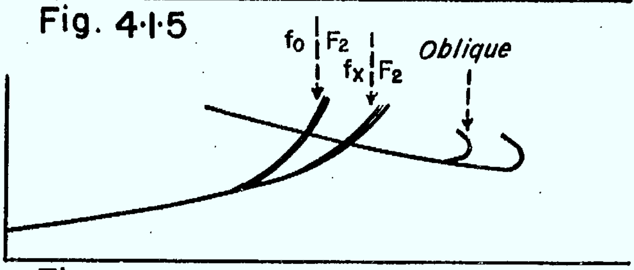


Fig. 4·1·6

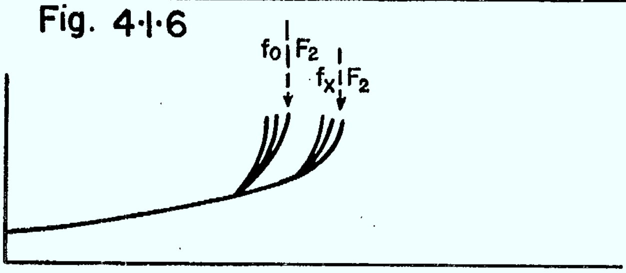


Fig. 4·1·7

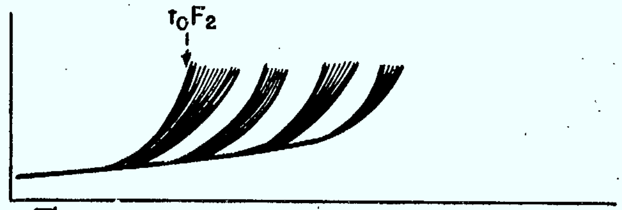


Fig. 4·1·8

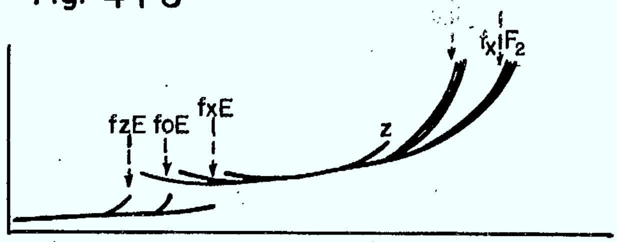


Fig. 4·1·9

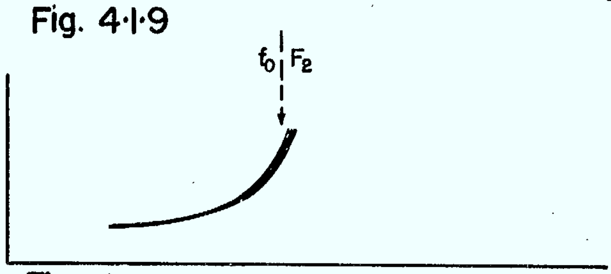


Fig. 4·1·10

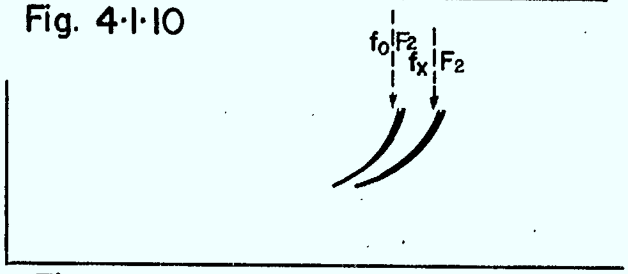


Fig. 4·1·11

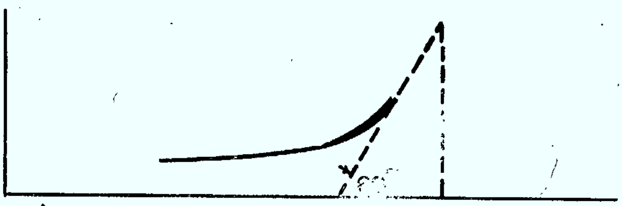


Fig. 4·1·12

observations show that one or other set of traces may disappear as though absorbed, and then reappear. This type of oscillation from one trace to the other may persist irregularly for several hours.

It is very difficult to say which is the correct trace to scale. Check the sweeps before and afterward for continuity and if this is not helpful scale the sweep with the lowest minimum virtual height.

4.1.5. This is a variation of conditions described in either 4.1.2. or 4.1.4. Unless by previous records it is shown not to be a type of polar-spur it should be scaled as a double trace as 4.1.4.

4.1.6. The slanting trace is produced by an oblique reflection. This effect is seen when a portion of the wave returning from the F region has been scattered by a cloud of intense sporadic E, follows a triangular path back to the ionospheric station.

4.1.7. This type of trace is known as a forked record. The ordinary and extra-ordinary traces are both split into two or three separate critical frequencies. In this case the separation between the lowest critical frequency of the ordinary branch and the lowest critical frequency of the extra-ordinary branch must be that normally observed between the o and x branches. Similarly the upper branches must show the usual separation. The highest frequency fork or branch of the ordinary trace is scaled as the foF2. Frequently one or more of the forks may become spread or one of the forks in either branch may not be present. In such cases sweeps before and after should be checked for continuity. When tabulating the highest critical frequency of a forked record, the 'Descriptive symbol' V is inserted as well as the numerical value.

4.1.8. *Brush Trace* - Three or more forks are seen which do not fit into pairs and do not have the proper separation for fz, fo and fx branches. No logical explanation can be given for this special type of splitting. When scaling, the lowest critical frequency is measured as the foF2 and a note made in the remarks column.

4.1.9. Sometimes the F region z trace is visible at frequencies below foE. This may help in differentiating the ordinary from the extraordinary E region trace.

4.1.10. When only one clear trace is present assume it to be the ordinary branch.

4.1.11. If only two traces are visible with a separation just under 1.0 Mc/s with no other indications, assume the lower critical frequency to be foF2 and the higher critical frequency to be fxF2.

4.1.12. The F2 region trace may not be visible near the critical frequency due to deviative absorption. The curve of the trace may be extrapolated to a critical frequency when the slope of the last visible part of the trace is at least 60 degrees to the horizontal. When this is done symbol P is inserted with the numerical value.

4.1.13. The F2 region may become stratified, with sharp increases in electron density appearing at greater heights within the region. When this phenomena exists, more than one critical may appear. When F1 region is present, it may be difficult to determine which critical corresponds to the normal F1 region. The highest critical of the ordinary branch is scaled as the foF2. Records before and after as well as for the same hours of the previous day must be used for determining foF1.

4.1.14. The electron density of the F2 region may decrease below that of the F1 region. This happens most frequently during the early morning sweeps when some disturbance in the F2 region has taken place. Then the F2 region is blanketed by the F1 region, and the wave frequency is increased beyond the F1 critical frequency, no

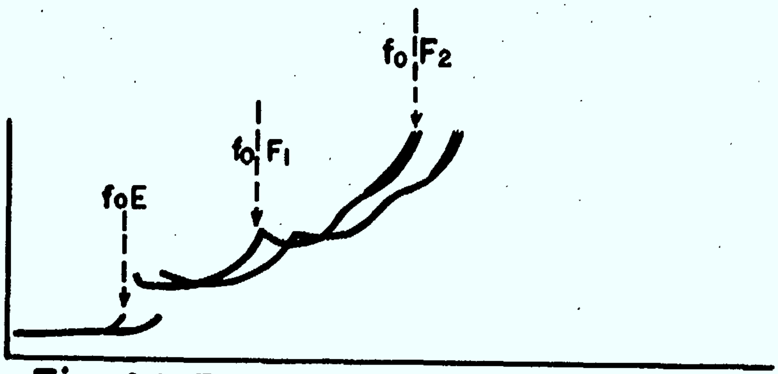


Fig. 4·1·13

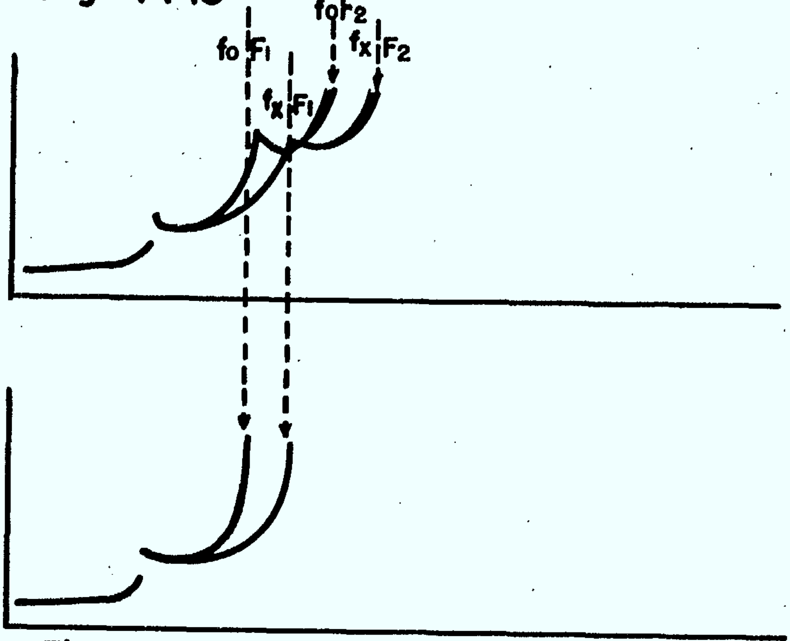


Fig. 4·1·14

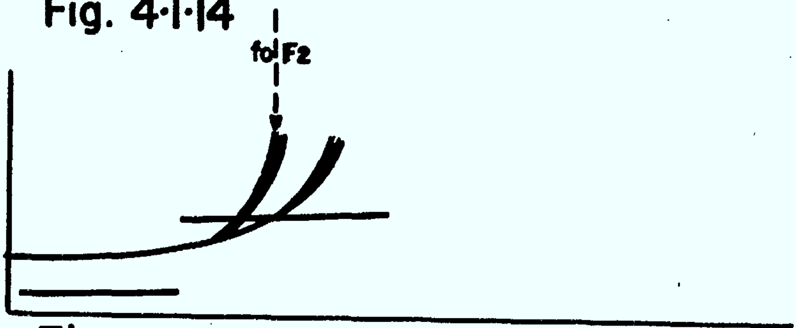


Fig. 4·1·15

reflections are visible from the F2 region. This phenomenon might not be recognized until the F2 region begins to reappear at great virtual heights. It can be recognized by checking the critical frequencies of the F2 and F1 regions for the previous day. Under such conditions the critical frequency of the F2 region is not measurable and 'Descriptive symbol' G is used in the tabulation.

4.1.15. This type of trace is similar to Sporadic E except it is seen up to F region heights. This has been called Sporadic F. Successive sweeps show changes in virtual height from very high in the F region to virtual heights of E layer. Analysis suggest that such traces are caused by oblique reflections from highly ionized sporadic clouds moving horizontally at high velocities. These velocities have been measured at approximately 400 km per hour at 100 km virtual height.

4.2. Evaluation of F2 Spreadiness

The F2 SPREADINESS is a measure of the spread of the F2 region h'f sweep line. The scale is rather arbitrary and is normally to the fo and fx branches. Where fo and fz is seen, spreadiness will be evaluated from these two components. Where all three branches are seen, the spreadiness will be estimated from the fo and fx, fo and fz and the highest figure of the two tabulated. The F1 trace should not be considered in this evaluation.

Number	SCALE OF F2 SPREADINESS
	Description (see corresponding figures).
4.2.1.	No spreadiness, branches clear and thin.
4.2.2.	Slightly spread but branches remaining clear.
4.2.3.	Separate branches very spread but no overlapping.
4.2.4.	Branches very spread and overlapping but critical frequencies of respective branches quite discernable.
4.2.5.	Badly spread with branches not separable leaving a solid trace with well defined edges and not extending over a frequency range of 2 Mc/s.
4.2.6.	Spread same as No. 5 but extending over a frequency range of more than 2 Mc/s.
4.2.7.	Wide spread with traces inseparable and only one edge clear.
4.2.8.	Large mass of spread with no definite form or shape.

The F2 spreadiness figure to be recorded as the hourly value, is the median of four estimated values, i.e. hourly values and the three preceding 15 minute values.

Example:

(a) (i) Values from 0215 hour to 0300 hour are 5,5,5,5,
Hourly value for 0300 hour is 5.

(ii) Values from 0215 hour to 0300 hour are 4,4,6,6,
Hourly value for 0300 hour is 5.

SCALE OF F2 SPREADINESS

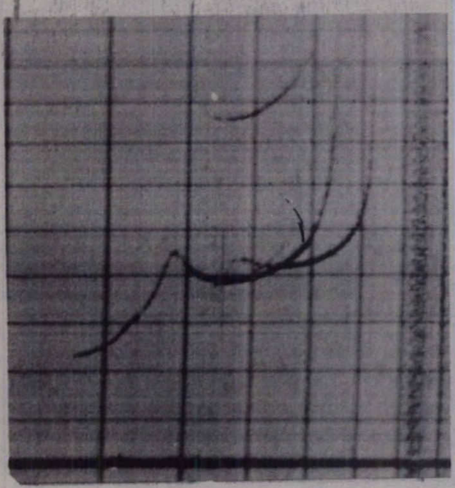


Fig. 4.2.1.

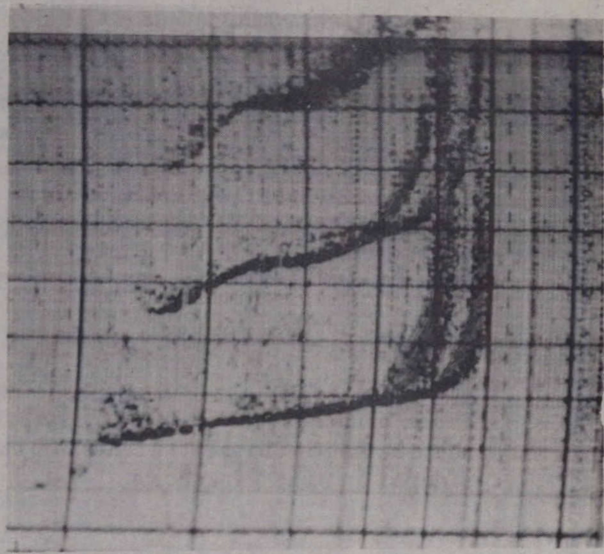


Fig. 4.2.3.

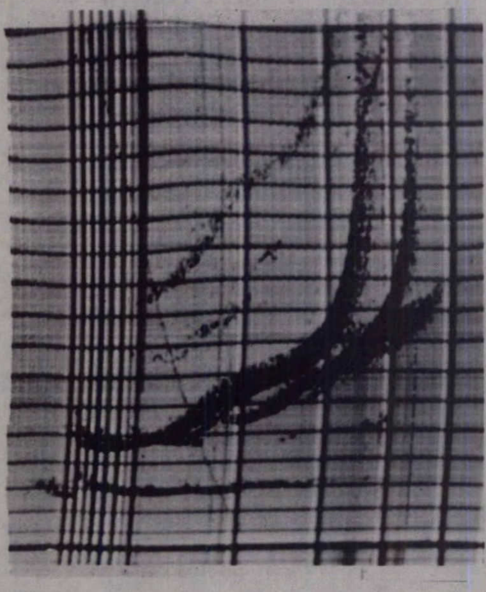


Fig. 4.2.2.

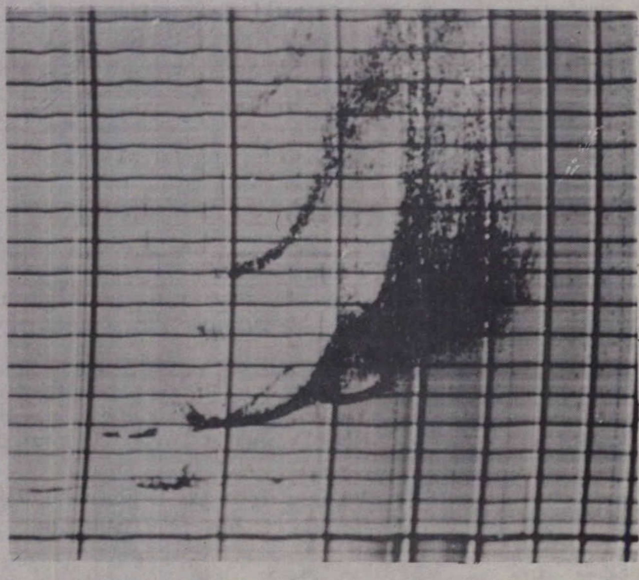


Fig. 4.2.4.

