REPORT UAG - 23

WORLD DATA CENTER A
for
Solar-Terrestrial Physics

U.R.S.I. HANDBOOK OF IONOGRAM INTERPRETATION AND REDUCTION
Second Edition November 1972

November 1972

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FOREWORD TO FIRST EDITION

This handbook has been prepared by the World Wide Soundings Committee (WWSC) in response to numerous requests for a manual of instructions suitable for use at the individual ionospheric stations forming the world-wide network. It is based on the first, second and third reports of the World Wide Soundings Committee.

The operators' handbook developed for use at stations associated with the U.S. network (CRPL memorandum No. 40-B, 1959) has been widely used in preparing sections 1-7 of this report.

Section 0.2 in the introduction, on "General Considerations and Principles", is included to show the important rules to be observed if, at any station, it is impossible to apply the standard rules and conventions fully.

It must be stressed that the value of the data for regional or world-wide studies depends on the maintenance of consistent reduction and tabulation methods at all stations, and proposals for changes in or clarifications of these rules should be forwarded to a member of the World Wide Soundings Committee. Particular care is necessary that local "houserules" are not in conflict with these principles.

Most sections of this book are written in the form of detailed instructions to the operators at ionospheric stations. However, the Introduction and the subsections marked .0 at the beginning of each section give the principles involved in more general form together with historical notes where these may help the operator or administrative staff to understand the detailed rules.

References in the text in the form A... give the pages on which corresponding or additional material can be found in the IGY Instruction Manual for the Ionosphere, Annals of the IGY, Volume III, Part I, English text. The reference shows whether the additional material is an ionogram [A (page) I, Fig....], a figure [A (page) F, Fig....], or is descriptive [A (page) D]. When the present text disagrees with that given in reference A or with the text of any previous report of the WWSC the new form is to be used.

Many figures are copied from USSR memorandum The Interpretation and Reduction of Ionograms (Vertical Soundings), by N. V. Mednikova (1958), or from the French SPIM handbook (1955) or are figures prepared by consultants and members of the WWSC for use in particular ionospheric networks. No acknowledgment is made in these cases.

The WWSC requests that points needing further clarification and suggestions for improving the handbook be sent to the chairman or members of the Committee. Any interim clarification eventually found necessary will be circulated to all stations in the URSI Information Bulletin.

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FOREWORD TO SECOND EDITION

The great successes of the International Geophysical Years, the International Cooperation Years and the International Years of the Quiet Sun (IGY, ICY, IQSY) owe much to careful systematic study of the ionosphere by numerous groups of workers using common and standardized methods of analysis and description. The advent of rockets and satellites and of other sophisticated new techniques has, if anything, increased the importance of reliable synoptic observation. This occurs because the old and new techniques are usually complementary, for example, a satellite can show spatial variations in great detail for a constant time but cannot show the time changes simply. In a dynamic atmosphere this is a serious limitation and the question of whether phenomena really changed in time or in space is often central to the correct understanding of the observed satellite data. Similarly rockets can give very detailed descriptions of distributions with height of many physical factors but the significance of the results is uncertain unless it is known, by cheaper synoptic type measurements, whether conditions were normal or abnormal and how they were changing in time.

Much international cooperation is being stimulated by the Inter-Union Commission for Solar-Terrestrial Physics (IUCSTP or STP for short). This, through its working groups, is promoting intensive studies of particular phenomena or events. Systematic synoptic measurements are essential to the success of such efforts in many fields and, in the case of rare phenomena, are often the only source of data. Thus low latitude aurora can often be identified by the appearance of high latitude types of sporadic E (particularly Es-a and Es-r or night E) on ionograms at stations where such phenomena are only seen a few times in a solar cycle. It is very important that such events should be accurately identified and reported.

Before and during the IGY the main users of ionospheric data were largely the groups who obtained them. Now, however, the number of scientists using the data who do not operate ionosondes greatly exceeds those who operate them. Such workers have no direct contact with the station network and depend on the data from different stations being comparable. Unless informed to the contrary they always assume that parameters published have been deduced according to the International Rules.

The diversion of interest from average behavior to detailed studies of particular events has also made it more important that the numerical data should be as complete as possible within the restriction that its accuracy should be adequate for it not to be misleading. Two proposals have been adopted for the time being:-

(a) The introduction of a new parameter, fxI, which is also needed for practical radio communications problems.

(b) A slight relaxation of the maximum inaccuracy rules at stations and times when the ionosphere does not allow numerical values with the normal rules but a worthwhile evaluation can be made at lower accuracy. Some minor changes have been made in the text to meet these new requirements.

During the IGY and up to its dissolution in 1961, the WWSC members acted as specialist advisors on particular problems and these were named in the Handbook. Experience has shown that the interests of individuals change greatly in a few years and that all that is needed is an address to which queries can be directed, leaving it to a consultant to put the questioner in touch with the current experts. At the Ottawa meeting of the International Union of Radio Science (URSI) its standing committee on Solar-Terrestrial Physics (the URSI/STP Committee) set up an Ionosonde Network Advisory Group, INAG, to help maintain standards and give advice to the Ionospheric Network. The names and addresses of the current members are appended to this foreword and any of these would be pleased to help. It is usually most convenient to make contact initially with the nearest member. This body issues, to all known stations and other interested people, a bulletin giving the latest International Recommendations of interest to the Network and with articles explaining particular points raised by operators at the stations. Any future amendments to this volume will be issued through these channels.

Chapter 10 of this edition on electron density determination, is intended for groups who seldom wish to make electron density computations, and is biased by the methods at present most widely used. With the widespread availability of computers, it is now often more efficient to use computer methods. In the near future a paper will be submitted to Radio Science giving the detailed rules needed when operating with the computer system developed at NOAA. Such rules depend, of course, on the type of program adopted.

A seminar held at Leningrad in May 1970 showed that there were still special problems with High Latitude Ionograms and put forward proposals to minimize these in the future (INAG Bulletin No. 4, August 1970). When these proposals have been properly criticized and modified, it is proposed to add a special High Latitude Supplement to this Handbook giving rules and examples in more detail. Pending this minor alterations have been made to the main text to show where the normal rules are likely to be insufficient.

FOREWORD TO SECOND EDITION

There have been many requests for ionograms to be added to this book. This has proved to be very difficult to arrange, partly because of the large amount of correspondence and editing needed and partly from the cost of reproduction in a useful form. INAG and the editors have therefore decided to supplement the references to ionograms in the Annals of the IGY, Volume III Part I by references to ionograms published in the new Atlas of Ionograms prepared by A. H. Shapley, World Data Center A, Upper Atmosphere Geophysics Report UAG-10, May 1970. These references are denoted B (page) I Fig....

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0 INTRODUCTION

0.0 Historical

The earliest routine ionospheric stations were almost all placed in temperate latitudes where the echo traces on the ionograms could usually be classified as belonging to a few easily recognized patterns. These patterns could be interpreted in terms of simple models of the structure of the ionosphere. Naturally the main characteristics of the patterns were named and measured regularly and attempts were made to interpret nonstandard patterns in terms of the nearest simple model. Difficulties arose during periods of ionospheric storm and the establishment of a station on the magnetic equator, Huancayo, showed that wide departures from the conventional patterns could occur even in quiet periods. However, even greater deviations occurred at high-latitude stations, where the ionograms not only showed many abnormal traces but were also liable to change fundamentally in the space of a few minutes. Many workers felt that the range of interpretations possible in these circumstances was so great that it was not practical to make high latitude observations comparable with those at temperate latitudes. The first major international effort to solve this problem was made by the URSI Special Committee on High Latitudes (SCHL) in a report published in the URSI Information Bulletin, 1955, No. 96, p. 44. The work of the SCHL showed that rather few ionospheric phenomena are restricted entirely to high latitudes, though the incidence of complex or difficult ionograms varies considerably with latitude. Thus the techniques developed originally for clarifying phenomena at high latitudes could form a basis for improving ionospheric observations for the whole world. Furthermore, it became clear that ionograms obtained at low latitudes also often differed from the simple standard medium latitude models. Attempts to reduce such ionograms were greatly influenced by the experience and knowledge of the operators at individual stations, so that the numerical data produced were rather questionable and inhomogeneous. It was obviously desirable to attempt to minimize these difficulties before starting the intensive observational program of the IGY.

The Special Committee on World Wide Ionospheric Soundings (WWSC) was appointed in September, 1955, by the URSI/AGI Committee and directed to consider the revision of the procedures for the production, reduction and presentation of ionograms and ionosphere characteristics. The Committee has always attempted to maintain the closest possible contact with station networks and individual stations through its members and consultants.

The First (Brussels) Report of the Committee was published in the URSI Information Bulletin No. 99, pp. 48-90. Two annexes to the report appeared in the URSI Information Bulletin No. 100, pp. 82-89. This First Report, which is a basis of the Handbook, was clarified, expanded and slightly amended in the Second (Tokyo-Lindau) Report. This was widely circulated in May, 1957, as the well-known "Green Book". A third meeting of the Committee, together with almost all its principal consultants and a number of especially invited participants, was held in Brussels, August-September, 1959. This enabled the experience and views of almost all soundings networks and of typical isolated stations to be considered, and showed the need and desire for further collaboration to enable world and regional problems in the morphology of the ionospheric layers to be studied efficiently. In particular, the Committee recognized the need to collect the techniques found valuable in the IGY in the form of a handbook of ionogram interpretation and reduction suitable for use at the individual stations of the world network. The first edition of this volume was the result of the work done by the Committee and its Consultants at Brussels and subsequently elsewhere, and the second edition has been revised by the editors in the light of comments made by users.

0.1 Development of Systematic Vertical Incidence Soundings

While the first routine ionospheric soundings stations were set up primarily for scientific purposes - to discover the causes and characteristics of the reflecting and absorbing layers in the ionosphere - the great expansion of the network during the Second World War was brought about by the need to make predictions of radio propagation conditions over the world. The data obtained were used almost exclusively for practical purposes and remarkably few studies were made to discover their significance and meaning. It is probable that only a small percentage of the ionograms obtained were examined by qualified research workers and most serious research work was concentrated at a few stations where qualified staff were available. However, the researches made showed that the reliability and comparability of the data were scarcely adequate even for the simplest investigations. This situation was radically changed by the special procedures and studies developed for, or as a result of, the International Geophysical Year. For the first time stations all over the world used essentially the same detailed conventions and methods, giving an invaluable improvement in the uniformity of the data produced. The new researches made possible by the improvement in quality and the greatly increased quantity of data have suggested new ways of studying the ionosphere and provoked similar researches at other epochs in the solar activity cycle. Thus the special effort of the IGY started a new phase in ionospheric research which will be marked by much closer international collaboration than had been usual in the past.

The literature of ionospheric studies shows the great value of having a wide geographic distribution of stations for the study of the morphology of the ionosphere, the analysis and understanding of great geophysical events, some of which are very infrequent, and the production of ionospheric maps for geophysical and radio propagation prediction projects. In general, space investigations give great detail of the variation of the ionosphere with position at a fixed time but cannot identify time development or separate time from space variations. Thus the data obtained are difficult to use unless monitored by ground based measurements. In the case of rockets these show whether the conditions during the firing were typical or abnormal. For satellites ground based observations enable the dynamic behaviour to be studied, thus indicating the type of forces responsible for the observed spatial variations. They are also essential for separating changes in time from those in space - a short-lived worldwide disturbance can look localized when observed by satellite as it is only seen in the parts of the orbit covered while it is active. Both rocket and satellite data are much more valuable if the geophysical conditions on each day are known. This is easily done using synoptic ground based data.

0.2 General Considerations and Principles used to Establish the Operating Rules and Conventions

0.21. The maintenance of an adequate network of stations and the circulation of sufficient data for scientific and practical purposes depend on the voluntary cooperation of organizations whose primary interests fall into four different fields:

(a) Those primarily concerned with earth environment studies.
(b) Those interested in the exact form of the ionosphere at a specified time, e.g. for comparison with rocket or satellite data or for studying time variations in events.
(c) Those primarily concerned with radio propagation problems, both surface and space.
(d) Those involved in geophysical studies which involve the ionosphere or in which ionospheric sounding provides convenient monitoring techniques.

Practical experience shows that most ionospheric problems can only be completely studied by using data from groups of stations, and hence demand the cooperation of many organizations and individuals. It frequently happens that data produced by one station or group are mainly used by another, quite independent group having little or no direct contact with the original observations. This situation is, of course quite normal in geophysical studies. The value of comparable data obtained from a group of stations greatly exceeds the value of the data from each station considered separately. Thus, no matter what the primary objective of the station may be, the greatest return is obtained if the observations made at the station can be used for the four overlapping basic types of investigation:

(a) To monitor the ionosphere above the station.
(b) To obtain significant median data to evaluate long-term changes.
(c) To study phenomena peculiar to the region.
(d) To study the global morphology of the ionosphere.

While it is advantageous to use the same techniques and conventions for all four purposes whenever possible, types (a) and (c) may call for local procedures in addition to those necessary for (b) and (d). However, even in these cases, the interchange of data and theories is greatly simplified if the same conventions are used everywhere.

Studies using new techniques, e.g. rockets, satellites, incoherent scatter, etc., often demand

(i) A knowledge of the median behaviour of the ionosphere.
(ii) Whether or not particular days, for which particular measurements are available, were typical average days.
(iii) The relations between geophysical conditions on particular days and average days.
(iv) Detailed variations in time during particular events.

Thus there is a need for a set of standard techniques and conventions applicable to the majority of problems likely to be investigated in different parts of the world.

0.22. It is, in principle, possible to develop the reduction of ionograms using four different points of view, each of which would suggest a particular set of parameters for measurement and interchange. These are:

(a) To make a phenomenological description of the ionogram.
(b) To give a simplified parametric description of the ionosphere overhead.
(c) To determine the electron density/height profile overhead.
(d) To identify and measure parameters which determine or describe the physical characteristics of the ionosphere.

Historically, most early work on ionograms was influenced mainly by the first possibility. Certain investigations at individual stations are directed towards (c) and (d). For the worldwide network as a whole, the second possibility is most appropriate and the choice of parameters and rules is, therefore, consistent with this concept. A discussion of the third possibility can be found in Chapter 10 of this book.

0.23. In considering what should be tabulated, it is well to bear in mind that the tabulations are primarily for use by people who will not see the records themselves and who are interested in problems solvable by tabulated data alone.

The selection of significant parameters is always a somewhat arbitrary process determined finally by the purpose for which the selection is made. In practice, it is also influenced by the ease of measurements; for example, a highly significant parameter which is very difficult to measure may be replaced by a less significant one which is easier to measure. This may increase the efficiency of the research as a whole.

There are several difficulties in applying these principles to worldwide investigations:

(i) A decision must be made that certain phenomena are more important than others.
(ii) Phenomena which are very important in some zones of the world can be almost or completely absent elsewhere.
(iii) Parameters which are significant and easy to measure in some areas are very difficult to measure in others.

This suggests that it is very desirable that three levels of selection should be made:

(a) Parameters required all over the world.
(b) Parameters required for regional studies.
(c) Parameters required for local studies at the station.

The principal international parameters fall mainly into class (a), though some are not measurable in all parts of the world. They include certain characteristics which are useful for investigating the incidence of particular phenomena, e. g. Es types. In general the local parameters, class (c), are seldom useful on a worldwide basis, mainly because the phenomena change with position and definitions and rules which give useful precision at one station become seriously misleading when applied in a different theater of operation.

0.24. The basic routine scalings at any station should delineate the essential features of the ionosphere overhead and should be used initially to produce representative data at relatively infrequent, hourly, intervals. It is important that these data be as complete as possible and controlled interpolation is therefore encouraged. (See Chapter 2).

The results tabulated should not be an exhaustive description of the record but represent the essential features of the first order vertical reflection rather than the characteristics of multiples, oblique echoes and transient phenomena. Multiple, as well as x- and z-traces, should be used as auxiliary guides in the interpretation of the first order ordinary pattern (see 1.03). Oblique traces should be ignored in the interpretation of f plots or in the tabulation of hourly values and should be omitted when recognized, unless they contribute to the understanding of the main trace.

While at temperate and low latitudes the intention is clearly to concentrate on vertical incidence traces in order to describe the "ionosphere overhead", the situation is sometimes more involved at high latitudes. There, it is often valuable to study the properties of ridges of ionization seen by oblique reflection. Nor does it apply to phenomena giving fxI greater than fxF2. It is intended to discuss these possibilities in the forthcoming "High Latitude Supplement".

It must be stressed that many ionospheric parameters, e. g. h'F, M(3000)F2 which are invaluable for geophysical or prediction purposes, do not directly measure physical phenomena and may be misleading in particular circumstances unless their properties are clearly understood. It is clearly the user's responsibility to make himself conversant with the subject so as to understand these points, whereas it is the operator's responsibility to reduce a difficult ionogram adequately according to the established rules.

0.25. The hourly tabulated data should be self-explanatory, representative of ionospheric conditions for the period centered at the hour and, as far as possible, not misleading for those receiving these data alone. In particular, the use of the standard international designations, foF2, foF1, foE, foEs, h'F, h'F2, fmin, etc., implies that the data conform to the reduction rules.

0.26. The following points are often overlooked:

(a) Where data are not published, adequate catalogues of the unpublished material, data or ionograms, need to be kept and published through the World Data Centers (WDC's).
(b) Techniques which save some labor at a station at the cost of considerable inconvenience to the user are not really economical.
(c) It is most economical to put data into a form suitable for computer handling at the earliest possible stage. At present most data are put into this form sooner or later and this is the preferred form for international interchange of data.
(d) The f-plot is a valuable tool for identifying variations in the ionosphere and the interpretation of complex records particularly at high latitudes.

0.27. The relative priorities of measuring different parameters will change with the development of the science and will depend on the existence of particular regional or worldwide studies. Guidance on these points will be found in the current URSI and INAG Information Bulletins.

However, it is particularly important to obtain representative numerical values whenever possible for the basic parameters of the most variable layers: foF2, M(3000)F2, foEs. It is also important to measure fmin, which is the sole index of absorption given by ionograms. For control purposes it is also an important parameter for monitoring the behavior of the ionosonde.

Further research on the data, however, appears to be developing into two widely different directions:

(a) Studies of the detailed structure of the ionosphere demanding detailed and accurate measurements of the instantaneous values of important ionospheric parameters.
(b) Studies of the general structure of the ionosphere and its variation with other phenomena demanding statistically representative and, as far as possible, complete sequences of data.

Instrumental, operational and ionospheric factors combine to make it possible to obtain relatively small quantities of highly accurate data or alternatively to produce more complete sequences of lower grade data. The best compromise depends on the equipment and staff available, the position of the station in the world network, and the type of work regarded as most important. Provided that the international rules and conventions are observed, useful work can be done even if the most desirable accuracy is not obtainable or all the data on the ionograms cannot be circulated. However, it is essential that the relatively few stations capable of producing ionograms of the highest quality should make every effort to maintain the best accuracy practical.

A similar problem arises with electron density profile calculations where precise profiles demand first class ionograms, very elaborate computing procedures and the highest possible accuracy of measuring virtual height and frequency. This is usually uneconomical where statistical data are required and relatively simple techniques are then preferable. The former is a specialized problem not discussed in this volume and the procedures for the latter may be found in Chapter 10.

0.3 Writing Conventions

By International Agreement, all symbols which represent parameters which are or may be interchanged internationally are designated by on-the-line symbols for example foF2, or M(3000)F2.

Frequency, f, height, h, the ordinary, extraordinary and z modes, o x z and the Es types (see section 4.8) are always written with small (lower case) letters except when produced by machines in which these are not available (Computer, Telex or Telegram outputs).

As is normal scientific practice, physical quantities are designated in suffix form unless they are actually measured.

In this edition we have modernized the symbol for magnetic field, substituting B for H throughout. Thus the electron gyrofrequency is now written f_B instead of f_H, the traditional but incorrect form. This is widespread but not universal practice at present. The corresponding correction term is fB/2 instead of fH/2.

Since the numerical factors in equations linking physical parameters depend on the system of units used, we have adopted the convention that the parameter is divided by the units in use. Thus, if the electron density N is measured in m^{-3} and the plasma frequency fN in MHz, the relation between N and fN; $N = 1.24\cdot10^{10}\ (fN)^2$, becomes $N/m^{-3} = 1.24\cdot10^{10}\ (fN/MHz)^2$ (equations 1.1 in section 1.04). This is read as N in $m^{-3} = 1.24\cdot10^{10}$ (fN in MHz)^2.

0.4 Acknowledgements

A Handbook of this type is the result of the efforts of many experts in different countries. The final form, the decisions on what to put in, leave out or modity, has been the responsibility of the Editors. Thus, the names of contributors are only included in the text where the Editors felt that users might wish to discuss particular points with them. These are mainly new techniques. Mr. A. H. Shapley was responsible for the original proposal to revise the Handbook.

The Editors wish to acknowledge the help they have received from members of INAG, experts in the fields of topside soundings, electron density profile analysis and high latitude phenomena. Most of the modifications to the text of the first edition have been made as a result of comments or requests for clarification made by numerous operators. They have also had much help from meetings arranged under the auspices of the URSI-STP Committee, INAG, and National groups involved in operating VI networks.

Many of the figures in this edition are new or redrawn and the Editors are grateful to the Directors and staff of the Science Research Council Radio and Space Research Station, Slough, England, and World Data Center A, Boulder, U.S.A. for their help in preparing both figures and text. The aid given by Mr. Richard Smith and Mrs. E. Hurst to W. R. Piggott needs special mention. Figures Nos. 1.9, 1.10, 11.11, 11.12 are reproduced by the kind permission of Springer-Verlag Heidelburg and taken from Vol. 49/2 of the Encyclopedia of Physics (contribution by K. Rawer and K. Suchy, "Radio Observations of the Ionosphere", pp 1-546, 1967).

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The publication would not have proved possible without the prolonged efforts of J. Virginia Lincoln, World Data Center A, who was in charge of publication. W. R. Piggott wishes to thank the Directors of the Radio and Space Research Station who have supported this work.

NOTES

1 FUNDAMENTAL CONSIDERATIONS AND DEFINITIONS

1.0 General

1.01. The ionosphere is that part of the atmosphere where free electrons occur in an appreciable density so as to influence considerably the propagation of radio waves. It is convenient to divide the ionosphere into three regions, called D, E and F.

D - The zone between about 75 km and about 95 km above the earth in which the ionization is found that is mainly responsible for absorption of those high frequency radio waves which are reflected by higher layers.

E - The zone between about 95 km and about 150 km above the earth in which the normal daytime E layer is usually found. Other layers in this zone are also described with the prefix E, e.g. the thick layer E2 or the highly variable thin layer Es.

F - The zone above about 150 km in which the most important reflecting layer, F2, is usually found. Other stratifications in this zone are also described with the prefix F, e.g. the temperate latitude regular stratification F1 and the low-latitude semiregular stratification F1.5.

1.02. The standard ionosonde [A70D] produces photographic records known as ionograms, which show the variations of the virtual height of reflection as a function of the radio frequency, h'(f) [A25D, A31D]. The frequency band normally used is from about 1 MHz to about 20 MHz though some ionosondes can be operated down to about 0.20 MHz when interference allows. Short descriptions and copies of ionograms from most types of ionosonde will be found in the Atlas of Ionograms, B section, p. 1.1 - 1.11. The ionograms actually show the time of travel of the pulse signal from the transmitter to the cathode ray tube, reflection in the ionosphere normally occurring at vertical incidence. As this signal always travels more slowly in the ionosphere and in the receiver than in free space, the heights observed always exceed the true heights of reflection. If the frequency of a radio signal reflected from a single thick layer is increased the virtual height increases more rapidly than the true height. When the level of maximum electron density in the layer is reached, the virtual height becomes effectively infinite (Fig. 1.1). The frequency at which this occurs is called the critical frequency of the layer. If the reflecting layer is very thin, the increase in

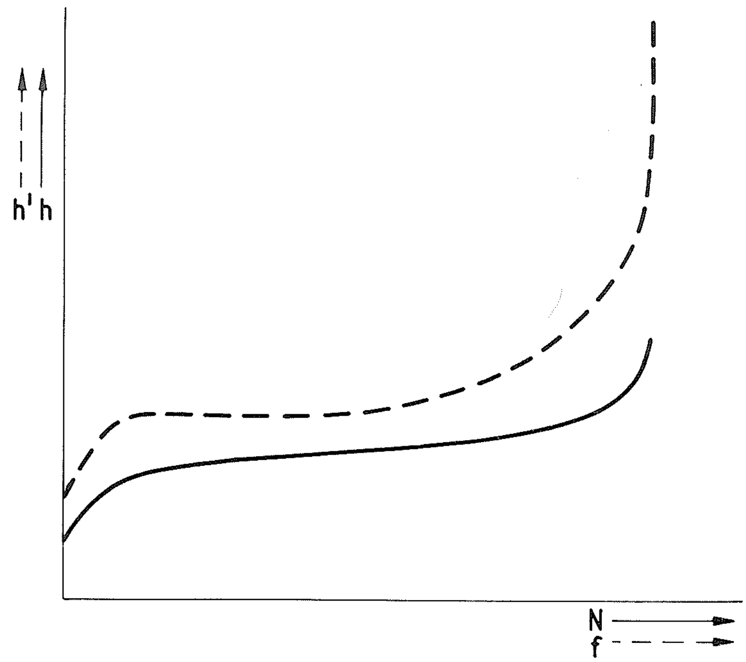

Fig. 1.1 Relations between virtual height and true height (no magnetic field).
________ ionization distribution, ------ h'(f) pattern.

virtual height with frequency cannot be observed but the amplitude of the signal appears to decrease rapidly above a certain frequency [A40D] [B section III]. The highest frequency at which a clear, almost continuous trace is obtained is called the top frequency of the trace [A40I, Figs. 31, 33, 34].