SCALE OF F2 SPREADINESS

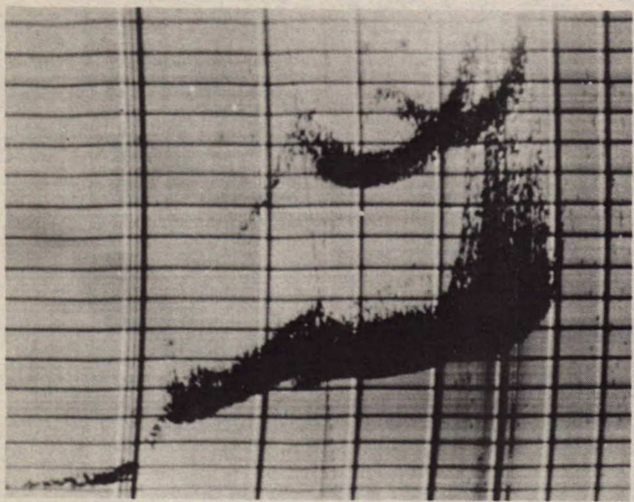


Fig. 4.2.5.

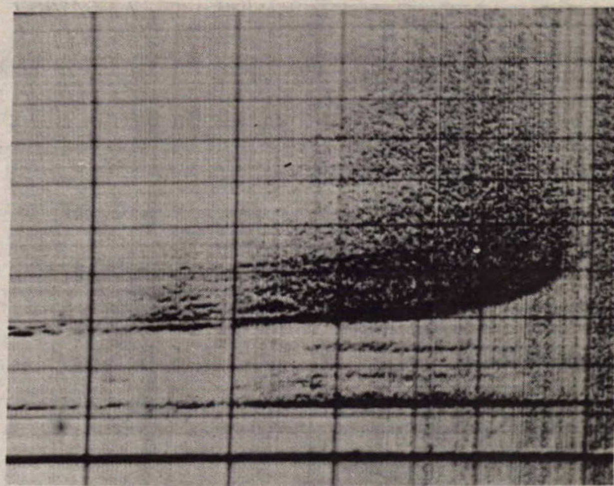


Fig. 4.2.7.

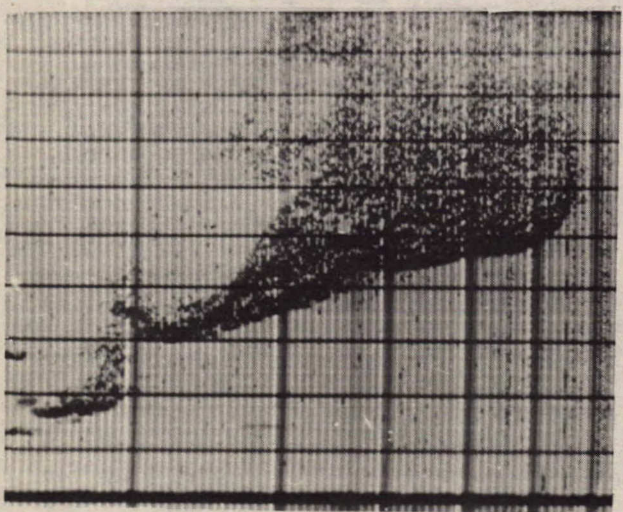


Fig. 4.2.6.

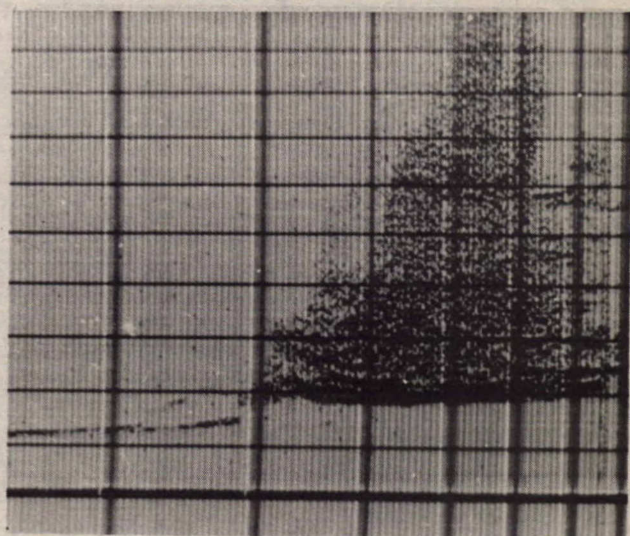


Fig. 4.2.8.

(b) If the median value is a fraction, the *whole number nearest* to the hourly value is taken.

(i) Values from 0215 hour to 0300 hour are 4,5,5,3,
Median of the values is 4½.
Value for the 0300 hour is 3.
Whole number nearest the hourly value is 4.

4.3. Scaling the F1 Critical Frequency and Minimum Virtual Height of F2

The critical frequency of the F1 region trace on a vertical-incidence record is the frequency at which an abrupt change in virtual height takes place on an h′f curve between the critical frequency of E layer and the critical frequency of the F2 region. In the summer this is well defined but in winter many different sweeps are encountered.

4.3.1. This type of trace is seen at all Canadian stations during summer months near local noon. This is the normal type of trace in which no difficulty is experienced in scaling either the F1 critical or minimum virtual height of F2.

4.3.2. The critical frequency of the F1 trace in this example is quite measurable due to its abruptness, but the slope of the F2 trace does not reach zero at any point. In this case the virtual height of F2 is represented by 'Descriptive symbol' L.

4.3.3. The critical frequency of F1 trace in this example is not measurable due to the slow rise in slope but the slope of the F2 trace does become zero. In this case the critical frequency of F1 is represented by 'Descriptive symbol' L and the minimum virtual height of F2 trace measured at its lowest point.

4.3.4. Here the slope of the F1 trace is not great enough for the critical frequency to be scaled and the slope of the F2 trace does not reach zero. Neither the critical frequency of F1 nor the minimum virtual height of the F2 trace can be scaled. Both are represented by 'Descriptive symbol' L.

4.3.5. Sometimes the critical frequency of F1 is not measurable due to the slow rise in the slope. The rise of the multiple echo trace is steeper and when present it may be possible to use it to determine the foF1.

During the hours that F1 trace is not visible when it is normally expected to be present, 'Descriptive symbol' Q should be inserted in the tabulation to indicate its absence. Every hour that F1 trace is visible or expected to be visible is indicated on the tabulation sheets either by a numerical value or a 'Descriptive symbol'.

4.4. Scaling the Normal E Critical Frequency

The normal E critical frequency on a vertical-incidence record is that frequency where retardation (upturn of the trace) show on an h′f curve in the E layer. In some instances at northern Canadian stations, little or no retardation is seen, The following rules are to assist in scaling sweeps such as those illustrated.

4.4.1. This is the ideal type of trace in which retardation (turn up of the trace) is seen both at the E layer critical frequency and the minimum frequency of the F region. The inside edge of the upturn is scaled as the critical frequency of E layer.

4.4.2. In this sweep neither the E layer trace or minimum frequency of the F region trace show any retardation. If the separation in frequency between the end of the E trace and beginning of the F trace is not greater than 0.5 Mc/s., the E trace may be extrapolated to the mid-point of these traces adding 'Descriptive symbol' P to the numerical value scaled.

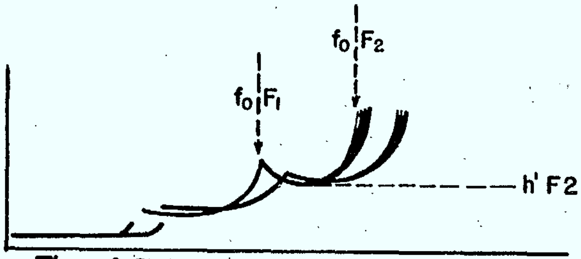


Fig. 4·3·1

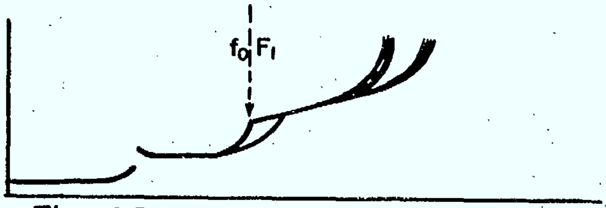


Fig. 4·3·2

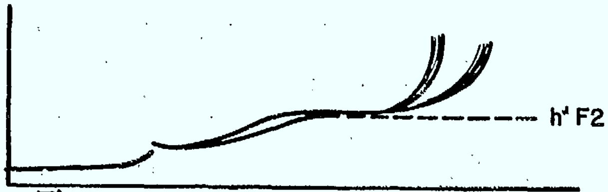


Fig. 4·3·3

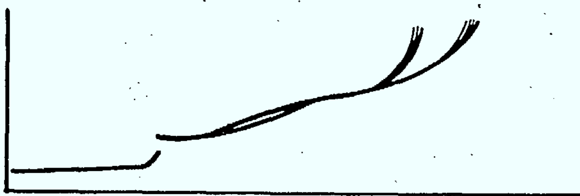


Fig. 4·3·4

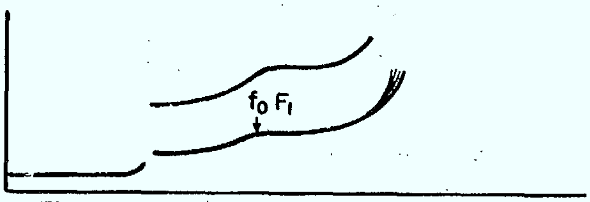


Fig. 4·3·5

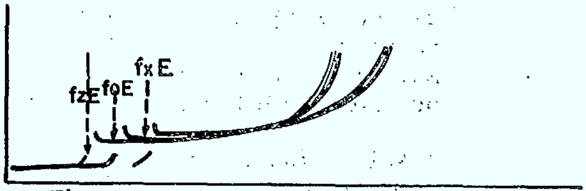


Fig. 4·4·1

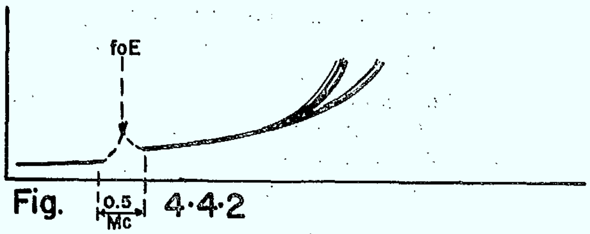


Fig. 4·4·2

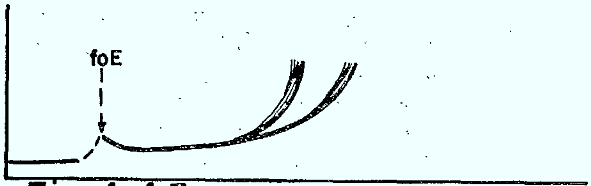


Fig. 4·4·3

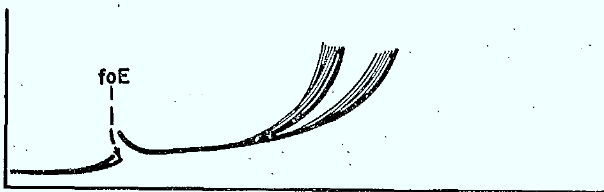


Fig. 4·4·4

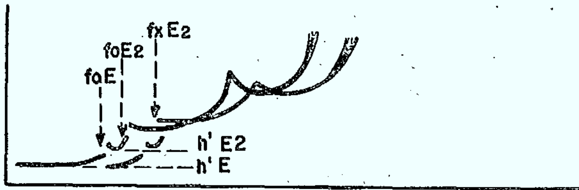


Fig. 4·4·5

4.4.3. In this example the E layer trace shows no retardation. The minimum frequency of the F region trace is considerably retarded. If the separation between these traces is not greater than 0.5 Mc/s. and no Sporadic E is present, the E trace may be drawn to join the end of the F trace, adding 'Descriptive symbol' P to the numerical value scaled.

4.4.4. The E layer critical trace may become spread or forked. Then, the same rules apply as in scaling the foF2. In case of spread, the inside edge of the upturn is scaled and in case of forks, the highest fork is scaled as the critical frequency.

4.4.5. Frequently the E layer becomes stratified, with a sharp increase in electron density appearing at some height within the layer. When this phenomenon exists, a second critical frequency trace is seen on the h'f sweep at a greater virtual height. This second trace is referred to as E2. The E2 stratification may or may not have an extra-ordinary critical frequency showing, depending upon the amount of absorption at the time. Where E2 is seen quite regularly, it is tabulated on a separate sheet. Note that E2 traces are not to be scaled for foE.

4.4.6. All E traces mentioned above in this sub section are the types that normally occur during the daylight hours and are assumed to be formed by ultra-violet light from the sun. At some of the northern Canadian stations, during the dark hours, when normal E traces have decreased below the equipment limit other traces are seen at the same virtual height. These may show considerable retardation in both ordinary and extra-ordinary branches, and must be due to ionization from other causes. These sweeps have been called 'Night E'. Night E appears to be a refracting medium similar to the normal daylight type. Therefore, Night E is tabulated on the normal E tabulation sheets, but only when all of the following conditions are met:-

(a) When definite retardation (upturn at criticals) is present.

(b) When both ordinary and extra-ordinary branches are distinguishable.

(c) When there is some continuity with hours before and after.

4.5. The Critical Frequency of Sporadic E

Sporadic E is thought to be due to reflection or refraction from patches of intense ionization existing at E region heights. The horizontal extent of such patches is not yet known.

At polar ionospheric stations it is mainly a night time phenomenon, but at the southern Canadian stations Es is seen during the day as well.

There is some difficulty in measuring the characteristics of the layers when normal E and Sporadic E echoes are both present.

The following examples illustrate scaling procedure for Es records:

4.5.1. Both normal E layer and Sporadic E are present. It may be impossible to scale the maximum frequency of Sporadic E and the minimum virtual height of normal E layer.

4.5.2. In this case the frequency of Sporadic E is greater than that of normal E layer trace. Frequently there is not sufficient distinct E region trace to measure. Then the 'Descriptive symbol' A is used in tabulation.