1.03. The Earth's magnetic field, in general causes a radio wave incident on the bottom of the ionosphere to be divided into two waves of different polarization which are reflected independently in the ionosphere [A26D]. These waves are known as magneto-ionic or, preferably, magneto-electronic component waves. They are due to the interaction of the electrons in the plasma with the magnetic field. Modern plasma theory shows that the presence of ions can introduce additional modes and waves which can be observed experimentally and are accurately described as magneto-ionic waves. By analogy with optical double refraction, one is called the ordinary wave and one the extraordinary wave.

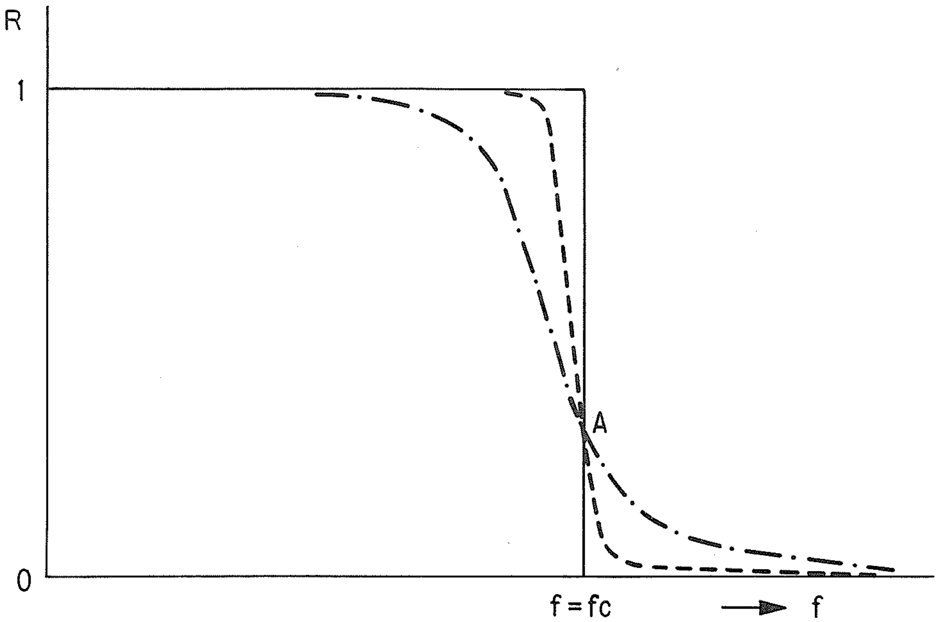

Fig. 1.2 Reflection coefficient R of a thin and thick layer as a function of frequency.
—— thick
---- thin
·-·- very thin

The value of R at A depends on the shape of the layer.

Since the conditions of reflection for the two components are different, each produces its own h'(f) pattern. These are similar but displaced in frequency. The extraordinary ray has the higher critical frequency (Fig. 1.3). In certain circumstances a third mode of reflection is possible in which the critical frequencies are lower than for the ordinary wave mode [A32D]. This is called the z mode or third magneto-ionic component and is described more fully in section 1.05 below.

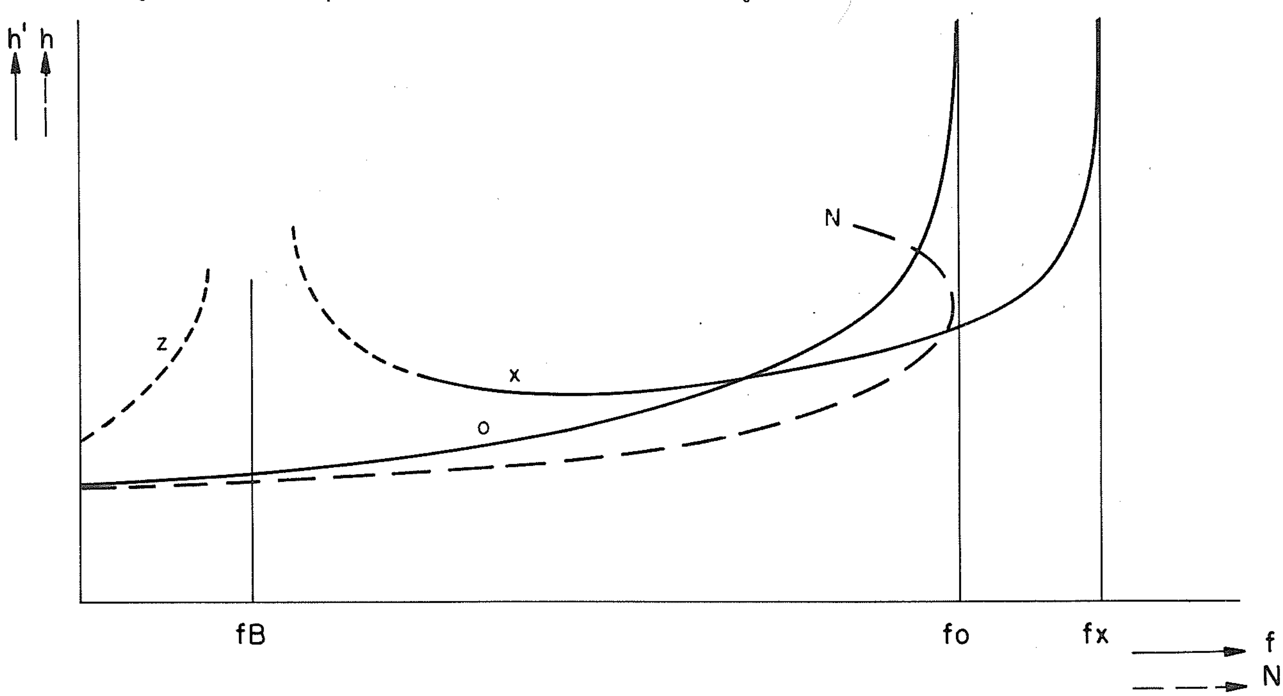

Fig. 1.3 Relations between virtual and true height with magnetic field.
-- electron density distribution — h'f pattern.

1.04. Relations between the basic magneto-electronic parameters

The three basic parameters that affect radio sounding in a magneto-electronic medium are the electron number density N, the total magnetic induction B and the angle between the magnetic field direction and the direction of propagation, Θ. N and B are directly related to the electron plasma frequency fN and the electron gyrofrequency fB respectively.

$$N/m^{-3} = 1.24 \cdot 10^{10} \, (fN/MHz)^2 \quad (1.1)$$

or $$fN/MHz = 8.98 \cdot 10^{-6} \, (N/cm^{-3})^{\frac{1}{2}} \quad (1.2)$$

and $$B/Gs = 0.35723 \, fB/MHz \quad (1.3)$$

or $$fB/MHz = 2.7993 \, B/Gs = 2.8 \, B/Gs. \quad (1.4)$$

In these equations the unit of magnetic induction is the Gauss (Gs). The corresponding MKS unit is the Tesla (T). 1T = 10^6Gs.

Note B and fB decrease with increase in height, h, above the surface as $1/(1+h/R_E)^3$ where R_E is the radius of the Earth.

The gyrofrequency fB is the natural resonance frequency of the electrons about a magnetic field of strength B.

The relations between the critical frequencies fo, fx, fz of the ordinary, extraordinary and z modes are:

$$fx^2 - fxfB \fallingdotseq fo^2 \quad (1.5)$$

giving the well known rule

$$fx - fo = fB/2 \quad (1.6)$$

which holds provided fo >> fB;

and $$fz^2 + fzfB = fo^2 \quad (1.7)$$

or $$fx - fz = fB \quad (1.8)$$

When conditions allow reflection of the extraordinary mode at frequencies near the gyrofrequency, fB, the x-mode trace shows a special type of retardation near the gyrofrequency (Fig. 1.4). The x mode is more strongly absorbed than the o mode so that the retardation near fB is only seen when absorption is small. The patterns which would be expected as the ordinary wave critical frequency fo changes from fo >> fB to fo ≒ fB and fo < fB are shown schematically in Fig. 1.4.

The expressions for fx-fo and fo-fz given by the magneto-electronic theory are

$$fx-fo = fxfB/(fx+fo)$$

and

$$fo-fz = fzfB/(fz+fo)$$

which can differ significantly from the usual approximations

$$fx-fo = fB/2, \; fo-fz = fB/2$$

when fo is not large compared with fB. For such cases fx-fo is greater than fB/2 and fo-fz correspondingly smaller so that fx-fz = fB. In practice, the separation fx-fo does not increase as rapidly as would be expected from theory when fo decreases below fB. However, the full expression shown above should be used when scaling low critical frequencies. It is convenient to make a table or graph of values of fo corresponding to given values of fx, fz, using the local value of fB.

1.05. The z mode: The z-mode traces are generated by waves which have been propagated along the magnetic field until they reach the z-mode reflection level, $fz^2 + fzfB = fo^2$. This can occur through coupling at levels where the collision frequency is high or by scattering by irregularities or by reflection in layers tilted so as to be perpendicular to the lines of magnetic field. The two types of ionogram are very dissimilar (Fig. 1.6). Coupling is important below the gyrofrequency (Fig. 1.6, 1.5) and affects higher frequencies and higher levels as the dip approaches the vertical. Thus the z traces due to this cause are most complete on the lowest frequencies and are most frequently observed at high magnetic latitudes [A331, Figs. 23, 24; A34F, Fig. 25]. [B IIA 1. Sept. 19, IIB 3 June, IIB 15 Sept., IIB 17 Sept., III 30 1a.] The z mode is often observed on low frequency ionograms at night for frequencies below the gyrofrequency (Fig. 1.5) and the trace can be readily identified by the frequency separation from the o-and x-mode traces, by its smaller absorption which gives a stronger trace and by its retardation at both fzE and foE [B III 30 1a].

At high latitudes or when the critical frequency is near fB, the z and o modes are relatively stronger than the x mode and care is needed to avoid confusing z and o traces with o and x traces. The x mode may be missing whenever the absorption is significant.

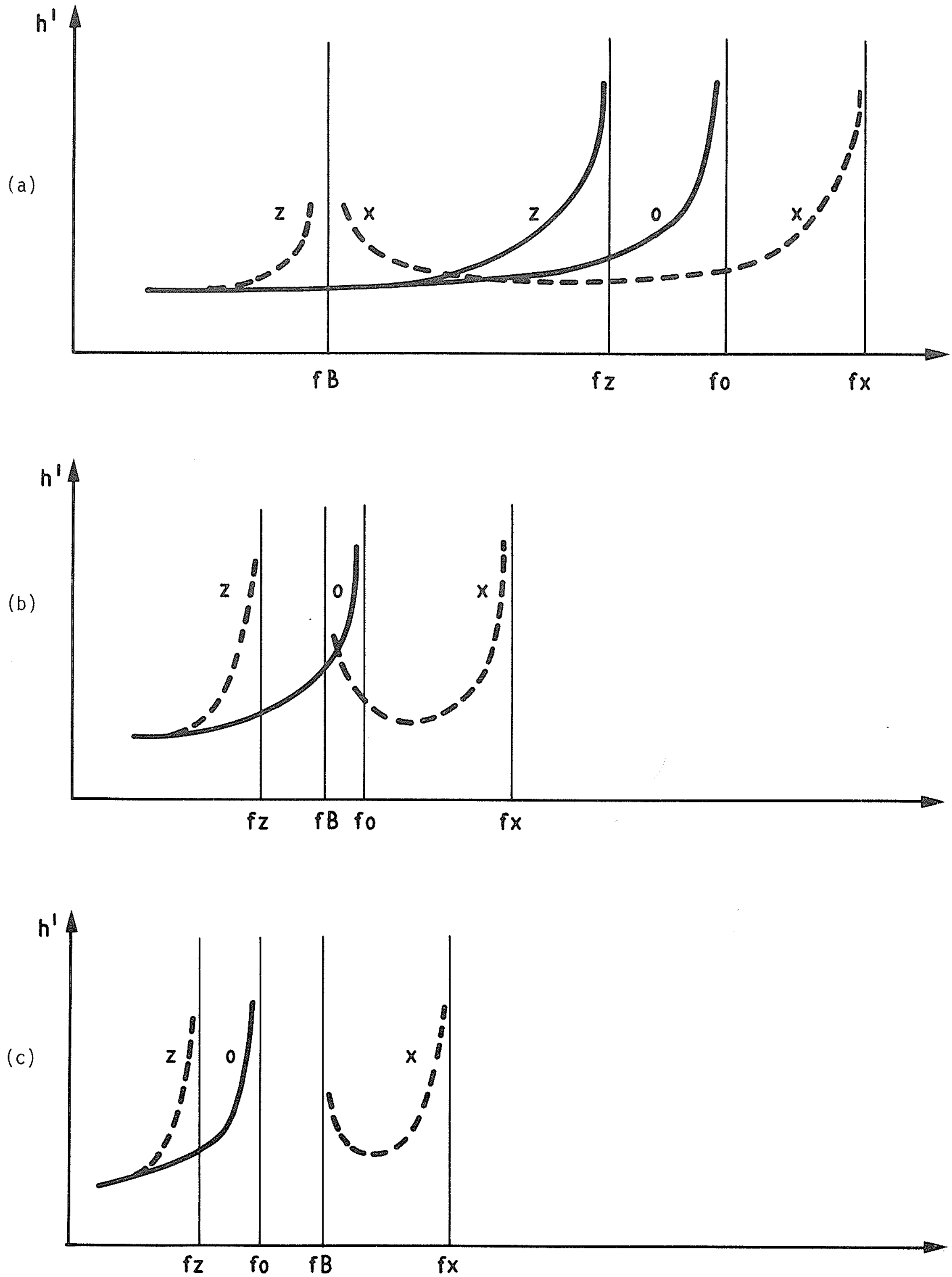

Fig. 1.4 Pattern of o- x- and z-mode traces as to changes
(a) fo>>fB. (b) fo = fB. (c) fo<fB.