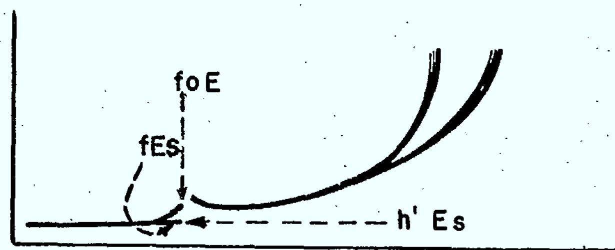


Fig. 4·5·1

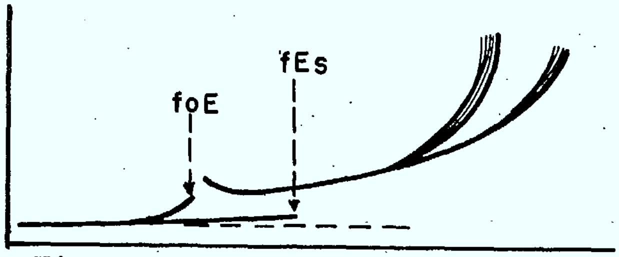


Fig. 4·5·2

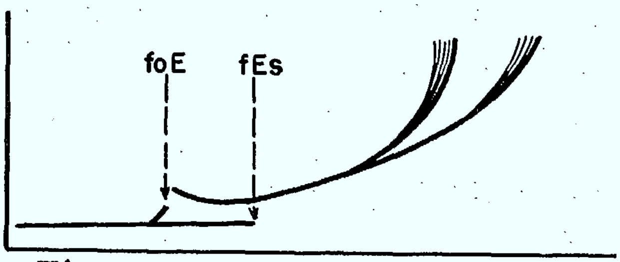


Fig. 4·5·3

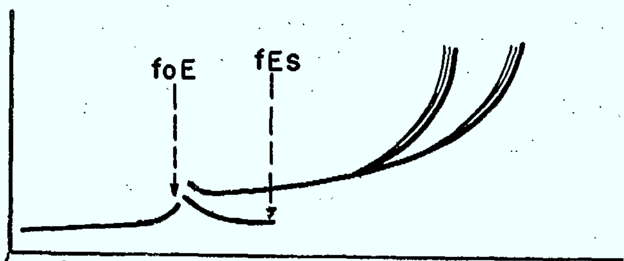


Fig. 4·5·4

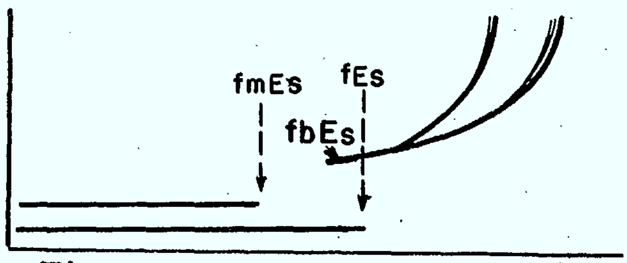


Fig. 4·5·5

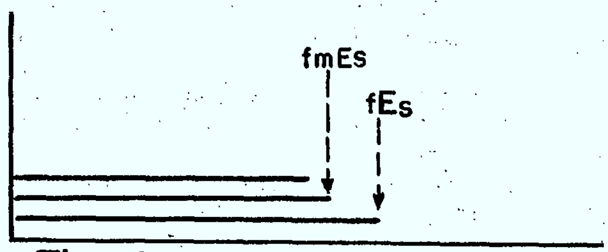


Fig. 4·5·6

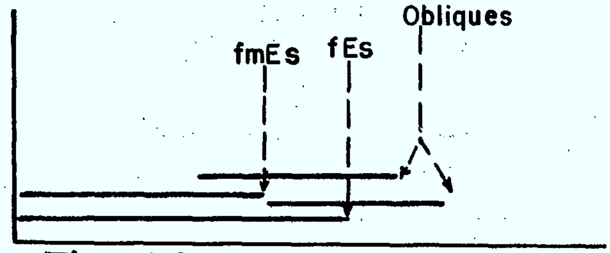


Fig. 4·5·7

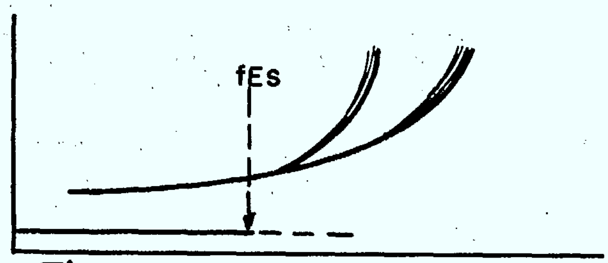


Fig. 4·5·8(a)

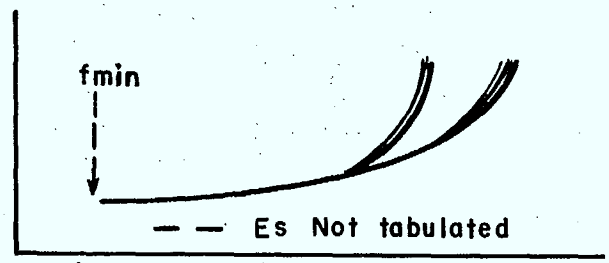


Fig. 4·5·8(b)

4.5.3. This example is one of which normal E layer trace and Sporadic E trace are at the same virtual height. Here h'E is recorded as well as h'Es. As in the previous example it is often difficult to see the retardation effect at the foE.

4.5.4. Sometimes the Sporadic E occurs at a height greater than that of E layer. The E layer in this case is not blanketed, consequently both virtual height and the critical frequency of E layer are measurable. Due to the retardation in the E layer trace near the critical frequency, the Es trace has a downsweep similar to that seen in the F1 trace at the same frequencies.

4.5.5. This is Sporadic E of the blanketing type. Only the higher frequency end of the F trace is visible. The frequency of Sporadic E is recorded as the highest frequency of the first echo. 'Descriptive symbol' A is used on tabulation sheets to describe missing values from higher regions.

fbEs is the lowest frequency at which F region echoes are observed through intense blanketing type Sporadic E.

fmEs is the highest frequency of the first multiple reflection from Sporadic E.

4.5.6. This is an example of multiple Sporadic E. Frequently two or more multiples may be seen to quite high frequencies. The highest frequency of the first echo (fEs) being recorded, and highest frequency of the first multiple of Sporadic E are recorded on separate monthly tabulation sheets as fmEs. It should be noted that obliques from Sporadic E should not be recorded as multiples, that is, reflections which are not twice the virtual height of the first echo. It will be noticed that the frequency of the multiple is somewhat lower than that of the first reflection.

4.5.7. Quite often, traces which are not at multiple heights of the first reflection are seen. In the past these traces have been recorded as Sporadic E2. Under certain conditions, reflections may be at frequencies less than the fEs but more often they are present at higher frequencies. Analysis does not show any preferred virtual height, and traces are considered to be due to oblique reflections. No tabulations of such traces are made at present.

4.5.8. Occasionally Es traces appear to be patchy as shown in this example. The highest frequency of Sporadic E which appears as a continuous solid trace is scaled as the frequency of Sporadic E (fEs), adding 'Descriptive symbol' Y to indicate that patches extend above this frequency. (a) If only a few patches are seen above the minimum frequency of the equipment, the frequency of Sporadic E is not tabulated but replaced with 'Descriptive symbol' Y. (See figure 4.5.8. (b))

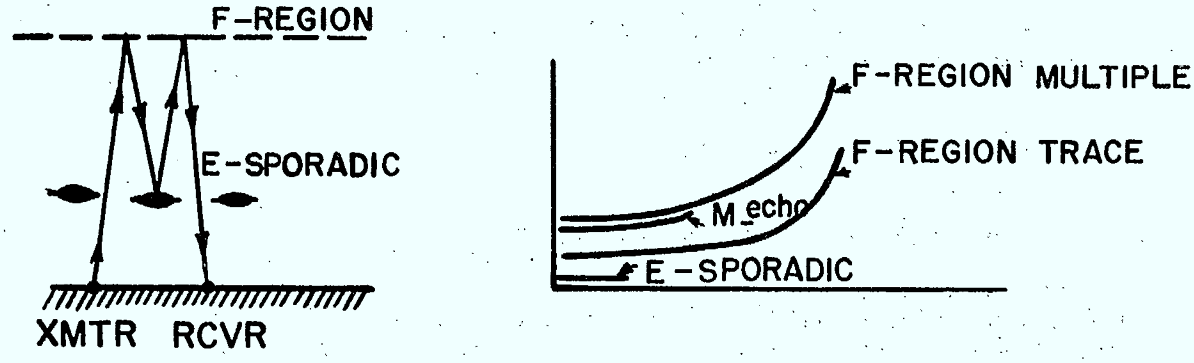
NOTE

> It is important to differentiate between the day-time Sporadic E and the extraordinary trace of the normal E layer. When a trace in the daytime extends past the critical frequency E layer to about 1. Mc it is nearly always the extraordinary branch of the normal E layer trace.

4.6. M and N Type Reflections

Occasionally conditions exist where a radio wave travels up to the F region, down to a Sporadic E cloud, up to the F region and back down to the ground. These are known as 'M' type echoes, on h'f sweeps they appear as traces twice the virtual height of the F region minus the virtual height of Sporadic E.

TYPE M ECHOES



TYPE N ECHOES

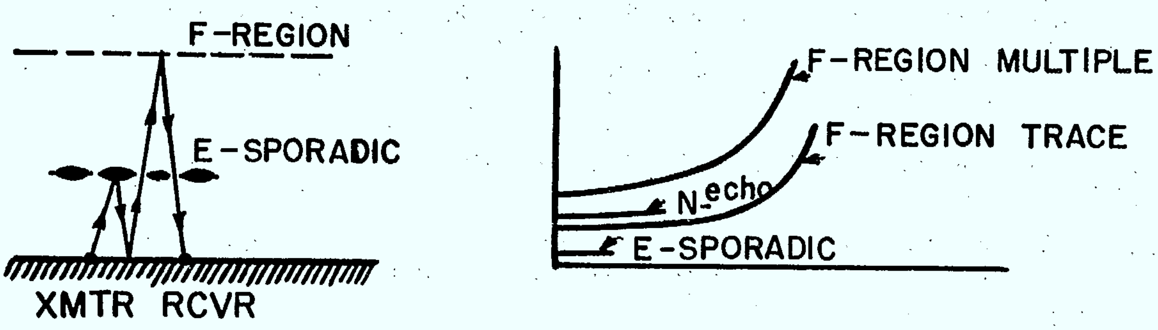


Fig. 4·6

Under certain conditions type 'N' echoes may be seen. Here, the radio wave is refracted from a Sporadic E cloud, reflects at the earth and travels up to the F region and return. This trace appears on the sweep at a virtual height of the F region plus the virtual height of the E layer. Figure 4.6, illustrates both types of reflection.

Occasionally both types 'M' and 'N' reflections appear at the same time. No tabulation is made of these traces.

4.7. The Gyromagnetic Frequency

4.7.1. Effect of the Earth's Magnetic Field

The electrons in the ionosphere are in a state of continuous agitation. Due to the presence of the earth's magnetic field this agitation is not random and electrons tend to revolve about the lines of force of the earth's field. The frequency of revolution of the electrons depends upon the strength of the magnetic field in the ionospheric region. This frequency is called the gyrofrequency and is denoted by f_H.

In the presence of the magnetic field a radio wave entering an ionized region is doubly refracted. The ordinary-wave is not greatly affected by the earth's field. The extra-ordinary-wave of a particular frequency is returned from less ionized levels than the ordinary-wave. Consequently its critical frequency will be greater than that of the ordinary-wave. The difference between the critical frequencies of the two is directly related to the intensity of the earth's field. It can be shown that it is approximately equal to half the value of the gyrofrequency for the ionized region.

Near the earth's geomagnetic axis the lines of force are almost vertical, vertical transmissions from an ionospheric station, then travel along the lines of force and it is found that the ordinary-wave critical frequency, now called the longitudinal wave, is then the amount of the gyrofrequency below the extra-ordinary critical frequency.

In polar regions all three components may be observed at one time. Typical sweeps are illustrated in Figure 4.7.1.

In order to assist in identifying these three component waves a table is drawn up of critical frequency separations to be expected at Canadian Ionospheric stations.

STATION	foE - 3.0 Mc.		foF2 - 3.0 Mc.		foF2 - 10.0 Mc.	
	fx - fo	fo - fz	fx - fo	fo - fz	fx - fo	fo - fz
BAKER LAKE	0.90	0.79	0.83	0.65	0.77	0.72
CHURCHILL	0.93	0.71	0.84	0.66	0.78	0.73
FORT CHIMO	0.88	0.68	0.80	0.63	0.74	0.69
OTTAWA	0.88	0.68	0.81	0.64	0.75	0.70
WINNIPEG	0.93	0.71	0.85	0.66	0.78	0.73
PRINCE RUPERT	0.87	0.67	0.80	0.63	0.74	0.69
RESOLUTE BAY	0.88	0.68	0.81	0.64	0.75	0.70
ST JOHN'S	0.81	0.64	0.74	0.60	0.69	0.65

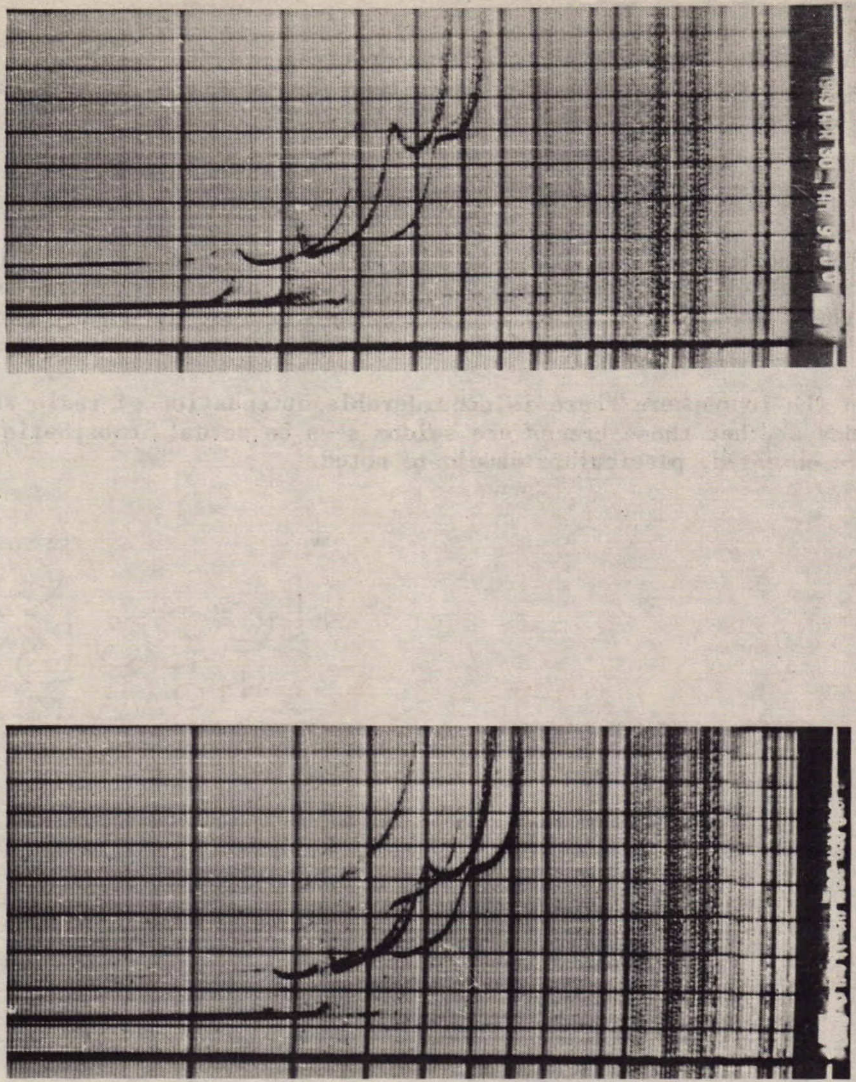


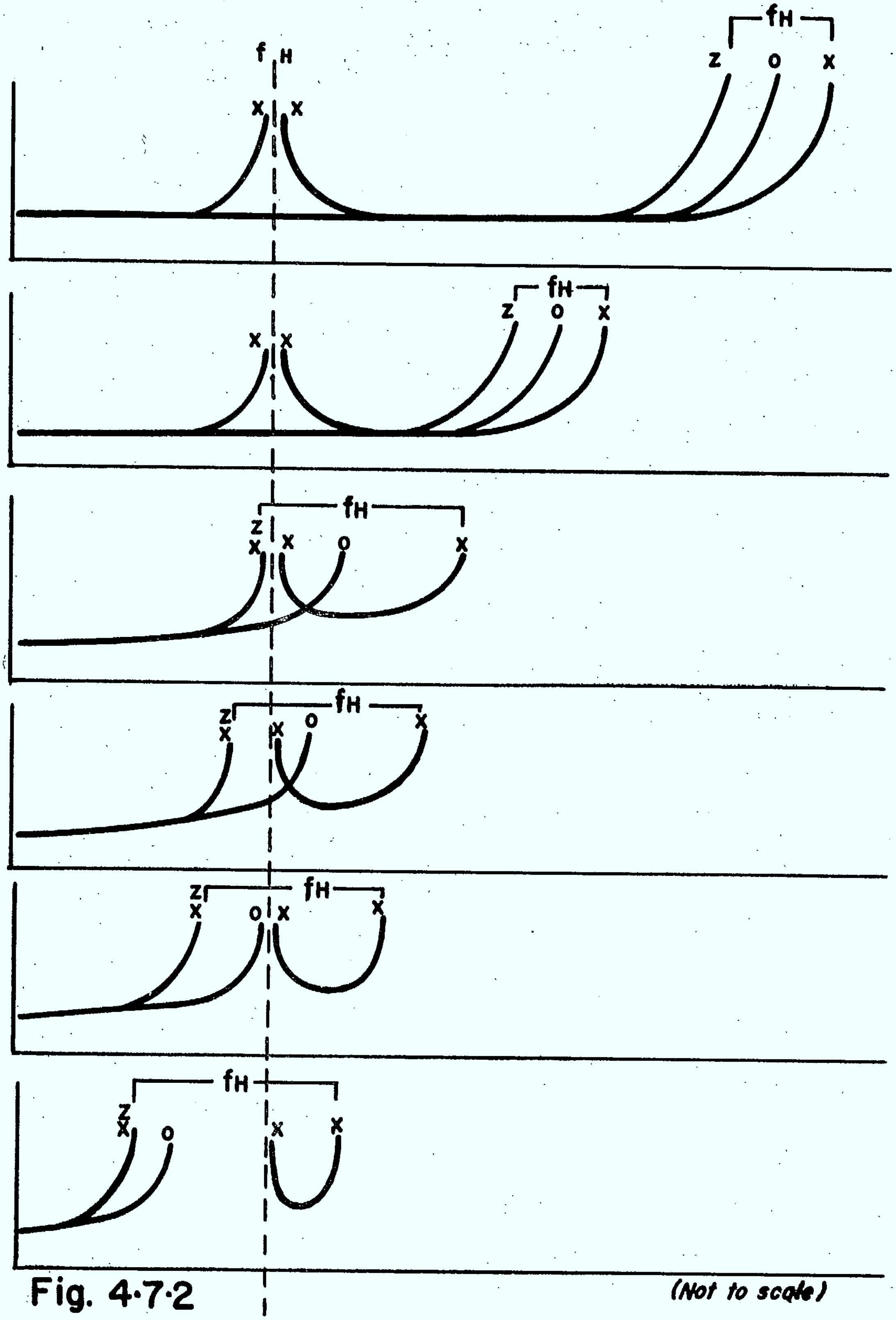
Fig. 4·7·1

These values of separation are theoretical and are only applicable to ionospherically undisturbed days. When using them for estimation of critical frequencies, the sweeps before and afterwards should also be examined and used as a guide.