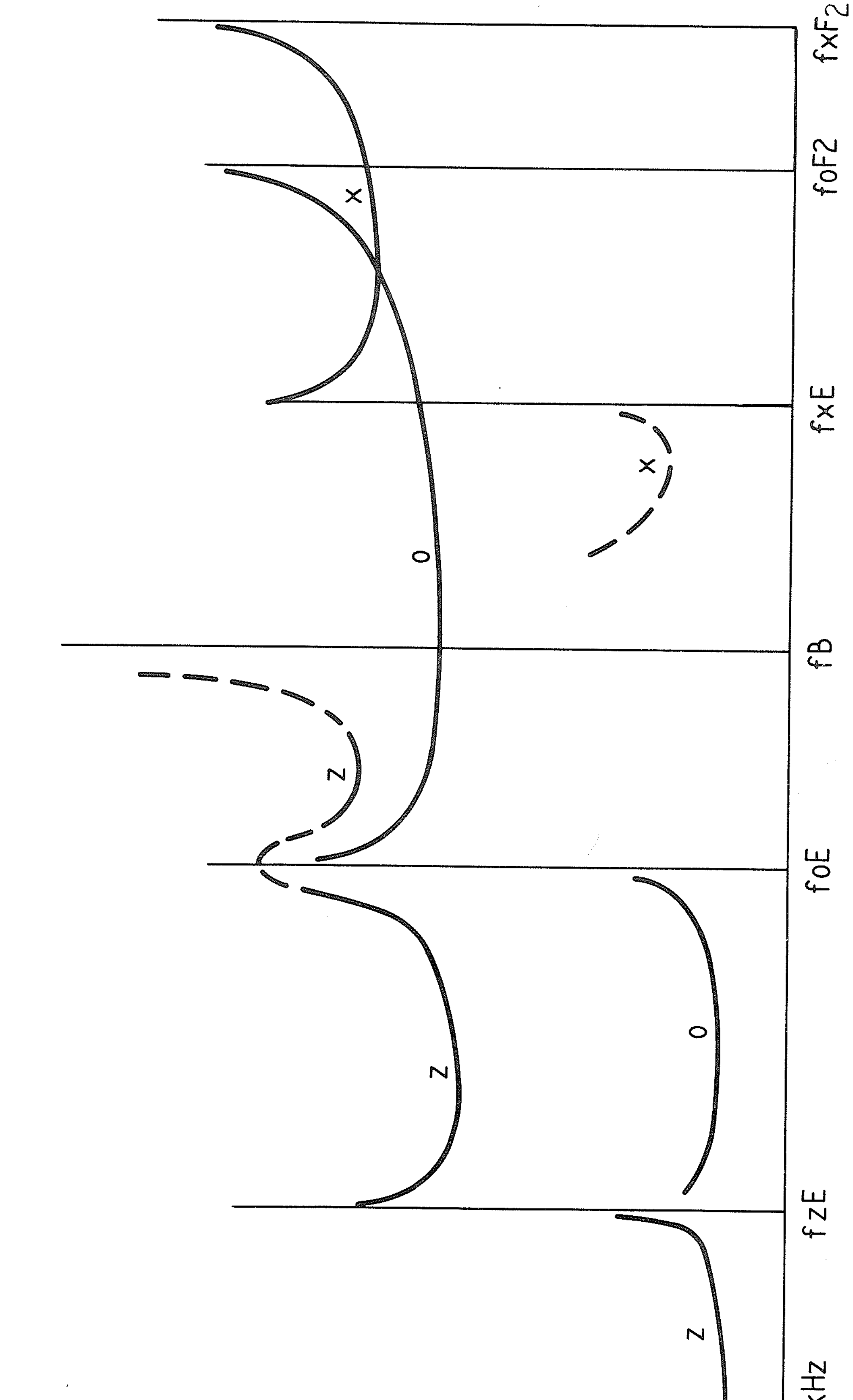

Fig. 1.5 Low frequency ionogram at night normal E and F traces. No Es.
Parts which are usually not seen shown dashed.

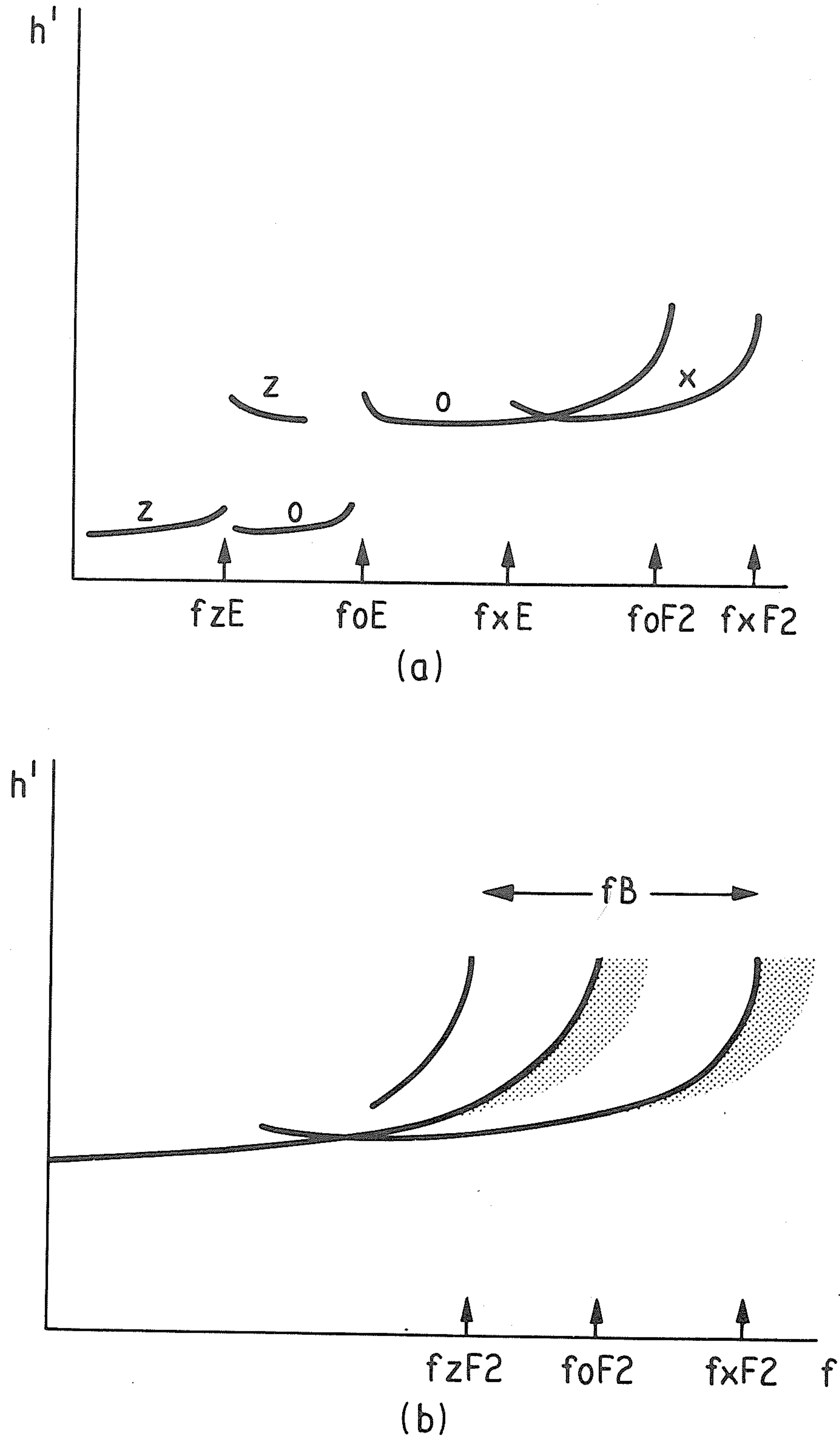

Fig. 1.6 z mode
(a) due to coupling
(b) due to scattering
(Note z trace is not scattered in (b)).

When there is scattering present some energy is reflected along the line of force and reflected n the z mode. The z-mode echo then increases in strength with the amount of scattering present until energy is scattered out of it faster than into it. This type of z-mode reflection is thus confined to periods of medium scatter.

1.06. Most ionograms contain an immense amount of information about the conditions in the ionosphere, but this is in a form which is prohibitively inefficient for many important investigations. It is, therefore, necessary to select certain features of the ionogram which are particularly significant for scientific or operational studies and to develop techniques for evaluating their characteristics. This process is called 'scaling the ionogram'. Clearly there are two main steps in the scaling process: the selection of significant parameters and the formation of rules for recognizing and measuring the significant parameters.

Usually it is sufficient to assume that the ionosphere is concentric with the earth and simple scaling is based on this assumption. The ionograms can often show when this assumption is not true and advanced scaling enables significant parameters to be deduced in these cases. This is more fully explained in sections 2.70 - 2.73.

1.07. The selection of particular parameters as significant is determined by their value for further study. The main parameters are based on the features of the relatively simple ionograms often obtained at temperate latitudes. This has produced a number of simple, pictorial concepts - the critical frequency, the minimum virtual height, the top frequency of an Es trace* shown in idealized form in Figs. 1.7, 1.8 and on an ionogram in Fig. 1.9.

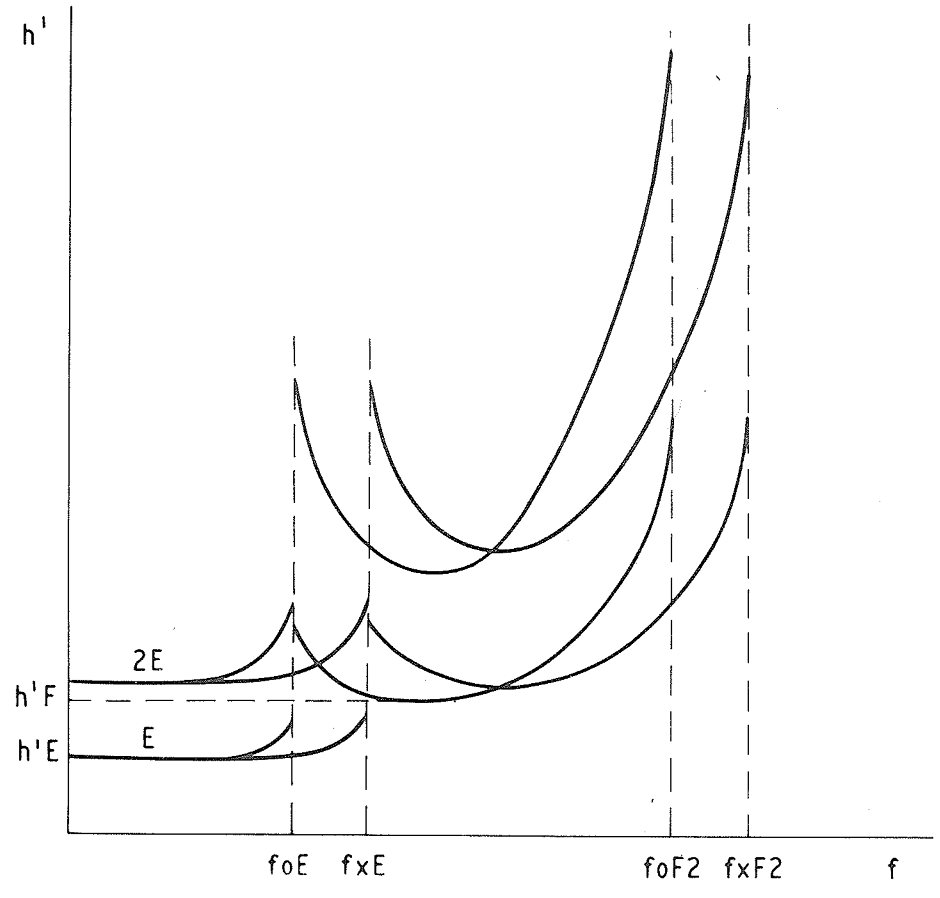

Fig. 1.7 Idealized ionogram when two layers are present.

* These have been generalized by Rawer et al., J. Atmo. Terr. Phys., 1955, 6, 69-87

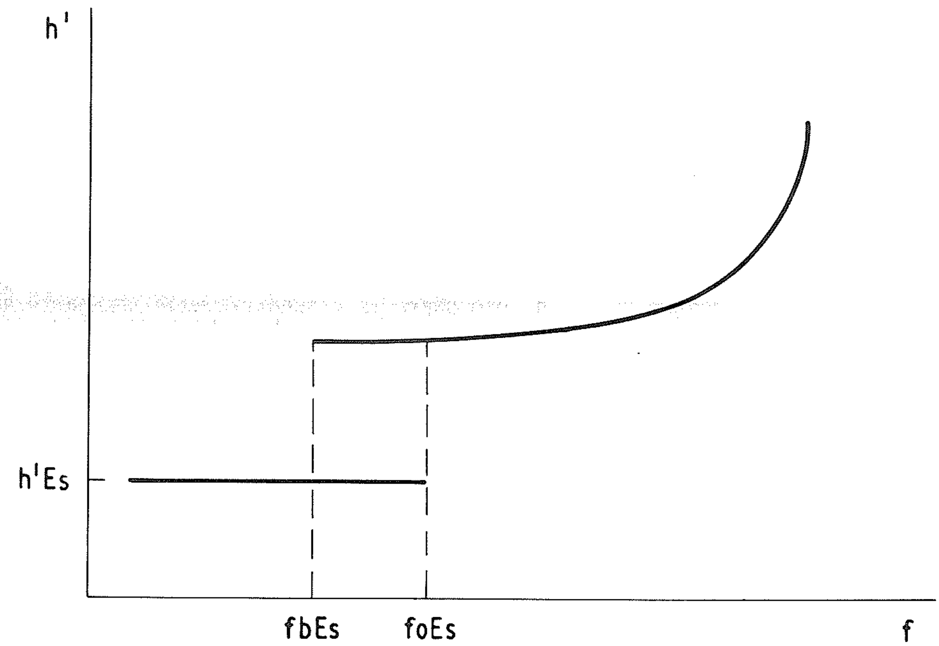

Fig. 1.8 Idealized ordinary ray pattern when a thin layer is present. Note that the quantity corresponding to the critical frequency of a thick layer always lies between foEs and fbEs.

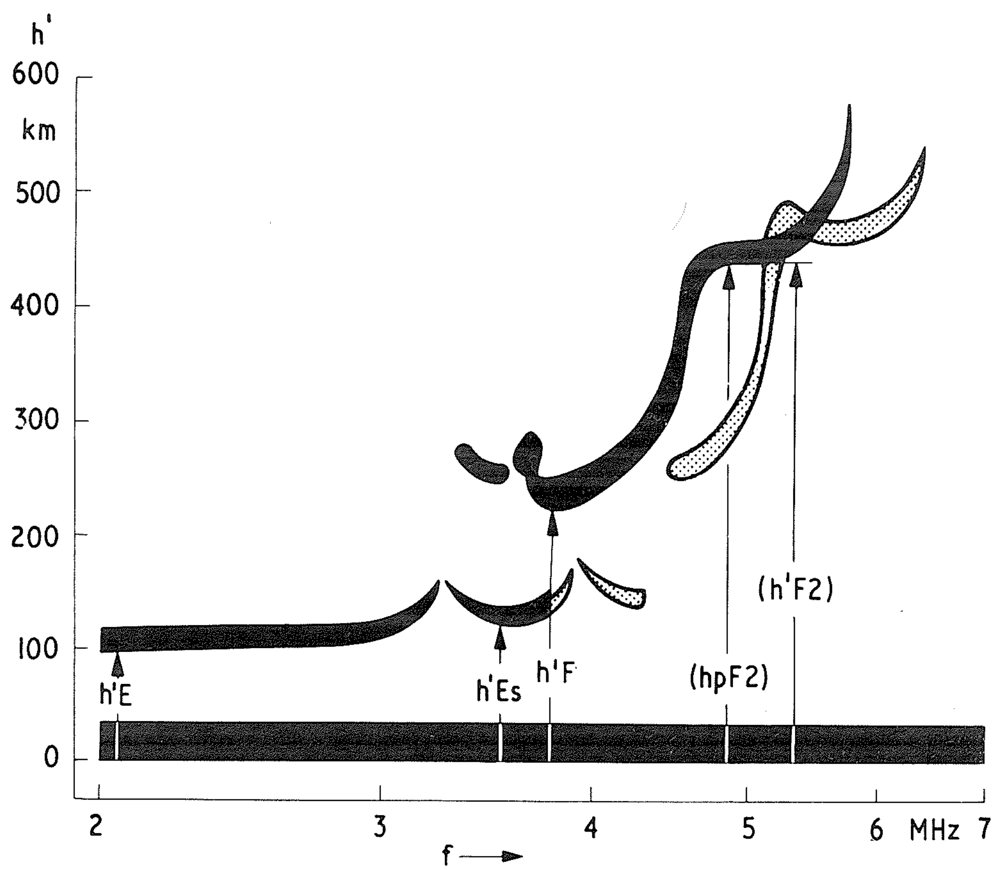

Fig. 1.9 Typical day time ionogram with minimum virtual heights h'E, h'Es, h'F, h'F2, and the "parabolic height" h_pF2. These are all read from the o trace (black).

The following definitions, selection rules and measurement conventions can be applied to any magneto-ionic component:

(a) Top frequency of a layer: The highest frequency at which an echo trace is obtained from the layer at vertical incidence (weak discontinuous traces are ignored).

(b) Blanketing frequency of a layer: The lowest frequency at which the layer begins to become transparent. This is usually identified by the appearance of echoes from a layer at greater heights.

(c) Critical frequency of a layer: The highest frequency at which the layer reflects and transmits equally. The definition shows that the critical frequency of a layer always lies between its top frequency and its blanketing frequency.

In the most common case of a horizontal thick layer, all three characteristic frequencies are identical, and are made clearly visible by the retardation at the critical frequency. In the case of a thin layer, the top and blanketing frequencies can be different. The critical frequency can, in principle, be determined from the amplitudes of the different echoes. As this is impracticable at most stations, both the top and blanketing frequency should be scaled for a thin layer. This concept determines the rules for scaling Es traces.

(d) Minimum virtual height is the height at which the trace is horizontal. For a thick layer this can only occur if there is a lower thick layer causing group retardation which balances the change of virtual height with frequency due to the reflecting layer. In all these cases the observed minimum virtual height is above the true height. By convention, if the change of virtual height with frequency is not detectable at the lowest frequencies reflected by the layer the observed value is considered to be exact (Figs. 1.4, 1.6, 1.7).

(e) Maximum Usable Frequency (MUF): This is a propagation concept which is defined as the highest frequency for ionospheric transmission over an oblique path, for a given system performance. To prevent confusion, the following definitions have been adopted by CCIR*.

(i) Operational MUF is the highest frequency that permits acceptable operation between given points at a given time, and under specified working conditions.

(ii) Classical MUF is the highest frequency that can be propagated by a particular mode between specified terminals by ionospheric refraction alone; it can be experimentally determined as the frequency at which the high- and low-angle rays merge into a single ray.

(iii) Standard MUF is an approximation to the classical MUF, that is obtained by application of the conventional transmission curve (section 1.5) to vertical-incidence ionograms, together with the use of a distance factor.

Note: Note that the classical MUF and standard MUF are to be applied only to propagation involving the regular layers.

The Operational MUF may exceed the Classical MUF when ionospheric or ground scatter is present. The Operational MUF may, therefore, vary with transmitted power and receiver sensitivity whereas the Classical and Standard MUF are determined by the geometry of the mode of propagation. All MUF values refer to a given distance and this should always be stated. These definitions apply to the individual measurements of MUF. Where median or mean MUF is intended the qualifying words 'median' or 'mean' must be included.

1.08. Standard MUF(3000) as a vertical incidence parameter.

In principle it should be possible to calculate the Standard MUF corresponding to a given ionospheric trace but the numerical value depends slightly on the exact method of calculation used. In 1953 the WWSC adopted the standard transmission curve due to N. Smith, noting that the other current methods gave essentially the same results. The procedure described in section 1.5, is really a graphical analysis to find the apparent height of the maximum electron density of the layer. This exceeds the real height by an amount dependent on the retardation at lower heights. The maximum usable frequency determined in this way depends on the shape of the electron density profile and is mainly determined by the real height of maximum electron density and the critical frequency of the layer. The standard distance, 3000 km, is fixed by convention. It should be noted that the MUF factor can have geophysical as well as practical applications through its close association with the height of maximum density.

* New Delhi, 1970 C.C.I.R., Rec 373-2, Vol. II part 2, p. 45-46, published by I.T.U. Geneva, 1971.

While, in the past the main importance of the MUF factor has been for propagation applications, its ease of measurement and close connection at any station with the height of maximum ionization of the reflecting layer makes it an important parameter for studying geophysical phenomena. Care must be taken when there is much retardation in the lower parts of the ionosphere since then the apparent height of maximum deduced from the factor can be much higher than the real height. The following semi-empirical relations have been established between the standard MUF factor, M(3000)F2, and the apparent maximum height of the F2 layer, e.g. as deduced by the parameter hpF2 (section 1.4 below)

CCIR* hpF2 = -176 + 1490/M(3000) (1.9)

40°N-40°S** hpF2 = -225 + 1650/M(3000) (1.10)

The CCIR relation is widely used. Unfortunately it often gives too high a value for the height of maximum of the F2 layer particularly in summer periods. This is mainly due to the effects of retardation below the F2 layer. The formula should not be used at high latitudes.

The relation between hpF2, deduced from M(3000)F2 equation (1.9), and some measured values of hM, deduced by a full electron density analysis, is shown in Fig. 1.10. Measured values of M(3000)F2 and hM are plotted as points.***

1.09. For the purposes of evaluating oblique incidence ionograms, URSI recommends the term Junction Frequency (JF) for the Classical MUF, and the term Estimated Junction Frequency (EJF) for the Standard MUF which is, however, widened to include other methods of estimation. These distinctions are not important in vertical incidence analysis where all measurements refer to the Standard MUF as defined by C.C.I.R.

Maximum Observed Frequency (MOF), is the highest frequency that can be detected on an oblique-incidence ionogram.

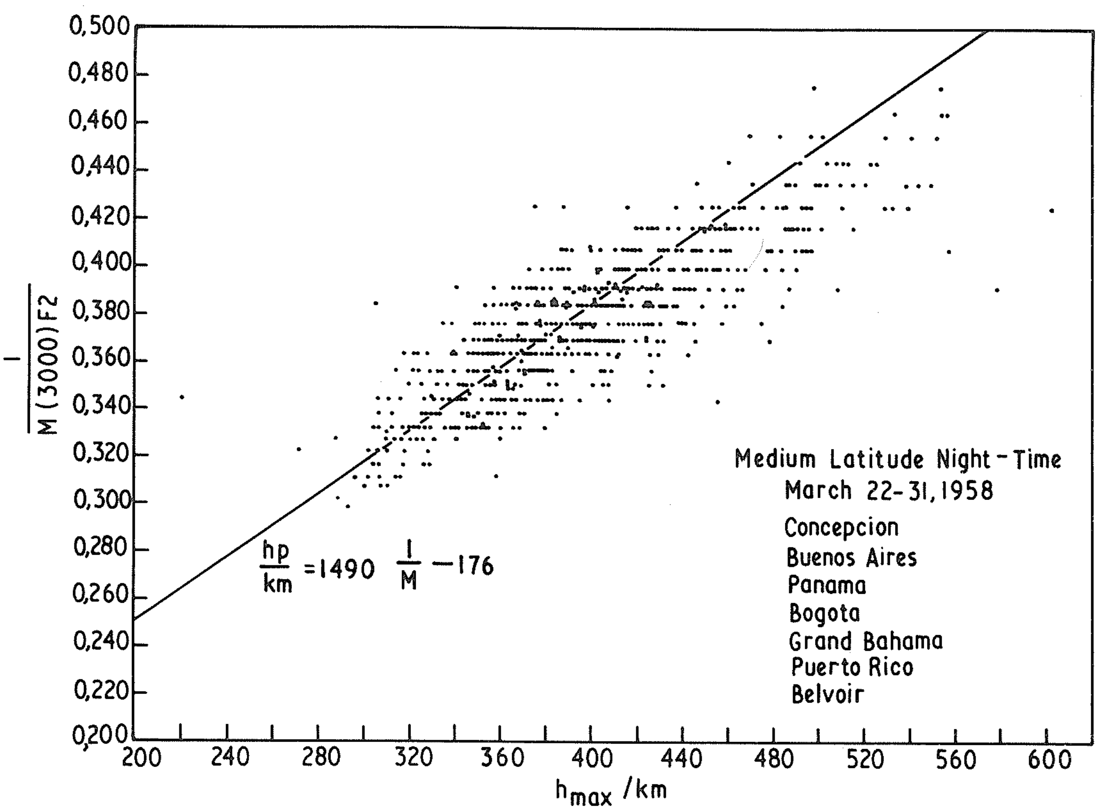

Fig. 1.10 Correlation between 1/M(3000)F2 and hM for night hours, medium latitude.