4.7.2. h'f Records Near the Gyromagnetic Frequency

When the transmission frequency is near the gyrofrequency for an ionized region, resonance effects are present and the ionospheric looks quite different. Fig. 4.7.2. shows the shapes of the sweep traces as the critical frequencies of the ionized region drops to values less than the gyro-frequency.

In the ionosphere there is considerable attenuation of radio waves near this frequency so that those traces are seldom seen on actual ionospheric records. When they are observed, particulars should be noted.



f H
x x
z o x
fH
x x
z o x
fH
z x x o x
fH
z x x o x
fH
z x o x x
fH
z x o x x
fH
(Not to scale)

Fig. 4·7·2

SECTION 5

CONVERSION OF VERTICAL - INCIDENCE MEASUREMENTS TO OBLIQUE - ANGLE TRANSMISSION

5.1. General

The vertical-incidence measurements taken at ionospheric stations throughout the world may be converted into useful information regarding transmissions at oblique angles. In this section will be shown the relations existing between skip distances, maximum usable frequencies (MUF's), virtual heights of the ionospheric layers, and the angles of incidence with the vertical of the transmitted waves.

5.2. Definitions

5.2.1. Critical Frequency - fo

Consider a transmitter radiating in all directions from a fixed point on the ground. For simplicity a single ionized layer is assumed to be present above the transmitter and only the ordinary wave is considered. The layer will have associated with it a critical frequency, fo, which is dependent upon the ionization density of the layer. Frequencies at vertical incidence will penetrate the layer whereas frequencies less than the critical frequency transmitted at vertical incidence will be refracted by the layer.

5.2.2. Critical Angle of Elevation, α

Referring to Figure 5.2.2., consider a transmitter radiating in all directions at a fixed frequency greater than the critical frequency of the ionized layer. The radiation at 90° to the horizontal will thus penetrate the layer but the radiation at small angles from the horizontal may be refracted downwards by the layer. The critical angle of elevation, α, is defined as being the maximum angle of elevation from the horizontal at which transmitted waves are refracted by the layer. Radiation at angles of elevation greater than α penetrate the layer and the radiation at the angle of elevation α and at angles of elevation smaller than α are refracted by the layer.

5.2.3. Skip Distance, d

The radiation from the transmitter at the critical angle of elevation, α, is returned to the ground at a distance, d, from the transmitter. This distance, d, is defined as the skip distance for the fixed frequency considered. Radiation from the transmitter at angles of elevation smaller than α will reach the ground at distances greater than d.

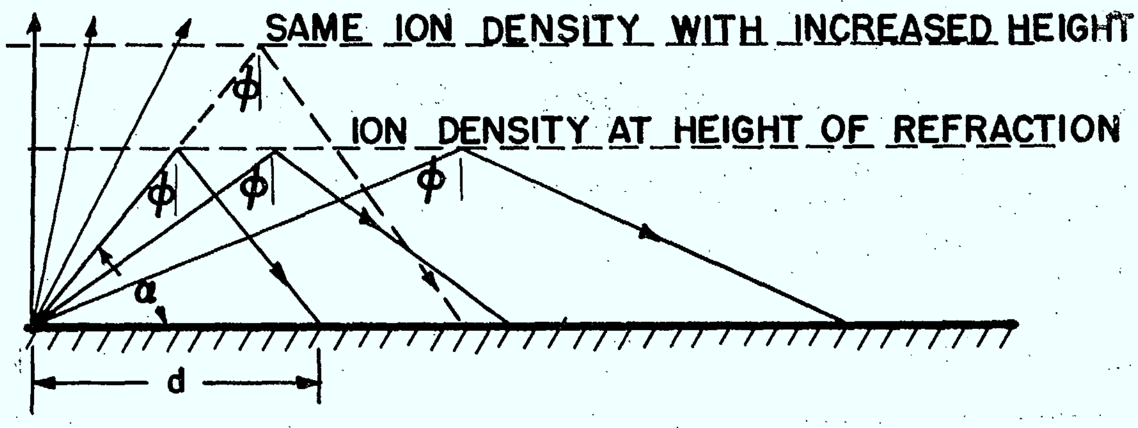


Fig. 5·2·2

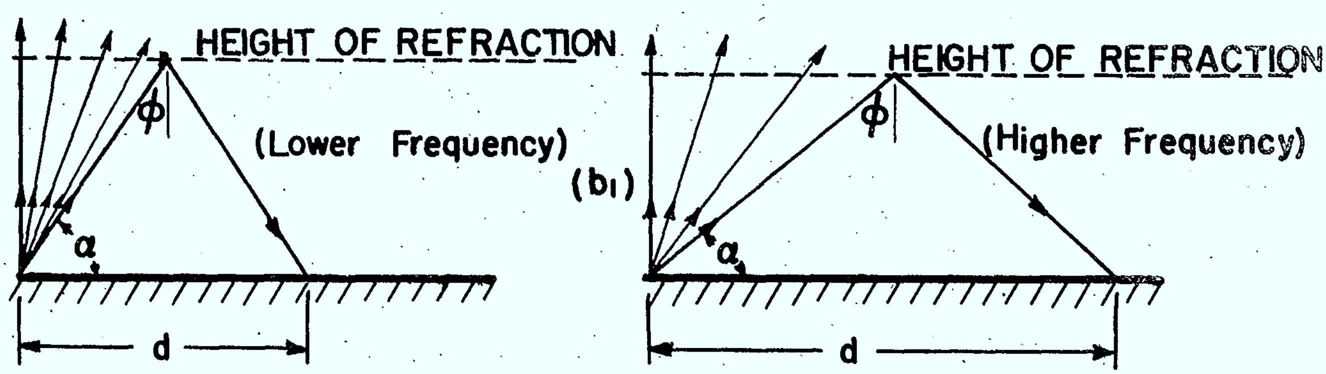


Fig. 5·3

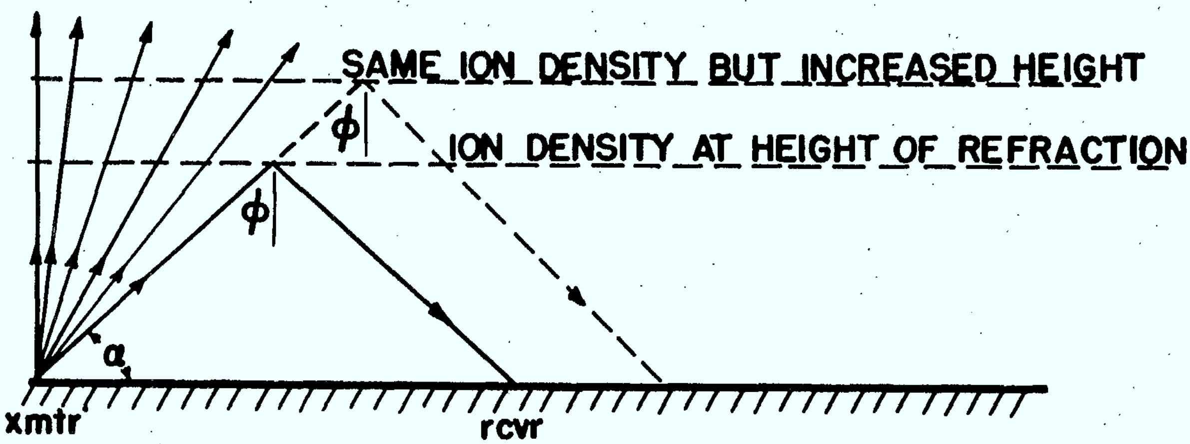


Fig. 5·4(a)

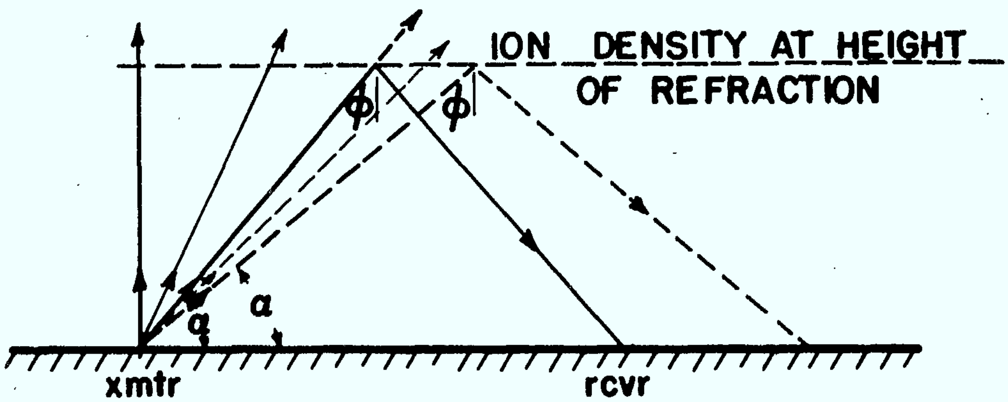


Fig. 5·4(b)

5.3. Relation between Critical Frequency, Critical Angle of Elevation and Skip Distance

The skip distance can be calculated from the relation

$$\text{Tangent } \phi = \frac{(\frac{d}{2})}{h'}$$

where $\text{secant}\,\phi = \frac{\text{transmitted frequency}}{\text{critical frequency}}$

and h' = virtual height of refraction at the mid-point of the path.

ϕ is, in fact the complement of the critical angle of elevation and is measured from the vertical at the point the wave enters the ionosphere.

The critical frequency, is determined by vertical incidence measurements at the mid-point of the path.

From the above relations the following effects can be determined by changes in the critical frequency and the virtual height of refraction of the mid-point of the path:

(a) if h' remains constant and fo increases then secant ϕ decreases, shortening the skip distance, d.

(b) if fo remains constant and h' increases then secant ϕ remains constant and the skip distance, d, is increased.

(c) if fo and h' both remain constant and the frequency of the transmitter is increased then secant ϕ increases and the skip distance increases. This is illustrated in figure 5.3.

5.4. Maximum Usable Frequency M.U.F.

The highest frequency, that may be transmitted between two points by means of refraction from an ionized region is defined as the Maximum Usable Frequency, MUF, for this distance. Over the given distance the MUF for a radio sky-wave transmission will depend upon the following:

(1) The direction of propagation into the ionized refracting region. The direction is dependent upon the height of the region and the distance between the transmitter and receiver.

(2) The maximum ionization density of the region in which the refraction takes place. This quantity may be represented in terms of critical frequency of the ordinary ray measured at vertical-incidence at the point of refraction.

For the fixed distance the maximum usable frequency is given by MUF = (secant ϕ) × fo.

Consider now a receiver placed on the ground at a fixed distance from the transmitter. Assume that the transmitter radiates in all directions at a frequency slightly greater than fo and assume that fo and h' of the layer at the mid-point of the transmission path are such that the skip distance is exactly equal to the distance separating the receiver from the transmitter. Thus the radiation from the transmitter at angles of elevation greater than the critical angle will penetrate the layer whereas radiation at the critical angle of elevation will be refracted downward and will arrive at the receiver. Radiation at angles of elevation less than the critical angle will be refracted downward and will reach the ground at distances beyond the receiver. From the discussion of the changes affecting the skip distance, the following conclusions can be drawn regarding reception at the receiver:

(a) if fo remains constant and h' increases the skip distance, d, is increased and the sky-wave will not be received at the receiver. This effect is shown in figure 5.4. (a). In order to continue communication between the transmitter and the receiver it is necessary to lower the frequency of the transmitter thus decreasing ϕ and decreasing the skip distance.

(b) if h' remains constant and fo decreases the critical angle of elevation (α) will decrease and the skip distance will increase. Radiation from the transmitter at the former critical angle of elevation now penetrate the layer. In order to decrease the skip distance it is necessary to decrease the transmitter frequency. This is illustrated in 5.4 (b).

5.5. Transmission Curves

To aid in the calculation of MUF's a series of curves are drawn which may be applied directly to the h'f sweeps. The following procedures are to be used:

(a) If the frequency scale of the h'f curve is linear, use is made of sets of MUF curves similar to those of figures 5.5 (a) and 5.5 (b). Families of MUF curves are drawn on transparent paper for each distance. To obtain an MUF for a given distance it is necessary to select the family of curves for the given distance and place the transparency over the h'f record in such a manner that both the frequency scales and the height scales coincide. The curve which is tangent to the h'f curve represents the MUF for the given distance.

(b) if the frequency scale of the h'f curve is logarithmic it is necessary to use a transmission slide as shown in figures 5.5. (c). The slide is constructed with virtual height represented on a linear scale and the M-factor = secant ϕ represented on a logarithmic scale. The transmission slide is placed over the h'f curve so that the height scales coincide. The transmission slide is moved horizontally until the h'f curve is tangent to the distance curve of the slide.

The M-factor is then read from the *slider* as the secant ϕ corresponding to the critical frequency of the ordinary-wave branch. The M.U.F. may be read from the h'f curve frequency scale at the point where secant ϕ is equal to 1.0.

In the foregoing discussion, for simplicity of illustration, the earth and the ionosphere have been considered as being flat. To obtain accurate measurements the curvature of both the ionosphere and the earth must be considered. The diagrams 5.5. (a), 5.5 (b) and 5.5. (c) have therefore been constructed taking this into account.

M.U.F. for 1500 Kilometers

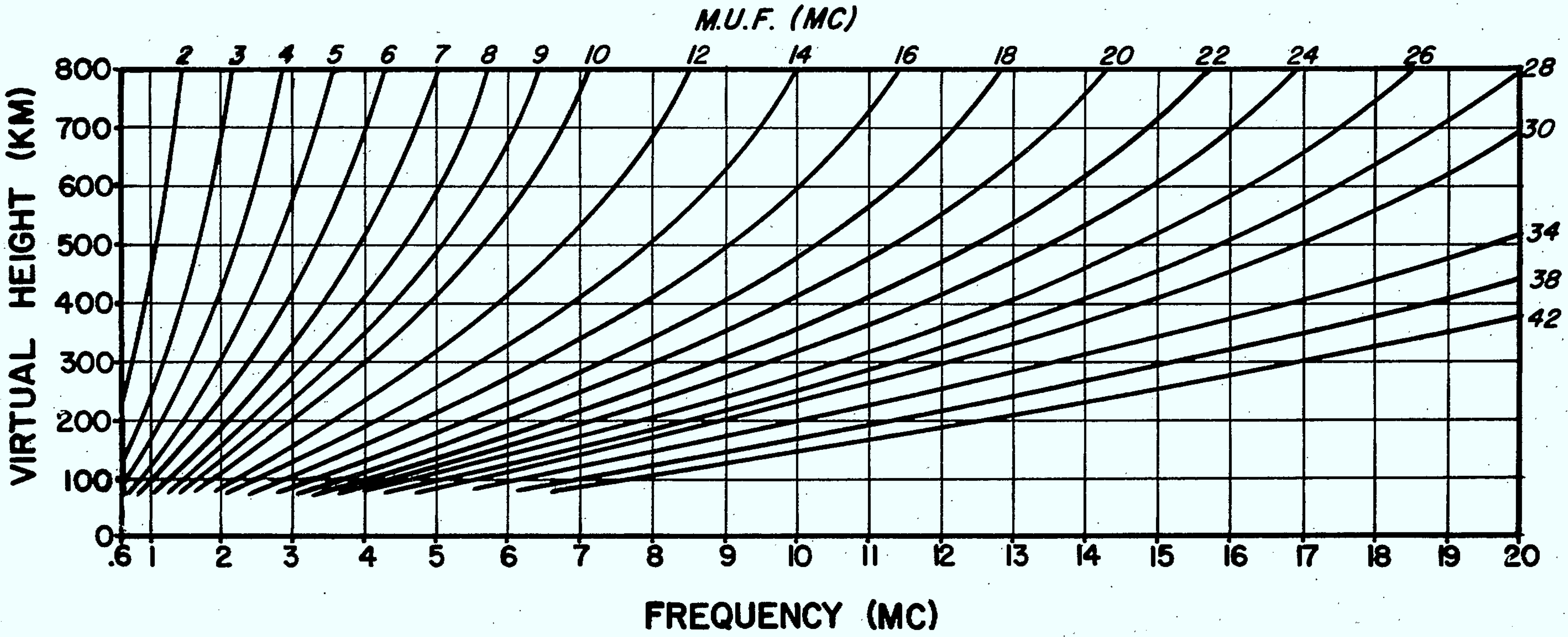


Fig 5·5(a)

M.U.F. for 3000 Kilometers

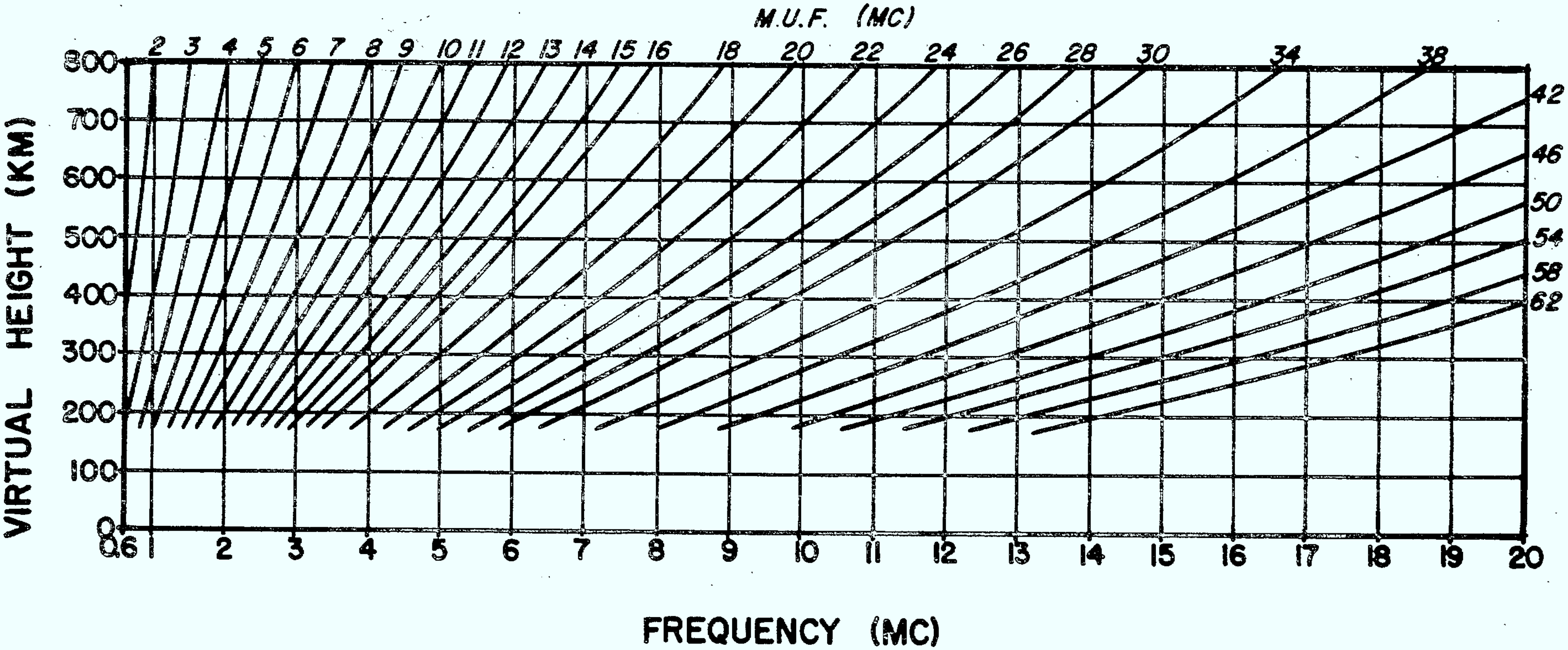


Fig. 5·5(b)

SECTION 6

ATTENUATION MEASUREMENTS

6.1. Theory

Radio waves passing into the ionosphere are all attenuated to a degree beyond the normal inverse distance effect. There are two principal absorbing effects in the ionosphere which cause this attenuation. One takes place while the radio wave is being refracted in the ionized region. It is called deviative absorption and is greatest at frequencies near the critical frequency of the region. The other takes place while the radio wave is passing through a lower ionized region. This latter is called non-deviative absorption.

At ionospheric stations an attempt is made to measure only the non-deviative absorption so that measurements near critical frequencies are not used. It is assumed that there is negligeable deviative absorption at frequencies away from the critical frequency of any region through which the radio wave passes.

The amplitude e_1 of a signal returned from an ionospheric region, assuming no attenuation on refraction, is:

$e_1 = \frac{A}{2hk}$ Where A is a factor depending upon the transmitter, receiver and antenna characteristics.

k is the non-deviative absorption factor.

h is the height of the refracting region above ground.

The amplitude of the 1st multiple echo e_2 from the ionospheric region is:

$e_2 = \frac{A\rho g}{4hk^2}$ Where ρg is the reflection coefficient at the ground.

Here ρg is assumed to be unity.

Then let $m = \frac{A}{2h_o}$ where h_o is arbitrarily set at 100 Km.

$$e_1 = \frac{mh_o}{h} \cdot \frac{1}{k} \qquad\qquad e_2 = \frac{mh_o}{2h} \cdot \frac{1}{k^2}$$

Measurements are normally made directly in decibels above one microvolt input to the receiver. The equation may then be written using equivalent upper case letters:

$$E_1 = M - C - K, \quad \text{where } C = 20 \log \frac{2}{ho}$$

$$E_2' = M - C - 2K - 6, \quad \text{where } 6 = 20 \log 2$$

$$\text{then} \quad K = E_1 - E_2' - 6 = M - E_1 - C$$

$$M = E_1 + C + K$$

These are the basic equations used in calculation of absorption.

It is found that for normal non-deviative absorption K is proportional to $\frac{1}{f^2}$

$$\text{or } DG = Kf^2$$

where D is a measure of absorption, independent of frequency, G is a factor depending upon the relation between the wave frequency and the gyrofrequency.

Values of D are given in table 6.2.2.

6.2. Observations

Attenuation is measured on some, or all, of the following frequencies: 2.0 Mc/s., 2.6 Mc/s., 3.2 Mc/s., 3.8 Mc/s., 4.4 Mc/s., 5.2 Mc/s. Measurements are taken on ordinary ray echoes for E layer and Sporadic E, and F1 and F2 regions as well, unless these frequencies are within 0.5 Mc/s. of any ordinary ray critical frequency. This rule is to be used with certain discretion, the attenuation being measured on the flat portion of the h'f curve. This will eliminate measurements including deviative absorption in the ionosphere due to the slowing down of the wave near the critical frequency.

The absorption is to be tabulated for each of the three regions: E Layer, Sporadic E and F region.

Fifteen snap readings of amplitude of both first echo and multiple are made. Readings should be made at equal intervals (5 to 10 seconds).

The virtual height of the first echo is recorded for each frequency, in order that the height correction (C) may be applied. (Table 6.2. (a)).

The median value for each 15 readings is calculated, and a correction is made from the receiver calibration chart. The K value for the first echo is calculated using the previously calculated monthly median M value. Also, the M value is calculated for use in the next month's tabulations from observations in which both first echo and multiple are seen. From the K value for each frequency is found the corresponding D figure in Table 6.2 (b).

An hourly Average D figure is tabulated for each ionospheric region (E layer, Sporadic E, F region).

Table 6.2. (a) Correction for Virtual Heights

Virt. height	C	Virt. height	C	Virt. height	C
90 - 100	0	170 - 180	5	300 - 330	10
110	1	190 - 210	6	340 - 370	11
120 - 130	2	220 - 230	7	380 - 420	12
140	3	240 - 260	8	430 - 470	13
150 - 160	4	270 - 290	9	480 - 530	14

Table 6.2. (b)

D FIGURES FOR VALUES OF K

2.0 Mc/s.		2.6 Mc/s.		3.2 Mc/s.		3.8 Mc/s.		4.4 Mc/s.		5.2 Mc/s.	
K	D	K	D	K	D	K	D	K	D	K	D
1	11	1	16	1	21	1	27	1	34	1	44
2	23	2	31	2	42	2	55	2	68	2	88
3	34	3	47	3	64	3	82	3	102	3	132
4	45	4	63	4	85	4	110	4	136	4	175
5	57	5	79	5	106	5	137	5	170	5	219
6	68	6	94	6	127	6	165	6	204	6	263
7	80	7	110	7	149	7	192	7	238	7	307
8	91	8	126	8	170	8	220	8	272	8	350
9	102	9	142	9	191	9	247	9	306	9	395
10	114	10	157	10	212	10	275	10	340	10	439
11	125	11	175	11	234	11	302	11	374	11	482
12	136	12	189	12	255	12	330	12	408	12	526
13	148	13	205	13	276	13	357	13	442	13	570
14	159	14	220	14	297	14	385	14	476	14	614
15	170	15	236	15	318	15	412	15	510	15	657
16	182	16	252	16	340	16	439	16	544	16	702
17	194	17	268	17	361	17	467	17	578	17	746
18	205	18	283	18	382	18	495	18	612	18	789
19	216	19	299	19	403	19	522	19	646	19	833
20	227	20	315	20	424	20	549	20	680	20	877
21	239	21	331	21	446	21	577	21	714	21	921
22	250	22	346	22	467	22	604	22	748	22	965
23	261	23	362	23	488	23	632	23	782	23	1009
24	273	24	378	24	510	24	659	24	816	24	1052
25	284	25	394	25	531	25	687	25	850	25	1096
26	295	26	409	26	552	26	714	26	884	26	1140
27	307	27	425	27	573	27	742	27	918	27	1182
28	318	28	440	28	594	28	769	28	952	28	1228
29	330	29	457	29	616	29	797	29	986	29	1271
30	341	30	472	30	637	30	824	30	1020	30	1324
31	352	31	488	31	658	31	852	31	1054	31	1360
32	364	32	504	32	679	32	879	32	1088	32	1404
33	375	33	520	33	701	33	907	33	1122	33	1447
34	386	34	535	34	722	34	934	34	1156	34	1491
35	398	35	551	35	743	35	962	35	1190	35	1535
36	409	36	567	36	764	36	989	36	1224	36	1579
37	420	37	583	37	786	37	1016	37	1259	37	1623
38	432	38	598	38	807	38	1044	38	1293	38	1667
39	443	39	614	39	828	39	1071	39	1327	39	1711
40	455	40	630	40	849	40	1099	40	1361	40	1754
41	466	41	646	41	870	41	1126	41	1395	41	1798
42	477	42	661	42	892	42	1154	42	1429	42	1842
43	489	43	677	43	913	43	1181	43	1463	43	1886
44	500	44	693	44	934	44	1209	44	1497	44	1930
45	511	45	709	45	955	45	1236	45	1531	45	1974
46	523	46	724	46	977	46	1264	46	1565	46	2018
47	534	47	740	47	998	47	1291	47	1599	47	2061
48	545	48	756	48	1019	48	1319	48	1633	48	2105
49	557	49	772	49	1040	49	1346	49	1667	49	2149
50	568	50	787	50	1062	50	1374	50	1721	50	2193
51	580	51	803	51	1083	51	1401	51	1735	51	2237
52	591	52	819	52	1104	52	1429	52	1796	52	2281
53	602	53	835	53	1125	53	1456	53	1803	53	2325
54	614	54	850	54	1146	54	1484	54	1837	54	2368
55	625	55	866	55	1168	55	1511	55	1871	55	2412
56	636	56	882	56	1189	56	1538	56	1905	56	2456
57	648	57	898	57	1210	57	1566	57	1939	57	2500
58	659	58	913	58	1231	58	1593	58	1973	58	2544
59	670	59	929	59	1253	59	1621	59	2007	59	2588
60	682	60	945	60	1274	60	1648	60	2041	60	2632

6.3. Calibration of Equipment

A manual vertical incidence equipment is used for attenuation measurements as it can easily be set on fixed frequencies while measurements are being made. A receiver is used in which the gain control may be calibrated directly in decibels. To minimize changes of calibration with frequency it is most practical to control the IF-gain using a special type attenuator graduated directly in decibels. On the cathode ray tube of the ionospheric equipment are placed two reference lines. With the attenuator set at zero gain, a line is drawn along the bottom of the sweep trace. The other line is drawn parallel to it about half wave between zero and maximum receiver gain. The exact position of this second line is not important. A standard signal generator is used for calibration of the receiver gain. This generator must be one of the precision types in which the output may be adjusted by means of a variable attenuator with fixed multipliers. There should also be some means of keeping the carrier-set constant throughout the frequency range. Calibrations are made by applying a given signal and varying the receiver attenuator until the signal amplitude reaches the half-way reference line on the cathode ray tube.

To calibrate, remove the antenna from the receiver and connect the signal generator output to the antenna and ground posts. Set the signal generator at the lowest specified fixed frequency on which measurements are to be taken and tune the receiver to frequency for maximum response. Turn the receiver RF-gain to maximum. Set the signal generator attenuator to 1.0 microvolts and multiplier at the various settings of 1, 10, 100, 1000 corresponding to 0, 20, 40 and 60 decibels above 1 microvolt. Vary the receiver attenuator to bring the signal up to the half-way reference level for each of the multiplier settings. Set the signal generator attenuator to 3.16 microvolts and multiplier at 1, 10, 100 and 1000 corresponding to 10, 30, 50, 70 decibels above 1 microvolts, and repeat. Plot a graph of the decibel reading of the signal generator against the decibel reading of the receiver attenuator. Calibrations are made on each frequency to be used for measurement. The plots are used for correcting the receiver attenuator readings. These calibrations should be made once every day so that if any equipment trouble exists, it will be noticed immediately without much loss of records.

To make attenuation measurements, reconnect the antenna to the receiver and obtain an echo at one of the calibrated frequencies. Adjust the receiver attenuator until the peak of the echo reaches the half-way reference level. The attenuator setting in decibels now corresponds to the signal amplitude of the echo above one microvolt.

SECTION 7

SIGNAL STRENGTH MEASUREMENTS OF DISTANT RADIO TRANSMITTERS

7.1. Aural Monitoring

Monitoring WWV frequencies of 2.5, 5.0, 10.0, 15.0, 20.0, 25.0 and 30.0 megacycles, as well as 35.0 Mc/s where a suitable receiver is available, is carried out every hour of each day. This is done preferably just before the automatic recorder takes its sweep. WWVH (Hawaii) is monitored on 5.0, 10.0, 15.0 megacycles each hour.