* Shimazaki, T., J. Radio Res. Lab., Japan 2, 85-97, 1955
** Lyon, A. J. and Thomas, L., J. Atmos. Terr. Phys., 25, 373-386, 1963
*** Wright, J. W. and McDuffie, R. E., J. Radio Res. Lab., Japan 7, 409-420, 1960

1.1 Conventions for Identifying Critical and Characteristic Frequencies

1.10. The main reflecting layers vary in height with time, and near sunrise and sunset, when the solar Zenith angle is near 90°, traces due to normal E can be found at remarkably large heights. Apart from these times a useful general guide is that F-layer traces are mainly found above 200 km, or are continuous with traces above this height, whereas E-layer traces are found below 180 km, usually nearer 100 to 130 km.

With the exception of fxI (section 1.22), international frequency parameters are defined by the ordinary wave component (Fig. 1.11). For each characteristic, there is a corresponding extraordinary wave frequency defined in the same way but with ordinary wave replaced by extraordinary wave in the definition.

1.11. foF2: The ordinary wave critical frequency of the highest stratification in the F region is to be called the F2 critical frequency, foF2. This convention applies when ambiguities are caused by the presence of F1.5 or other stratifications but not in the case where foF2 is known to be below foF1. Particular care is necessary at high-latitude stations where foF2 can be less than foF1 for long periods.

1.12. foF1.5: The ordinary wave critical frequency of the intermediate stratification between F1 and F2 that is often observed at certain middle and low latitude stations (used for local or regional studies).

1.13. foF1: The ordinary wave F1 critical frequency at low and high latitudes is to be identified by the conditions of continuity with F1 at temperate latitudes. At temperate latitudes this is usually mostly present in summer months, though the incidence varies with solar cycle. At low latitudes the general structure of the F layer is more complicated and it is often impossible to identify any regular layer continuous with the temperate latitude F1 layer. In this case no attempt to tabulate foF1 should be made. The ratio foF1/foE for a given station is usually remarkably constant, though it varies slightly with position. This can be used as a guide when the interpretation is doubtful.

1.14. foE: The ordinary wave critical frequency corresponding to the lowest thick layer stratification in the E region which causes a discontinuity in the height of the E trace. In the absence of blanketing low-type Es, the trace giving foE must be continuous in height with the whole E trace, otherwise it is E2. When the identification of the appropriate discontinuity is doubtful the critical frequency which is most nearly continuous with that found from the sequence of ionograms or at the corresponding time on other days, is adopted as the normal E-layer critical frequency. Particular care is necessary when an E2 trace may be present and the E trace is not visible because of blanketing (A)*, absorption (B), or because the true value of foE is below the lower limit of the ionosonde (E). In the presence of blanketing Es of the cusp type (section 4.83) the E trace may need to be extrapolated (section 4.24) in order to obtain the critical frequency.

1.15. Night E: The ionogram pattern corresponding to night E is very similar to that for normal E. The difference is that the critical frequency is significantly larger than would be expected for normal E at the time involved and varies rapidly with time. Night E is often preceded or followed by retardation type Es or auroral type Es and is due to particle bombardment causing excess ionization in the E region. Thus at night when foE for normal E is between 300 kHz and 500 kHz, night E often shows values of foE between 1 MHz and 5 MHz. When night E is present, as shown by group retardation in the E or higher traces, the critical frequency of this layer is included in the foE tabulation. Normal E is not seen in these conditions.

1.16. foE2: The critical frequency of an occulting thick layer which sometimes appears between the normal E and F1 layers. When the critical frequency shows a discontinuity (e.g. a true cusp) with the F trace it is tabulated as foE2, when the trace shows a maximum but no cusp tabulate as foF0.5 (Fig. 1.12). Since this is always transitory, the value of h'F (section 1.32) is not representative and is made doubtful. The characteristics foF0.5, foE2 are only reduced for local or regional studies and more restrictive conventions are allowable, if desired, for these purposes.

1.17. foEs: The ordinary wave top frequency corresponding to the highest frequency at which a mainly continuous Es trace is observed. It follows from the definition that foEs to some extent depends on the characteristics of the ionosonde (see detailed instructions in Chapter 4).

* For explanation of letter symbols see Chapter 3.

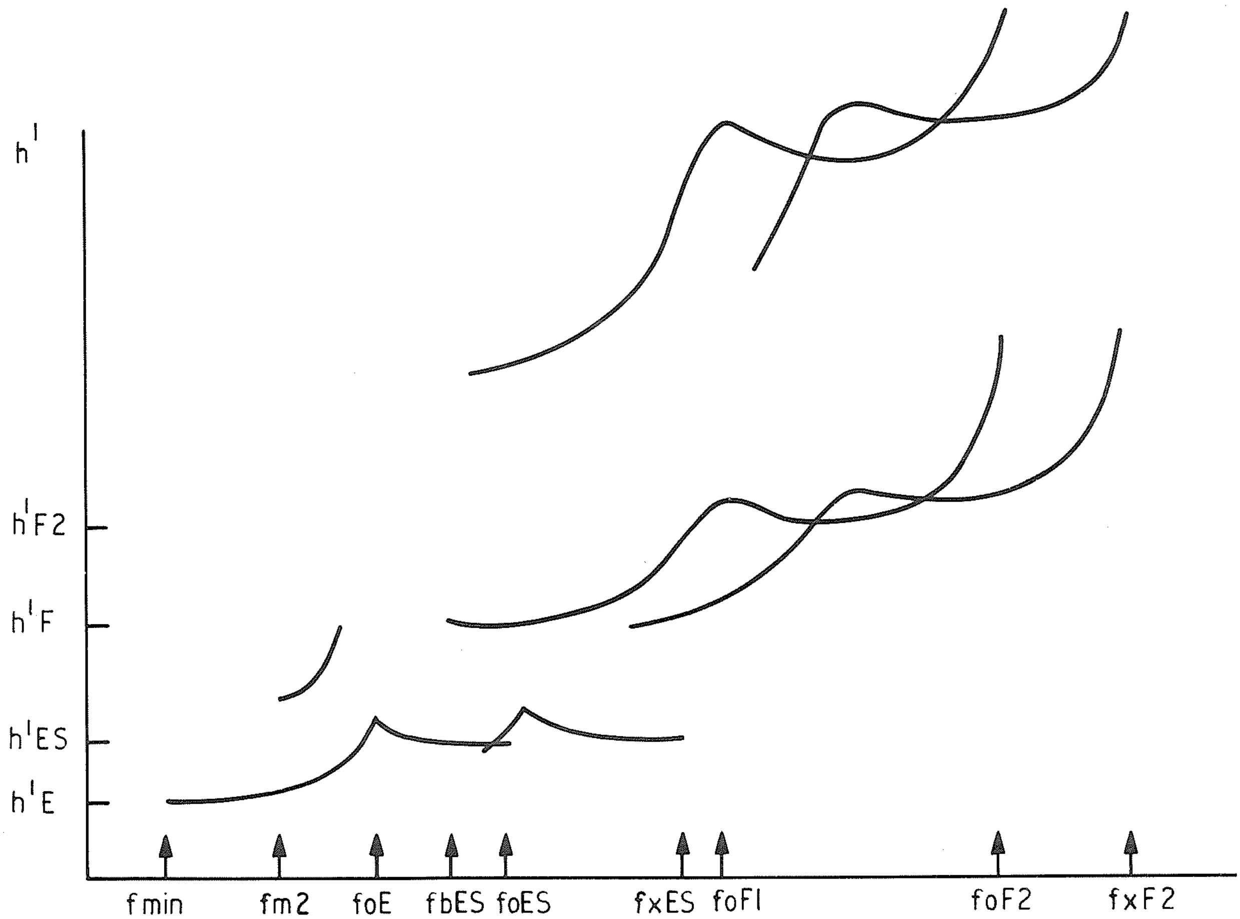

Fig. 1.11 Standard height and frequency parameters.

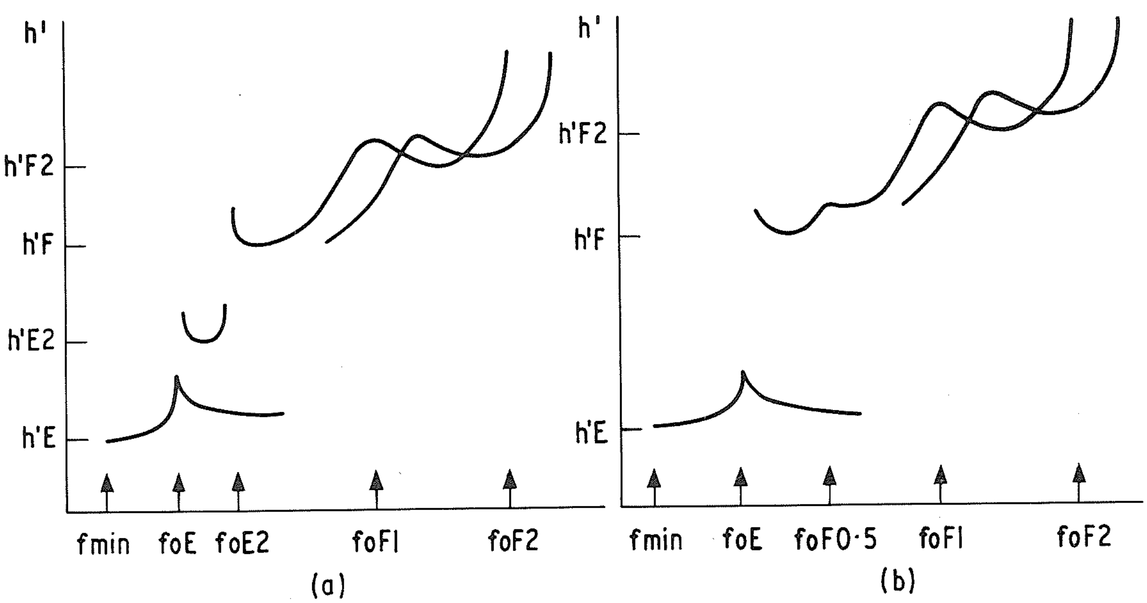

Fig. 1.12 Distinction between E2 and F0.5. In (b) h'F should be written (h'F)ÜH

1.18. fbEs: The blanketing frequency of an Es layer, i.e. the lowest ordinary wave frequency at which the Es layer begins to become transparent. This is usually determined from the minimum frequency at which ordinary wave reflections of the first order are observed from a layer at greater heights (see detailed instructions in Chapter 4).

1.19. fmin: The lowest frequency at which echo traces are observed on the ionogram. Logically fmin should always refer to the o-mode trace. In practice, however, the distinction between o-mode and z-mode is often difficult to make accurately. The gain in information is small since fmin for the o-mode is not usually determined by absorption in these cases. Cases where there is evidence that fmin is given by a z-mode trace should be described by letter Z.* The convention is that oblique or multiple order traces are ignored and also any very weak reflections from the D region (see detailed instructions in Chapter 2).

With some high sensitivity types of ionosonde fmin seldom shows changes of absorption except during very large events. For such equipments, fmin is not tabulated separately, but tables of fmin are replaced by tables of fm2, the minimum frequency of the second order ordinary wave trace (see section 1.24). The actual values of fmin must always be entered in all tables where the entry is qualified EB. (see also Chapter 13).

1.2 New Parameters

1.20. The URSI/STP Committee at Ottawa September 1969 approved and recommended the use of certain new ionogram parameters not used in previous years. The definitions are given here and the detailed rules for evaluating and tabulating them are collected in Chapter 3. For completeness the definitions of certain parameters used mainly for local or regional studies are also included in this section.

1.21. Spread F index, fxI: The URSI/STP Committee**, noting that a measure of the top frequency of spread F is urgently required for CCIR purposes and also has scientific interest, and that a proposal to introduce such an index has been widely supported by those responsible for stations, recommends that a new ionospheric parameter denoted fxI (with computer symbol 51) be adopted for international analysis, tabulation and normal circulation through WDCs and other publication methods, defined and applied according to the instructions following. It is recommended that all stations at high latitudes or subject to equatorial spread F tabulate and circulate this parameter, and that stations at other latitudes be invited to volunteer to analyze the parameter as a trial. Tests are particularly important at stations where the spread of frequencies of spread F often exceeds fB/2 at certain hours. It is very important to measure fxI at stations where spread F causes the foF2 count to be small at certain hours.

The parameter fxI is defined as the highest frequency on which reflections from the F region are recorded independent of whether they are reflected overhead or at oblique incidence. Thus, fxI is the top frequency of spread F traces including polar or equatorial spurs, but not including ground back scatter traces. Since this parameter can be gain sensitive it should always be measured using the normal gain ionogram. Special care is needed when foI (foI = fxI - fB/2) is near or below fB since absorption can then hide fxI. Detailed rules are given in section 3.3.

1.22. Frequency spread dfS: For scientific work, the frequency spread of the scatter pattern has been measured at a number of stations and is recognized as an international parameter for interchange on a voluntary basis. The symbol dfS is adopted for this. There are as yet no recognized international conventions for this parameter (see section 7.34).

dfS: The parameter dfS is provisionally defined as the total width in frequency of frequency spread traces for the F layer. The lower boundary is defined by the z or o mode, the upper by the x mode. Since dfS is particularly useful for regional studies agreement should be sought with collaborating institutes. If and when international conventions are agreed, these will be published in the URSI and INAG Information Bulletins.

1.23. fmI: The lowest frequency at which frequency spread traces are observed for the F layer. This is often equal to foF2.

1.24. Monitoring of absorption by ionosondes: The variation of absorption with position and time appears to be more complicated than can be adequately monitored by existing absorption stations. The URSI/STP has therefore adopted a new additional parameter, fm2.

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* For explanation of letter symbols see Chapter 3.
** URSI Bulletin No. 169 December 1968 p. 56.

Definition: fm2 is defined as the minimum frequency of the second order trace. Since the absorption loss in dB is twice as great for the second order trace as for the first, fm2 is more sensitive to absorption changes and less to equipment design than is fmin. It can only be used when two traces are usually available and is not valuable when fm2 = foE.

The following actions will give an improved measure of absorption for synoptic purposes and should be adopted, as appropriate:

(a) At stations where fmin is mainly determined by absorption, at least when it is appreciable, the operation of the ionosonde should be such as to make the fmin values consistent. In particular in any month, diurnal gain changes should be made at fixed times of day only and the gain at fixed time be kept as constant as possible. Where possible the times and gain changes in dB should be recorded and circulated with the fmin data.

At stations where the fmin for the second order trace, fm2, is mainly determined by absorption, measurements of fm2 will usually show absorption changes more accurately than fmin and be less sensitive to interference and equipment characteristics.

(b) At high sensitivity stations where fmin is not usually a measure of absorption, fm2 should be reduced and circulated instead of or in addition to fmin. Note in this case, the appropriate value of fmin should always be shown in tables of other parameters when the parameter is below fmin. e.g., . . . EB; . . . ES cases. (Chapter 3). The substitution of fm2 for fmin at stations in group (a) is preferred when local experience shows that this gives a better description of absorption changes.

1.25. fm3: The parameter fm3 is defined as the lowest frequency for the third order reflection (used only for local or regional studies). The measurement of absorption is more fully described in Chapter 12.

1.26. foI is the o-mode characteristic corresponding to the x-mode characteristic, fxI, (not in use at present except in explanations).

1.3 Conventions for Identifying and Scaling Virtual Heights

1.30. The minimum virtual height of reflection can only be determined at a point where the trace is essentially horizontal. In general, minimum virtual heights should only be scaled when this condition is met within the accuracy rules, section 2.2. See use of E Chapter 3.

1.31. In certain cases useful information can be obtained even when the trace is not horizontal. These occur when the trace is blanketed by a lower layer or is still falling at the lowest frequency of the ionogram. In these cases the minimum height observed should be qualified by E and interpreted 'minimum virtual height less than ...'.

Note that when the trace shows an inflection point with a horizontal tangent h'F2 can be determined; if it shows an inflection point without a horizontal tangent, no measurement is possible and the symbol L alone is used. Transient stratifications are to be disregarded in routine scaling, except that their presence is indicated by the descriptive letters H or V.

1.32. h'F: The minimum virtual height of the ordinary wave F trace taken as a whole.

1.33. h'F2: The minimum virtual height of the ordinary wave trace for the highest stable stratification in the F region.

1.34. h'E: The minimum virtual height of the normal E layer taken as a whole.

1.35. h'Es: The minimum height of the trace used to give the foEs data.

1.36. h'E2: The minimum virtual height of the ordinary wave E2-layer trace (used for local or regional studies only).

1.37. h'I: The minimum virtual slant range of the traces which determine fxI (in use on a voluntary basis).

1.38. h'F1.5: The minimum virtual height of the ordinary wave trace between foF1 and fo1.5 (used for local or regional studies only).

1.39. h'Ox: The virtual height of the x trace at foF2 (used for local or regional studies only).

1.4 Conventions for Determining Other Height Parameters

1.40. Certain indirect measures of the height of the maximum density of the F layer are in use and their definitions are given below. Note that these are not exact, the value obtained depends on the technique used and the parameter should only be tabulated using the international symbol if the international rules have been adopted.

1.41. hpF2: The virtual height of the ordinary wave mode at the frequency given by 0.834 foF2. For a single parabolic layer with no underlying ionization this is equal to the actual height of the maximum of the layer. In practice this is usually higher than the true height of maximum. At stations at low dip latitudes, or when foF2 is less than about 1.3 foF1, hpF2 is highly misleading. For this reason it is not recommended for general use. (Wright, J. W. and McDuffie, R. E., J. Radio Res. Lab., Japan, 7 409-420, 1960.)

1.42. hc: The height of the maximum obtained by fitting a theoretical h'f curve for the parabola of best fit to the observed ordinary wave trace near foF2 and correcting for underlying ionization (See Chapter 10, section 10.33, 10.4).

1.43. hmF2: The height of maximum obtained by fitting a theoretical h'f curve for the parabola of best fit to the observed ordinary wave trace near foF2 without correcting for underlying ionization. Note for hc and hmF2 the curve fit is made for frequencies greater than 0.9 times the critical frequency.

1.44. Values of the height of maximum deduced using full computer methods applied to both o-and x-mode traces are usually denoted hmaxF2 or h(Nm).

1.5 Conventions for Determining MUF Factors

1.50. MUF factors were originally introduced as conversion factors for oblique propagation computations. The Maximum Usable Frequency corresponding to a certain distance can be estimated by multiplying the critical frequency of the layer under consideration by the corresponding MUF factor. This definition corresponds to a rather simplified propagation model and it is now known that this Standard MUF is not necessarily identical with the Operational MUF of a radio circuit. Nevertheless, MUF factors are extremely useful as a basic parameter for practical predictions.

The standard transmission curve gives the ratio of the equivalent vertical and 3000 km oblique incidence frequencies which are reflected from a given virtual height assuming a standard simplified propagation model. Where 3000 km is adopted as a convenient conventional distance, the procedure provides a simple graphical solution of the calculation of the standard MUF (3000) and also of the corresponding MUF factor which is defined by

$$M(3000) = \frac{MUF(3000)}{fo}$$

where fo is the ordinary wave critical frequency.

The shape of the transmission curve is defined by the ratio at each virtual height given in the table below.

Virtual height (km)	200	250	300	350	400	500	600	700	800
Ratio	.220	.247	.274	.300	.325	.372	.417	.455	.490
MUF factor	4.55	4.05	3.65	3.33	3.08	2.69	2.40	2.20	2.04

If the ionogram has a logarithmic frequency scale, the standard transmission curve is made in the form of a transparent slider (Fig. 1.13). The abscissa scale of the slider is expressed as the MUF factor given above using the same scale units as the frequency scale of the ionogram but in opposite sense. When this curve is moved along the frequency axis until it just touches the ordinary ray trace (the height scales agreeing at the tangent point) the abscissa value given on the slider at the critical frequency of the layer is the factor M(3000) for this layer (Fig. 1.14). If the ionogram has a frequency scale other than logarithmic a set of standard MUF curves is prepared from the standard transmission curve, each curve corresponding to a certain MUF value (Fig. 1.14). The curve which just touches the trace gives the MUF; the M(3000) is obtained by division by the critical frequency of the corresponding layer.

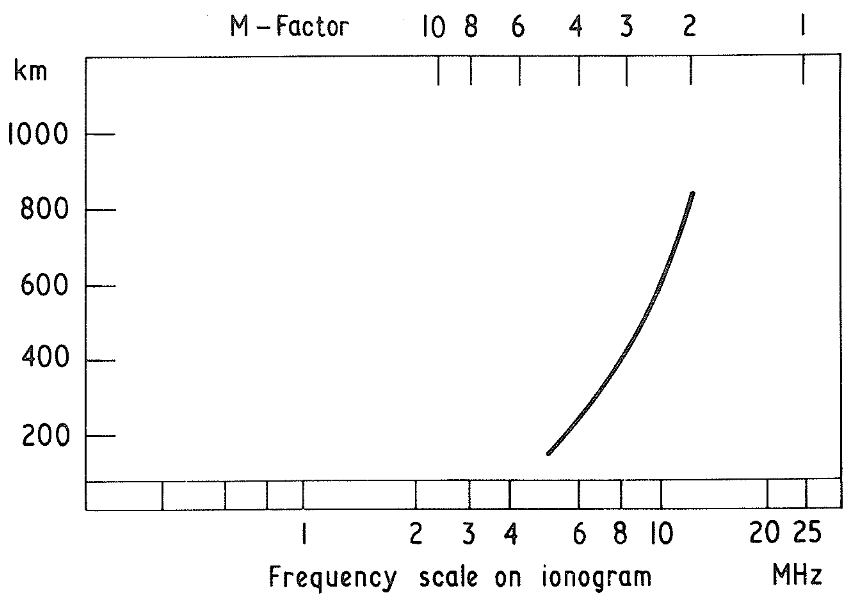


Fig. 1.13 MUF factor slider.

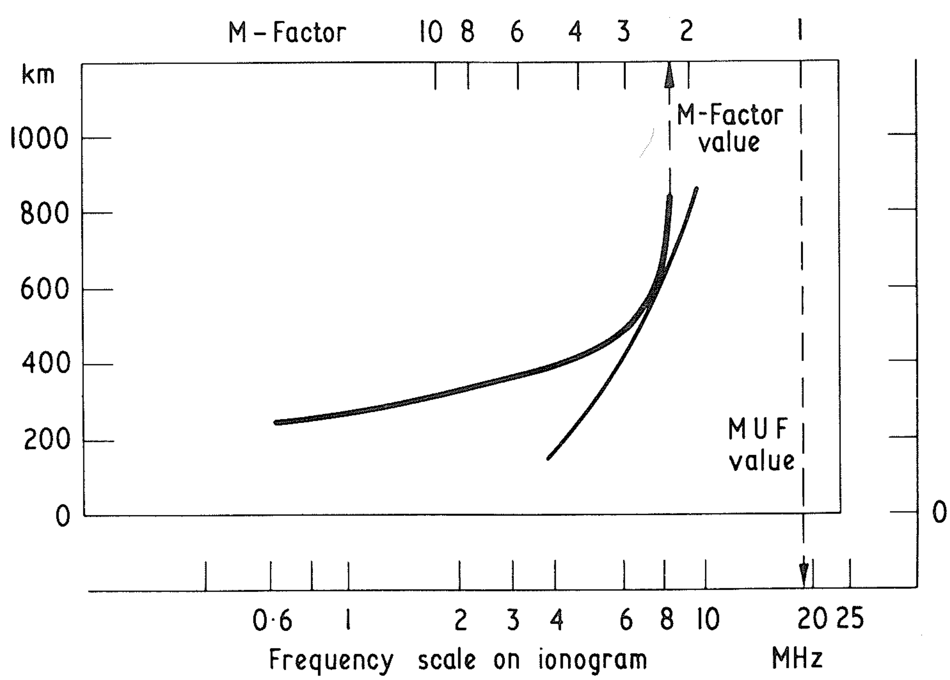


Fig. 1.14 Use of MUF factor slider.