The station is tuned in and monitored for at least 30 seconds, and an estimate of the average signal strength recorded. The scale used is from '0' to '9'; '0' being 'not heard', '9' extremely strong. If the receiver is equipped with an 'S' meter, it should be used.

The strength of the first four frequencies of WWV are recorded on one monthly sheet and the others are recorded on another. WWVH is tabulated on a separate monthly sheet.

At some stations the Canadian Time signal, station CHU, is also monitored.

7.1.1. WWV - WWVH Schedules as of Jan. 12, 1950

(From National Bureau of Standards letter Circular LC974)

(a) Standard radio frequencies of 2.5, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0 and 35 megacycles.

(b) Time announcements at 5 minute intervals by voice and International Morse Code.

(c) Standard Time intervals of 1 second, and 1, 4 and 5 minutes.

(d) Standard audio frequencies of 440 cycles (the standard musical pitch 'A' above middle 'C') and 600 cycles.

(e) Radio propagation disturbance warnings by International Morse Code consisting of the letters W, U, or N indicating warning, unstable conditions or normal respectively.

The audio frequencies are interrupted at precisely one minute before the hour and resumed precisely on the hour and each five minutes thereafter. Code announcements are in GCT (same as GMT) using the 24 hour system beginning with 0000 at midnight; voice announcements are in EST. The audio frequencies are transmitted alternately. The 600 cycle tone starts precisely on the hour and every 10 minutes thereafter, continuing for 4 minutes. Each carrier frequency is modulated by a seconds pulse which is heard as a faint click; the pulse at the beginning of the last second of each minute is omitted.

Station WWVH broadcasts on an experimental basis on 5, 10, and 15 Mc/s. The program of broadcasts on the three frequencies is essentially the same as that of WWV. Time announcements in GCT(GMT) are given from WWVH every five minutes by International Morse Code only.

7.1.2. CHU

CHU Ottawa Ontario, broadcasts continuously on standard frequency of 3330, 7335, 14670 kilocycles, modulated with an audio tone of 1000 cycles per second, the carrier being interrupted once every second. This signal is broadcast according to the 5-minute period coding. The identification of each minute of a 5-minute group is determined by the omission of secondsbeats. During the first minute there is an omission of the 29th second, 51st second and the 56 to 59th seconds. In the second minute the omissions are the same except that instead of the 51st second, the 52nd second is omitted. A similar sequence applies to the third and fourth minute. During the fifth minute, the 29th second is omitted as well as the 51st to 59th seconds.

Example: When the 51st second is omitted and 4 more seconds beats are sent, it indicates that there will be 4 more minutes to a 5-minute interval.

During the first minute of each hour, the call sign C H U is sent slowly in morse code twice. The second and successive minutes of the hour correspond to the second and successive minutes of a 5-minute period group.

If one's time-piece is not in error more than 4 minutes, it is possible to adjust the time piece to within 1/1000th of a second. In case the error is greater, it may be necessary to wait for the hour identification.

7.2. Signal Strength Recorder

Continuous signal strength measurements are made on a recording milliampere meter in conjunction with a receiver tuned to some standard signal such as WWV or CHU. By means of a signal generator the meter is calibrated in decibels or microvolts, corresponding to the amplitudes of the signal input of the receiver. On the continuous chart, a record is made of the signal strength of the station to which the receiver is tuned, indicating increases or decreases in the strength of the received signal.

One of the most important phenomena observed is the Sudden Ionospheric Disturbance (SID). This is identified by a sudden decrease in signal strength followed by a slower recovery, the whole phenomena lasting from a few minutes to not longer than about an hour. SID's occur only on the sunlit half of the hemisphere, and are due to sudden eruptions on the sun. When these eruptions occur, great quantities of ultraviolet light are omitted causing sudden and extreme absorption in the D region of the ionosphere. The amplitude of the disturbance is greatest when the sun is directly overhead and decreases with decrease in the solar elevation.

In order to be sure that a decrease on a signal strength recording is an SID and not just random fading or a change in reflection from one layer to another, continuous signal strength measurements are made on more than one frequency. The SID will show up on more than one frequency, the drop in signal strength occurring at the same instant on both recorders.

In Fig. 7.2 is shown a good example of an intense SID occurring at both Ottawa and Churchill. The SID shown begins at the same time at both stations and lasting for a longer period of time on the lower frequencies. The displacement of the SID's on the charts is due to the change in time from EST to CST.

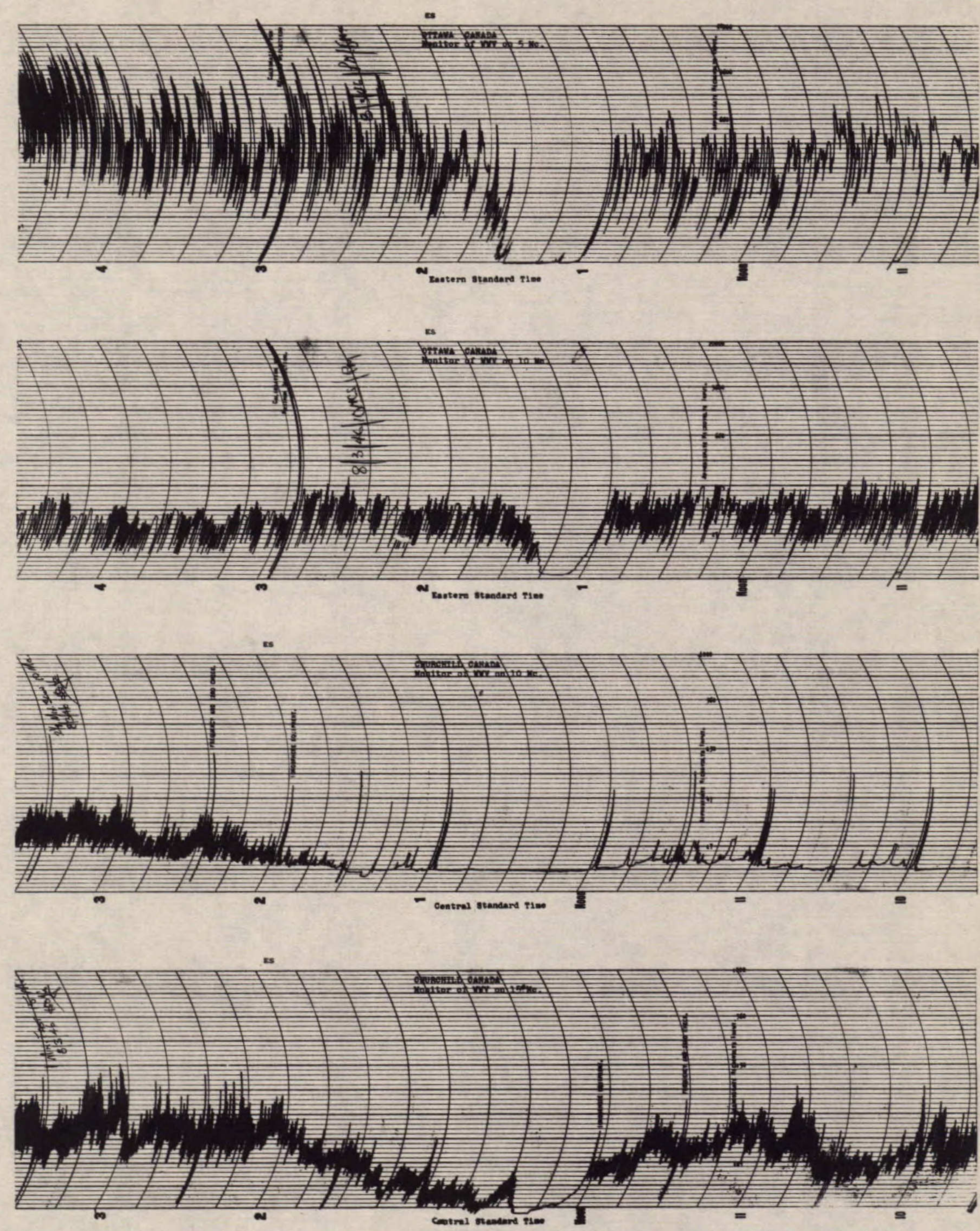


Fig. 7.2. Showing sudden ionospheric disturbance (SID).

SECTION 8

AURORAL OBSERVATIONS

8.1. The world map at the beginning of this manual, Fig. 1.1., shows the approximate position of the zone of maximum occurrence of auroral light. It crosses the central part of Canada. During ionospherically disturbed periods it extends southwards from its normal position. Aurora is seen frequently at most Canadian Ionospheric stations and a simple observing routine has been set up. This will give useful information on the movement and extent of the auroral light.

8.2. Coding of Auroral Observations

8.2.1. Presence of Aurora

Auroral observations are made on the hour throughout the hours of darkness.

When no aurora is observed and the observing conditions are favourable, the condition is *tabulated as O.*

When no aurora is observed due to cloudiness, strong moonlight, or no observation taken at that hour, the condition is *tabulated as X.*

No tabulations are made during daylight, but dusk and dawn are *tabulated as D.*

8.2.2. Position of Aurora in the Sky

For the purpose of actual auroral observations, the sky is divided into three sections from north to south, and three from west to east as shown in Figure 8.2.2.

Either a figure or a letter may be used to represent different sections of the sky.

1. N. North (45 degrees or lower)

2. Z. Zenith (above 45 degrees)

3. S. South (45 degrees south or lower)

4. E. East (45 degrees east or lower)

5. W. West (45 degrees west or lower)

If only a *single* 'Curtain' or 'Arc' is seen the position should be estimated at the base of the curtain and at the lower edge of the highest point in the arc. However, when several types of displays, both quiet and active, are present, simply estimate the extent of aurora and tabulate the section or sections of the sky in which aurora is seen. It should be remembered that even if only a small portion of the aurora is seen in one or more sections of the sky, the aurora should be reported as seen in these sections.

In tabulating position of aurora on Daily or Monthly Tabulation Sheets, use letters N,Z,S,E,W as described above. If aurora is seen in the north section of the sky, use letter N. If aurora is seen in the north as well as Zenith, NZ, or if aurora is seen in all portions of the sky, NZS. If seen only in the west, use W or if seen in the east as well as Zenith use EZ etc.

In the NOON SIGNAL described in section 11 use the figures corresponding to the letter occurring most frequently (Mode Value) during the night. For example: if the following positions have occurred N, NZ, XS, NZ the letter that has appeared most often is N and the number 1 is reported.

8.2.3. Intensity of the Aurora

The maximum intensity of the auroral light is estimated on a scale of 1 to 3.

1. Faint aurora
2. Moderate aurora
3. Brilliant aurora

The letters for position and figure for intensity will be combined into one group for tabulation purposes.

Example: If aurora is seen in NZS sections with intensity of 2, the tabulation will be NZS2 etc.

8.3. Observing Instructions

Each station should have a special auroral observation point at some convenient distance from the station building where no man-made lights will interfere with the observations. At this point, there should also be available a simple piece of equipment for measuring angles above the horizon. This equipment may consist of a vertical post or rod in the ground with a pointer fixed at a 45 degree angle above the horizontal and rotatable through 360 degrees.

Whenever possible, the observer should spend at least five minutes outside the station at the observing point before attempting to estimate position, extent and intensity. The purpose of this is to give the observer's eyes time to adjust for the vast change in light intensity.

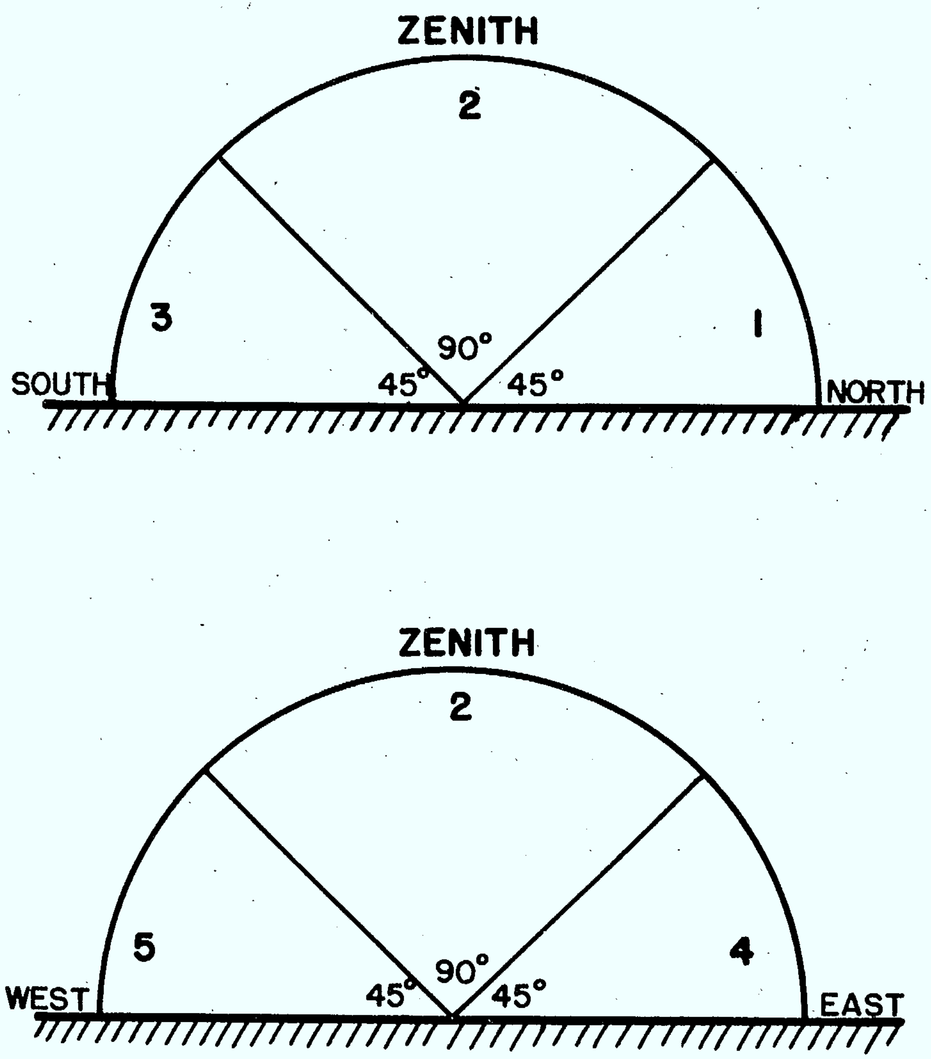


Fig. 8·2·2

SECTION 9

STATISTICS

9.1. Due to the large variations of the ionosphere from hour to hour and from day to day, the measurements made at ionospheric stations must be tabulated so that they may be analysed statistically. The following paragraphs explain some of the methods employed and the terms used.

Successive measurements of any element may vary because the measuring apparatus is too accurate or because there are a number of external causes of variation in the element. The latter cause is the main source of trouble in ionospheric measurements.

In order to study the general variations of the ionosphere, we must study representative values of the individual measurements.

9.2. **Representative Values**

Arithmetical Mean (also known as the average)

This is the sum of all the individual values, divided by the total number of values.

This the most common method of describing average conditions. It has the advantage of being simple to calculate and can represent any number of values. It can be worked out for part of the data and the result can be easily adjusted when the remainder of the data is obtained. It has the disadvantage that a single value which is a long way from the majority, will affect the mean greatly and give a poor representative value.

Median Value

The median value is the middle value. Half the values lie below it and half the values lie above it.

It is calculated by first counting the total number of values. This number is known as the median count. Starting at the lowest value, strike off the numbers in order of increasing magnitude, until the middle number is reached. This value is then the median value.

If there is an even number of values, the average of the two middle numbers is taken as the median. In ionospheric tabulations the median is rounded-off to the nearest even tenth. If the average of the two values is 7.05 the median value rounded-off becomes 7.0. As an additional example 5.55 is rounded-off to 5.6 and 5.45 would be 5.4.

It can be seen from the above that the median may be determined easily, but must be recalculated when additional values are available. It is not affected by single values which are a long way from the majority. The most useful feature of the median in connection with ionospheric measurements is that it can be determined even when some of the values are not measurable due to being outside the limits of measurement of equipment.

Mode

The value which occurs most frequently.

It is the most typical value, and can be found by a quick inspection without any calculations. It is not useful when values are spread out over a great range or when there are very few values.

7.7	9.9
8.0	9.7
7.6	8.5
7.7	8.3
9.9	8.0
7.9	7.9
7.9	7.9
7.5	7.9
7.0	7.9
9.7	7.9
8.5	7.8
7.8	7.8
7.8	7.8
7.8	7.8
7.9	7.8
7.7	7.8
7.7	7.7
7.9	7.7
7.8	7.7
8.3	7.7
7.9	7.7
7.7	7.7
7.7	7.7
7.8	7.7
7.4	7.6
7.6	7.6
7.8	7.6
7.6	7.5
7.7	7.4
7.7	7.0

This is a typical set of figures such as may occur in an ionospheric tabulation sheet. The figures are listed at random, and then rearranged in descending order of magnitude. In many sets of figures which represent physical measurements, the median, mode, and mean are the same value, however, if the values are unevenly distributed the three averages are not necessarily the same.

Count 30

Median 7.8

Mode 7.7

Mean 7.9

9.3 Dispersion

In addition to finding a representative value, we must know how much the individual values are spread around it. This is called the dispersion of the data. If the dispersion is small, then the corresponding representative value is fairly accurate. If the dispersion is large, we must use the representative values with caution.

At present we do not work out values of dispersion for ionospheric data. The individual values are tabulated as well as the median values and an estimation can be obtained by visual inspection of the columns of data.

9.4. Plotting Methods

Linear Unless there is special reason for using other types, plots are made on linear paper, that is, the divisions are equally spaced, both vertically and horizontally. There are of course, special papers made up with divisions numbered 0 to 24 hrs., 31 days, 365 days, five years by months etc. All are used to illustrate ionospheric variations.

Semi-Logarithmic

Semi-logarithmic paper (logarithmic scale on one side and a linear scale along the other side) is used for plotting manual ionospheric sweeps. A transmission slider can be applied directly to the sweep, and MUF's marked out in slide rule fashion.

Logarithmic

This paper is similar to the above but has logarithmic scales both ways and can be used to illustrate measurements differing by large amounts, that is 10, 100 or more times.

Polar

This consists of a number of concentric circles and radial lines. It is useful for plotting antenna patterns, D/F variations etc.

Figure 9.4 illustrates, on a reduced scale, the examples of the four types of papers described.

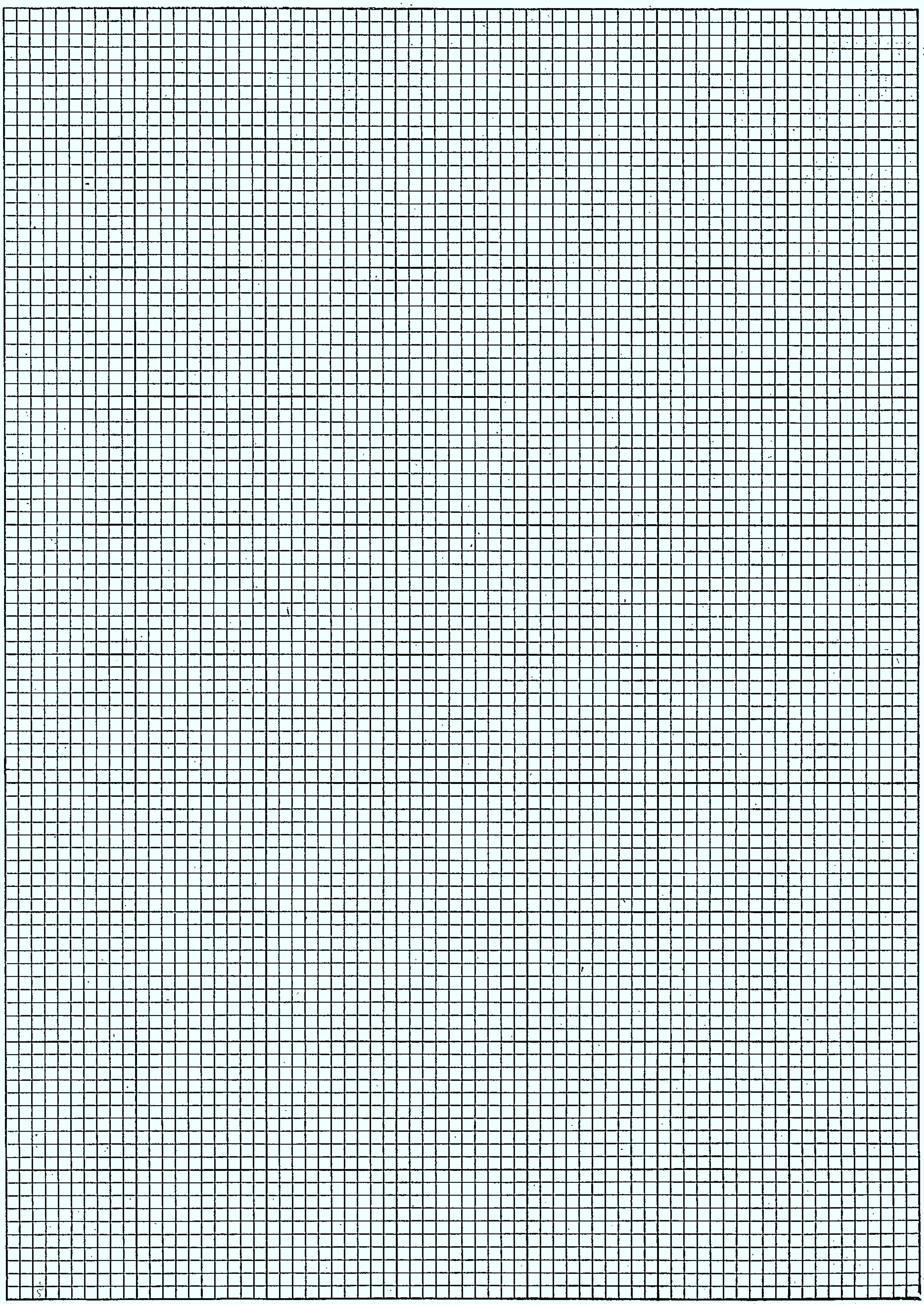


Fig. 9.4 LINEAR

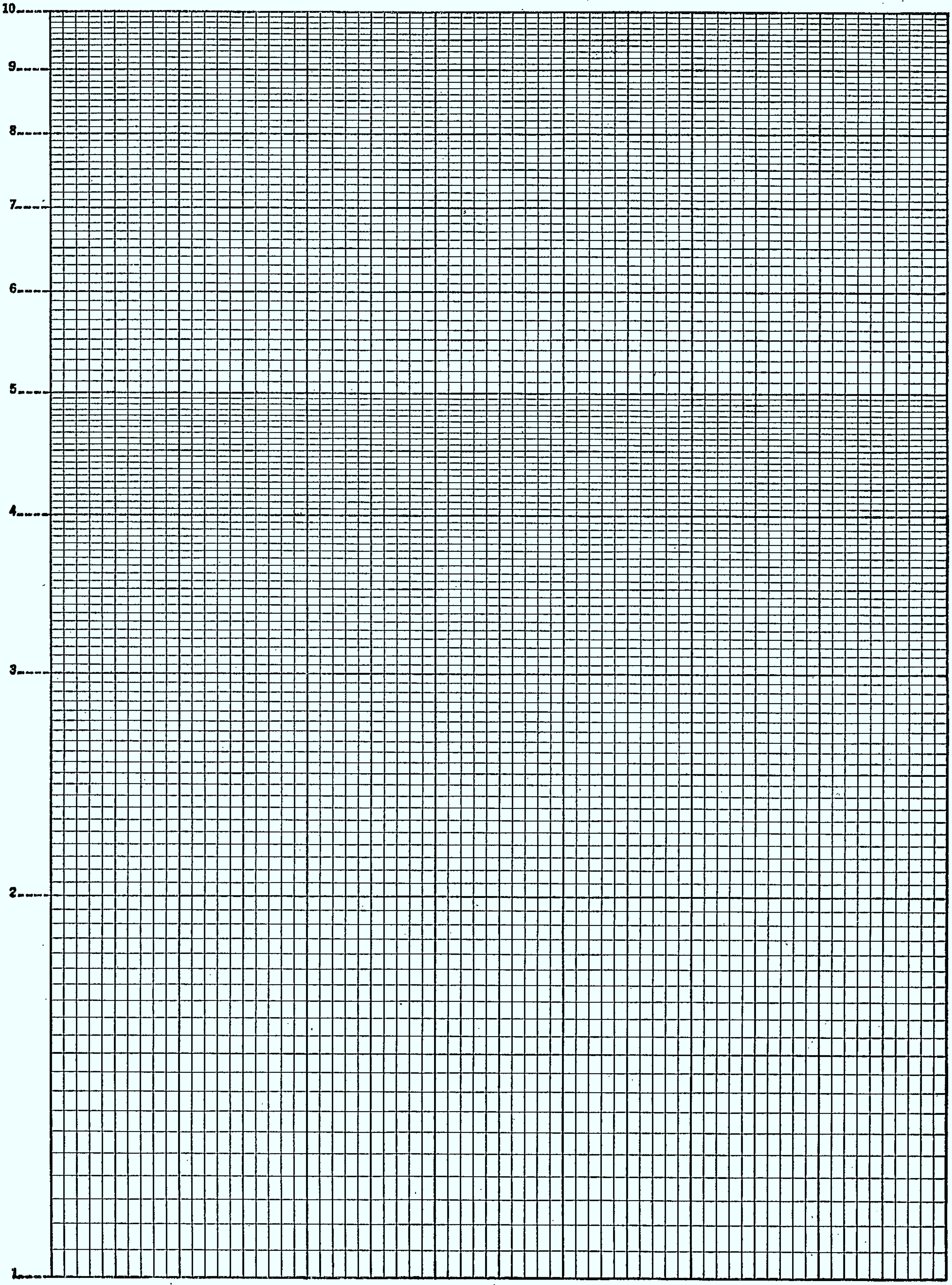


Fig. 9.4(A) SEMI - LOGARITHMIC

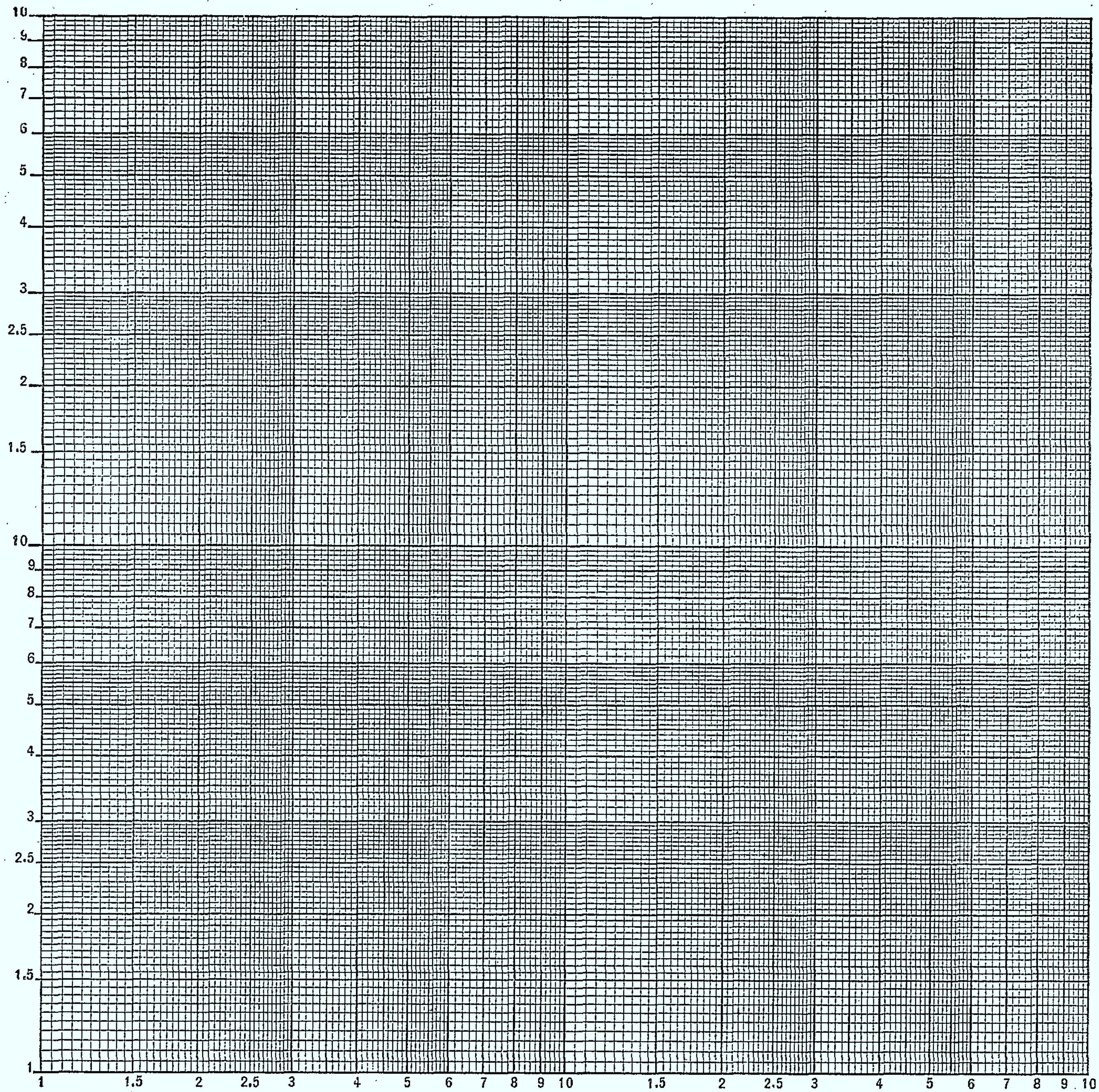


Fig. 9.4(B) LOGARITHMIC

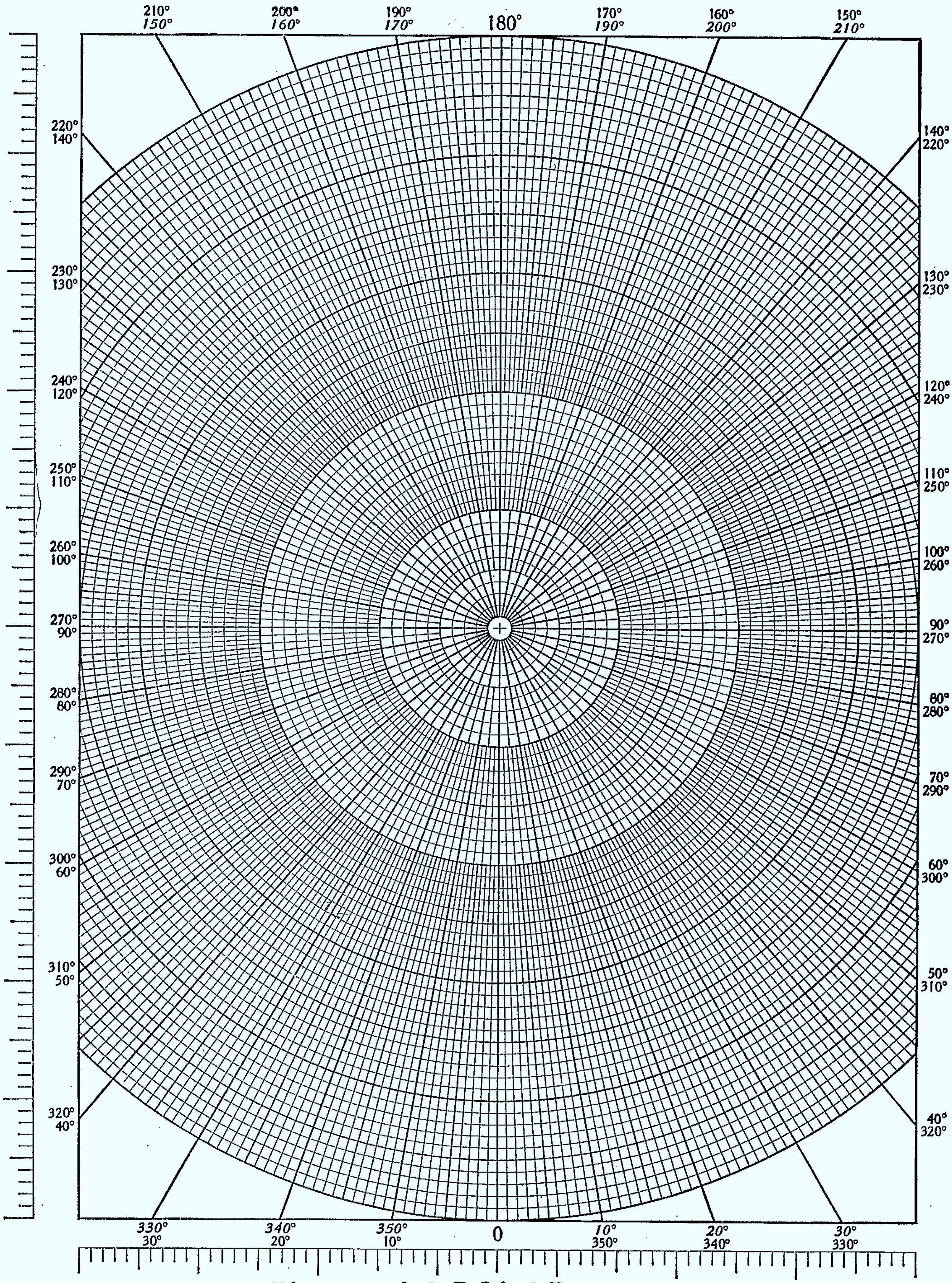


Fig. 9.4 (C) POLAR

SECTION 10

TABULATIONS

10.1. Ionospheric Characteristics to be Tabulated

The values of ionospheric characteristics scaled from the hourly records at all stations are as follows:

foF2	Critical frequency for the F2 region, ordinary-wave branch.
foF1	Critical frequency for the F1 region, ordinary-wave branch.
foE	Critical frequency for the E layer, ordinary-wave branch.
fEs	Highest frequency on which a continuous Sporadic E trace at the E layer height is observed.
fmEs	Highest frequency of the first multiple reflection of Sporadic E.
f-min	Minimum frequency of reflections seen from any region.
h'F2	Minimum virtual height of the F2 region.
h'F1	Minimum virtual height of the F1 region.
h'E	Minimum virtual height of the E layer.
h'Es	Minimum virtual height of the Sporadic E.
(M 3000)F2	Maximum usable *frequency factor* for F2 region for a distance of 3000 Km.
(M 3000)F1	Maximum usable *frequency factor* for F1 region for a distance of 3000 Km.
(M 1500)E	Maximum usable *frequency factor* for E layer for a distance of 1500 Km.
F2 Spreadiness	The amount of spread echo in the F2 region according to a scale from 1 to 8.
Aurora	Position and intensity of aurora during the dark hours.
WWV	The estimated signal strength of WWV on a scale from 1 to 9 on frequencies of 2.5, 5.0, 10., 15., 20., 25., and 30 Mc/s.

At some of the stations the following extra tabulations are made:

hpF2	A virtual height in the F2 region measured on the ordinary-wave branch at a frequency equal to 0.834 times the foF2.
foE2	Ordinary-wave critical frequency of a second stratification in the E layer.

h′E2	Minimum virtual height of a second stratification in the E layer.
fx and fz in all regions	Critical frequencies of both extra-ordinary branch and longitudinal branch in all three regions of the ionosphere.
WWVH	The estimated signal strength of WWVH on a scale from 1 to 9 on frequencies of 5.0, 10.0, and 15.0 Mc/s.

10.2. Daily Tabulation Sheets

Daily tabulation sheets should be filled in immediately after processing the film from the automatic recorder or in the case of a manual observation immediately after the sweep.

The values of foF2, foE, fEs, h′F2, h′E, h′Es as well as f-min, F2 Spreadiness and WWV will be filled in for every hour of the day. The values of foF1 and h′F1 shall be filled in when F1 region is normally expected to be present. Descriptive symbols shall be used accordingly where numerical values are missing. Under 'M' factor columns, no descriptive symbols are entered. Where 'M' factors are not obtained, spaces are left blank. Time and frequency of fmEs are to be entered in the column provided. Peculiar phenomena or particulars of stratification are to be entered in the remarks column. Aurora is to be entered during the dark hours as given in section 8, 'Auroral Observations'. Sample daily sheet is shown in figure 10.2.

10.3. Attenuation Tabulation

A suitable form for attenuation measurements is shown in figure 10.3. One sheet is required for each set of observations. The number of frequencies to be measured may be reduced at some stations and one sheet may do for more than one hour's observations.

10.4. Monthly Tabulation Sheets

A separate monthly tabulation sheet (Fig. 10.4) is compiled for each of the items shown in section 10.1. The values of items are transferred directly from the 'Daily Tabulation Sheets'. A characteristic is tabulated for each hour of the month and a median value (except for WWV) calculated for each hour in which five or more observations are available. The median and the *number of values* used to obtain the median (median count) are tabulated.

If half the values are in parentheses or interpolated, the median value is enclosed in parentheses.

foF2 Sheet

Every hour of each day is filled with a numerical value. Where numerical values are missing, spaces will be completed with descriptive symbols according to their definition.

Where only five to nine values for any hour are available, the median is considered doubtful and is enclosed in parentheses.

Only three descriptive symbols are used in computing median values. Symbol 'D' is counted as being higher than the median, while symbols 'E' and 'G' are usually counted as being lower than the median.

DAILY REPORT SHEET

L.S.T	f min	h'Es	f'Es	fmEs	h'E	f^oE	$h'F_1$	f^oF_1	$h'F_2$	f^oF_2	hpF_2	Spr. F_2	E-M 1500	F_1-M 3000	F_2-M 3000			AURORA	WWV	WWV	50MC	Obs. f^oF_2	OPERATORS LOG
0000																							
0100																							
0200																							
0300																							
0400																							
0500																							
0600																							
0700																							
0800																							
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1500																							
1600																							
1700																							
1800																							
1900																							
2000																							
2100																							
2200																							
2300																							

Fig. 10·2

DRTE(RPL)

Hour .... L.S.T.

HOURLY ATTENUATION SHEET

Station ....

Date ....

REGION	E or F						Es					
FREQ. Mc/s.	2.0	2.6	3.2	3.8	4.4	5.2	2.0	2.6	3.2	3.8	4.4	5.2
Virt. Hght.												
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
MEDIAN												
Corrected MEDIAN												
K = E1-E2-6												
h' CORRECTION												
M = E1+C+K												
MEDIAN M												
K = M-E1-C												
EQUIV. D												

EQUIV. D

REGION	E	F	Es
2.0			
2.6			
3.2			
3.8			
4.4			
5.2			
Average D value			

Fig. 10·3

DEFENCE RESEARCH TELECOMMUNICATIONS ESTABLISHMENT
RADIO PHYSICS LABORATORY

MONTHLY TABULATIONS

INITIALS______
______

STATION ________

LAT ________

LONG _____

TIME _____ °W MEAN TIME

G.M.T. − L.M.T. ____ hrs. ___ mins

MONTH __________ 19____

VALUES OF ________ IN ______

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	REMARKS
1																									
2																									
3																									
4																									
5																									
6																									
7																									
8																									
9																									
10																									
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25																									
26																									
27																									
28																									
29																									
30																									
31																									
MEDIAN																									
COUNT																									
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	

Fig 10·4

Symbol 'B' should not be used unless both F1 and E are absorbed.

foF1 Sheet

Every hour of each day where F1 is expected to be present, a numerical value or descriptive symbol is recorded. Hours at which F1 should be present but is not seen are filled with symbol 'Q'.

Symbol 'B' should not be used unless E layer is absorbed.

foE Sheet

Every hour of each day that E layer is present, either a numerical value or descriptive symbol is recorded.

The critical frequency of Night E is also entered on this sheet. At stations where Night E is observed the majority of time, all blank spaces should be filled approximately with descriptive symbols.

Descriptive symbol 'E' denotes that the critical frequency has decreased to a value below that of the recorder limit. This symbol is used extensively in the early morning and evening hours and is counted as being below the median value.

fEs Sheet

All hourly sweeps in which Es are seen are recorded. All blank spaces are filled with descriptive symbols according to definitions as follows:

Symbol G is used and counted in the median as equal to or less than foE when during the daylight hours normal E is seen and no Es observed. This does not apply at stations where h'Es is normally less than h'E.

Symbol E is used during dark hours when no Es is seen and where the f-min is equal to the lower limit of the recorder.

Symbol B is used when no Es is seen when f-min is higher than the lower limit of the recorder or when B is used on all other sheets.

fmEs Sheet

All hourly sweeps in which multiple Es are seen, the highest frequency of the first multiple is recorded. The hours and values should be obtained from the fmEs column of the 'Daily Tabulation Sheet'. No descriptive symbols are necessary on this sheet.

f-min Sheet

The minimum frequency of reflections from any region is recorded every hour. The only three descriptive symbols used on this sheet are 'C', 'B' and 'E'.

Descriptive symbol 'B' is only used where 'B' is recorded on all other sheets. In this case *only* is 'B' counted in the median count and considered as being higher than the median value.

Virtual Height Sheets

The minimum virtual heights of F2, F1, E and Es are recorded from each hourly sweep and entered on a separate tabulation sheet for each region.

Descriptive symbols are entered only when necessary and are *not* counted either in the median count or considered in the median values.

M Factor Sheets

The (M 3000) F2, (M 3000) F1, and (M 1500) E are entered on separate monthly tabulation sheets for each hour. No descriptive symbols are entered on these sheets.

F2 Spreadiness Sheets

The F2 spreadiness is evaluated every 15 minutes sweep (see 'Evaluation of F2 spreadiness') and an hourly figure each hour recorded on monthly tabulated sheets. Missing values are to be described by descriptive symbols. Descriptive symbols are not considered when computing median count or median values.

WWV and WWVH Sheets

The estimated signal strength of both WWV and WWVH are recorded hourly. These monthly values are to be *averaged*.

A sample monthly tabulation sheet is shown in figure 10.4.

10.5. Particulars of Ionospheric Stations

Headings on the monthly tabulation sheets from the various Canadian ionospheric stations are as follows:

STATION	LAT.	LONG.	MEAN TIME	GMT-LMT
BAKER LAKE, N.W.T.	64.3°N.	96.0°W	90°W	6 hrs 24 mins.
CHURCHILL, MAN.	58.8°N.	94.2°W	90°W	6 hrs 17 mins.
FORT CHIMO, QUE.	58.1°N.	68.3°W	75°W	4 hrs 33 mins.
OTTAWA, ONT.	45.4°N.	75.7°W	75°W	5 hrs 03 mins.
PRINCE RUPERT, B.C.	54.3°N.	130.3°W	120°W	8 hrs 41 mins.
RESOLUTE BAY, N.W.T.	74.7°N.	94.9°W	90°W	6 hrs 20 mins.
ST. JOHN'S, NFLD.	47.6°N.	52.7°W	60°W	3 hrs 31 mins.
THE PAS, MAN.	53.8°N.	101.2°W	90°W	6 hrs 45 mins.
WINNIPEG, MAN.	49.9°N.	97.4°W	90°W	6 hrs 29 mins.

SECTION 11

SIGNALS

11.1. Signals are transmitted to Ottawa for use in short term ionospheric disturbance forecasts and also to provide some basic data from isolated stations which have infrequent mail service.

The following figures are used in these signal messages from ionospheric stations.

Station Designations

Ottawa..............45	Fort Chimo..............58
St. John's..............48	Churchill..............59
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Equivalents for Missing Values

A..................01	F..................06
B..................02	G..................07
C..................03	N..................08
E..................05	S..................09

11.2. THE NOON SIGNAL

First group	2 figures	Station Designation
	3 figures	Message serial number
Second group	2 figures	Day of the month
	3 figures	foF2 at 1800 hrs previous day (tenths of a megacycle)
Third group	2 figures	foF2 at 0001 hrs (tenths of Mcs.)
	2 figures	foF2 at 0600 hrs " " "
	1 figure }	foF2 at 1200 hrs " " "
Fourth group	2 figures }	
	2 figures	Number of hrs of measurable F2
	1 figure	Average signal strength of WWV on 5 Mcs from 1800 hrs to 0600 hrs.

A 5 figure group for each hour Sporadic E is seen.	2 figures 3 figures	Hour of Sporadic E fEs in tenths of a Mc.
Series of figures divided into 5 fig. groups. If necessary fill in last group with X's. Missing values to be filled with figs. according to table.	1 figure 1 figure 1 figure	F2 spreadiness for 01 hr. F2 spreadiness for 02 hr. F2 spreadiness for 03 hr. Etc.

NOTE - Missing value equivalents are two digits even when used in F2 spreadiness groups.

For signal purposes only, lower frequency limit of recorder will be 1.0 Mc/s.

11.4. The Monthly Signal

First group	2 figures 3 figures	Station designation Message serial number
Series of 26 double figures	Median value of foF2 for the month for each hour of the day plus four figures for the sum of the values.	
Series of 28 figures	The second figure of the median (M 3000) F2 for the month for each hour of the day plus four figures for the sum of the *actual* factors.	

The signal is to be written in order making a series of 17 groups of five figures.

If for some hour a median value of foF2 is missing, the factor for that hour is also omitted. Missing values are to be filled in as 'O' in this signal.

Example:

Median F2 critical frequencies from 00 hrs to 23 hrs inclusive as follows:

3.4 3.0 X.X 2.5 2.7 3.7 4.1 4.5 4.8 5.2 5.0 4.9 5.1 5.0 4.9

4.9 5.1 5.1 5.2 5.2 5.1 4.6 4.2 3.6

Check 1019

(M 3000) F2 for the same period as follows:

3.1 3.1 X.X 3.1 3.1 3.3 3.3 3.1 3.2 3.0 2.9 2.8 2.9 3.0 2.8 2.9 3.0

3.0 3.1 3.2 3.2 3.1 3.1 3.1

Check 0704

Monthly signal from Resolute Bay with serial number 459 as follows:

75459 34300 02527 37414 54852 50495 15049 49515 15252 51464 23610

19110 11331 20989 08900 12211 10704

Fifth group	1 figure	Hours audible 5 Mcs WWV 04-12 hrs.
	1 figure	" " 10 " " " "
	1 figure	" " 15 " " " "
	1 figure	" " 20 " " " "
	1 figure	" " 25 " " " "
Sixth group	1 figure	Maximum fmEs 00-06 hrs to nearest Mc. (9 equals 9 Mcs or over)
	1 figure	Maximum intensity of Aurora
	2 figures	Percentage of Hrs of Aurora to total observable Hrs.
	1 figure	Average position of Aurora
Seventh group	1 figure	F2 spreadiness at 00 hrs
	1 figure	" " " 03 "
	1 figure	" " " 06 "
	1 figure	" " " 09 "
	1 figure	" " " 12 "

Example

Critical frequencies of F2 from 00 hrs. to 23 hrs. as follows:

5.0 F 4.7 4.3 3.9 C 2.5 3.4 E 4.8 5.6 9.6 10.0 11.8

11.5 10.9 9.8 9.0 P 8.1 B 5.1 4.7 3.6

Frequency of Sporadic E: fourth hour 5.5; seventh hour 11.2; eleventh hour 2.1; fourteenth hour 5.1; twentieth hour 3.1.

F2 Spreadiness

8 8 6 6 6 C 5 5 E 5 1 1 1 1 1 1 2 2 1 3 3 7 8

Daily Signal for Baker Lake on 11th day of the month with serial number 351 as follows:-

64351	11500	64743	39032	53405	48569	6/100	/118/
115/1	09989	04810	25147	36XXX	04055	07112	11020
14051	20031	88666	03550	55111	11122	13378	

11.3 **Long Daily Signal from Isolated Stations** (effective June 1, 1950)

First group	2 figures	Station designation
	3 figures	Message serial number
Series of figures divided into 5 fig. groups. If necessary fill in last group with X's. Missing values to be filled with Figs. according to table.	2 figures	Day of the month
	Values of foF2 from 00 Hrs. to 23 Hrs. expressed in tenths of a Mc. (Over 9.9 Mcs. use fraction-bar followed by 3 figures.)	

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