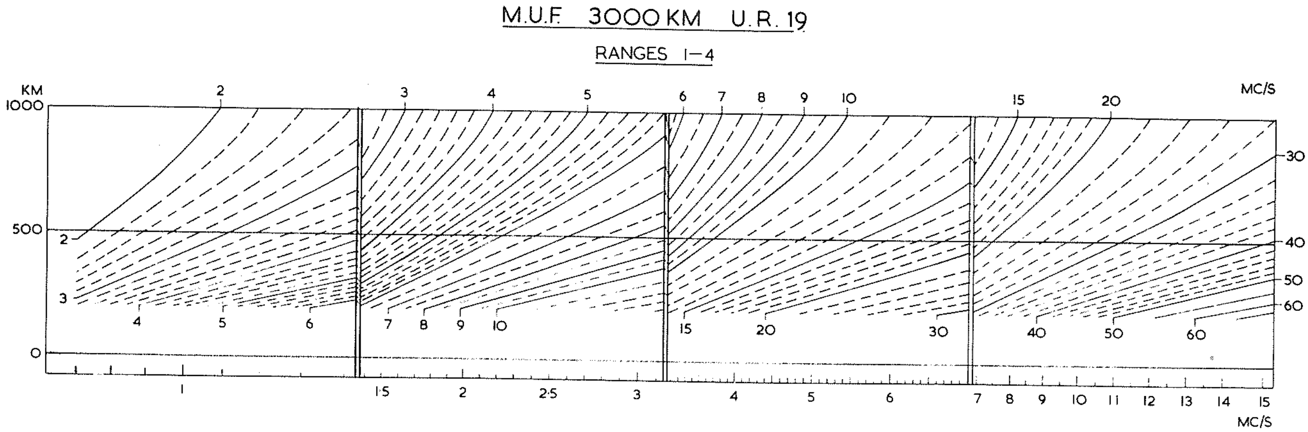


Fig. 1.15 Typical overlay for finding MUF's and MUF factors for ionograms with non-logarithmic frequency scales.

1.6 Characteristics to be Scaled

1.61. Monitoring the ionosphere demands that foF2, M(3000)F2 and a reasonably significant value for foEs, or parameters which can be converted into these, must be available from all stations. These are widely recognized as important parameters for scientific research also. The parameters fmin and fm2, where fmin is not significant, are also particularly significant both as an index of the behaviour of the ionosonde and as an index of important changes in absorption. (See Chapter 12).

The four parameters, foF2, M(3000)F2, foEs and fmin are, therefore, the most important parameters and should be circulated by all stations in the form of monthly tables of hourly values arranged so as to be convenient for manual or machine manipulation.

1.62. There is general agreement that the important parameters for world-wide reduction and circulation are at present:

(a) Frequencies: fxI, foF2, foF1, foE, foEs, fbEs, fmin or fm2
(b) Minimum virtual heights: h'F2, h'F, h'E, h'Es
(c) MUF factors: M(3000)F2, M(3000)F1 or the equivalent MUF(3000)F2 and MUF(3000)F1
(d) Es types: (see Chapter 4)

1.63. At many stations particular phenomena, which are not included in the world list of parameters, are important for local or regional research. Some typical characteristics of this type are given in Chapter 12. It is advantageous for these parameters to be reduced in a uniform manner in a given region and regional 'house-rules' are encouraged.

1.64. The f plot (see Chapter 6) is not only an efficient method of summarizing the data obtained on individual ionograms but is also an essential tool for those types of world-wide and regional studies in which the actual day-to-day variations in ionospheric phenomena are compared. f plots may be replaced by characteristic recordings (section 11.3) where these are available.

1.7 Soundings Schedules

The minimum useful schedule of routine soundings and reduction programs needed for scientific research and ionospheric prediction purposes is kept continuously under review as it changes with the development of the subject (see section 9.1 for details). Future recommendations will be found in the INAG Information Bulletins circulated to all known stations.

The minimum useful schedule of routine soundings is one sounding per hour taken so that the frequency 3 MHz occurs as near as possible to the hour for the nearest 15° meridian time, i.e. at U.T. ± x hours with x an integer. The adopted meridian should always be shown. The data may be expressed in U.T. with this also shown. The preferred schedule is quarter-hourly sounding, and this is the minimum which is useful at high latitudes or where layer tilt is common.

The minimum useful circulation of parameters is the four principal parameters given in section 1.61 above or their equivalent if notified internationally (e.g. fm2 instead of fmin, fbEs could be alternative for foEs). Almost all stations circulate the standard parameters, section 1.62.

An International World Day Calendar is published yearly by the IUWDS and reproduced in the URSI Information Bulletin, INAG Bulletin, STP Notes and elsewhere. This gives the dates when special efforts should be made to obtain more complete monitoring of the Ionosphere, e.g. by replacing an hourly schedule by a quarter-hourly, quarter-hourly by shorter intervals. Events occurring on dates given in the Calendar are given preference for detailed world-wide study. There is also an International network for circulating alerts for special events which is operated by the International Ursigram and World Days Service through its Regional Warning Centers. Stations are encouraged to collaborate by taking special measurements in some or all of these programs.

1.8 Station Operations

Instructions for routine maintenance vary with the type of ionosonde in use and should be obtained from the manufacturers or organizations providing the ionosonde. It is valuable to keep a reference note book containing notes on voltages currents and waveforms as shown by the local test gear which will be used. It is essential that all circuit changes are noted. In practice changes of staff usually occur suddenly and do not allow proper teaching on the peculiarities of the ionosonde. The best indication of proper operation is the ionogram and a set of reference ionograms should be made to show typical day, night, summer and winter conditions. It is also valuable to have a reference set showing effects of changes of gain and of particular operating faults. It is easy to 'cure' a fault by modifying a circuit which is operating correctly so that it compensates for the faulty (undiagnosed) circuit. When this has happened several faults may occur simultaneously giving difficult diagnosis.

A full set of performance checks should be made at regular intervals and after any major adjustment, and the results recorded so that the standard operating conditions can be reestablished after any fault. Gain changes should be made on the first day of the month and recorded. It is advisable to examine the previous year's data so that the optimum changes are made. This is particularly important near the equinoxes when conditions change rapidly in time and there may have been several months in which only small gain changes were necessary.

Review each month's data and note whether the gain in use was satisfactory, too high or too low so that the same mistake is not made next year.

If the ionograms are not analyzed as obtained it is strongly recommended that some extra ionograms be taken whenever the film is changed. These should be cut off and developed locally and inspected for quality.

It is important that the format of the ionogram is kept constant since otherwise overlays cannot be used. A convenient check, e.g. ink marks on the monitoring cathode ray tube to show the standard time base sizes, is essential. Marks showing the current gain adjustment settings are more easily checked rapidly than a table of values.

Always keep full notes on the causes of any failure.

The operation of the ionosonde should be checked as frequently as convenient since most failures occur without much warning. Incipient difficulties in reduction due to the operation of the ionosonde should be corrected as early as possible - it is usually not possible to reduce difficult ionograms unless the basic quality is good. Gradual deterioration is usually allowed to continue much too long and this causes the analysis to become crude and inaccurate.

NOTES

2.0 General Conventions

The primary purpose of describing and measuring the representative features of the ionosphere overhead is fulfilled by interchanging numerical values which are systematically determined from the ionograms taken at the hour in Universal Time. These are tabulated using a Local Standard Time referred to the nearest 15° standard meridian. At most stations this is identical with Local Civil Time. To avoid ambiguity the time used should always be shown on the tabulation sheets.

The following selection rules are adopted to make the data to be interchanged homogeneous:

(a) All numerical tabulations except for fxI refer to the ordinary-wave trace. The extraordinary-wave trace or the 'z' trace should be measured for a frequency characteristic when the ordinary-wave trace is not available or is doubtful, and the equivalent ordinary-wave parameter computed and tabulated with the appropriate qualifying letter (J or Z) and descriptive letter.

For fxI the ordinary trace should be measured when the extraordinary trace is missing (usually through absorption, B) and the equivalent extraordinary-wave parameter computed and tabulated with qualifying letter O and the appropriate descriptive letter. (See section 3.2)

(b) Multiple echoes should always be examined and scaled when necessary to confirm or assist the interpretation of the first order trace, but are not included in basic summary tables or graphs [A99I, Fig. 102], (except fm2 where used). They are particularly valuable for showing whether the ionosphere is effectively horizontally stratified, the assumption implicitly made in the analysis of ionograms from most parts of the world. At high and low latitudes this assumption is often not true and it is essential to study any multiple reflections present to see whether the assumption is true or not or if it is likely to be changing with time. The analysis rules when large tilts are present differ significantly from those normally used. (section 2.7).

(c) Traces due to very weak reflections should be ignored. Many ionograms show weak trace in addition to the traces of the normal reflecting layers. These traces seldom represent phenomena which can be studied efficiently on a world-wide basis using standard ionosondes. Even when they appear regularly at the stations, they rarely represent normal reflection in the ionosphere. They should be studied as a special research.

Normal traces weakened by attenuation phenomena or equipment faults are always treated as significant. The deduced characteristics may be described by B, R or C when appropriate. Thus when fmin is high a normal trace may look very weak but should be treated as a strong trace.

Note: The weak partial reflection from a steep gradient in the D region, [B III.10] normally at virtual heights below 95 km, is a valuable indication of high absorption and is classified as Es type d, (see section 4.83). The presence of this trace is ignored when determining fmin or foEs. If no other trace is present, all tabulations except Es types show B and Es type shows d.

(d) Traces due to oblique reflections and other transient phenomena should be ignored except as listed below. These traces are most readily recognized by comparisons with examples of the common standard types. Detailed examination of closely spaced sequences of records [A96I, Fig. 91] [B III pps. 18-26] and other special experiments are also useful. It is recommended that each station build up its own library of difficult records with their interpretations and draw on the experience of other groups of workers.

Rule (d) does not apply to:

(i) f plots where oblique F region reflections are always recorded;
(ii) slant Es which is tabulated as an Es type but not used to determine foEs or fbEs.
(iii) fxI which is normally generated by oblique reflections. (section 3.3).

2.1 Accuracy Considerations

The accuracy with which ionospheric heights and critical frequencies can be measured depends on the inherent accuracy of the equipment, the accuracy of the method of calibration and the reading accuracy used in reducing the ionograms. Since every reduction implies some simplification of the facts and the usable accuracy is often limited by the physical properties of the reflecting layers, a reasonable value for reading accuracy has been established internationally. Some research techniques, e.g. the accurate determination of the electron density height profile by the more advanced methods demand a greater accuracy than this. Conversely, variability in the ionosphere may demand lower standards of accuracy in some areas so that a reasonable sample of numerical data can be obtained. In general, ionosondes should be capable of giving ionograms with the required accuracy.

For some geophysical applications it is the relative change which is of interest. For this reason it is worth-while to maintain a good relative accuracy even though the absolute accuracy may be less certain. The convention adopted is that the accuracy implied by the numerical values should be determined by the reading accuracy and not by the absolute accuracy of the measurements. In general, the absolute accuracy of virtual height measurements is very much less than the relative accuracy conveniently available. There is often a serious systematic error in all height measurements fixed by the particular technique employed. This can be important for comparison with rocket or incoherent scatter experiments.

2.11. Accuracy of calibration of ionograms: The accuracy of frequency markers and of the repetition frequency of the height markers can be easily checked with the aid of a suitable frequency standard. It is recommended that the accuracy of these scales should be maintained to ± 0.1%.

It is more difficult to establish the correct zero point of the height markers than to maintain the spacing accuracy. Even when automatic synchronization of the transmitted pulse and height markers is used, a systematic error up to 10 km may be present. This error can be eliminated by a suitable calibration procedure, e.g., by using multiple reflections. In addition, the position of the lower edge of the trace usually depends on the amplitude of the received signal. This phenomenon cannot be neglected when accurate height measurements (e.g., ± 2 km) are required and suitable calibration is then necessary.

2.12. Techniques for calibration of trace height: The appropriate technique depends on the design of the ionosonde and the extent to which the virtual height recorded depends on the amplitude of the reflected signal. There are two main classes:

(a) ionosondes in which the height markers are rigidly locked with the ground pulse.
(b) ionosondes in which they can be shifted relative to the ground pulse.

In case (a) it is essential to evaluate the average error, which is primarily due to the finite delay of the echo in passing through the receiver, but can also be generated in pulse shaping circuits, and can be equivalent to a height error of up to 10 km. This should be determined (see below) and either be subtracted from all values before publication or a note of its value included with all height data. In case (b) the height markers are adjusted so that the height of the first trace is consistent with the height difference between first and second (or higher order) traces. This is best done using the multiple traces from flat totally reflecting Es. Great care must be taken that the setting is correct and does not drift with time. The details of the phenomena have been discussed at length by A. J. Lyon and Moorat, J. Atmos. Terr. Phys. 8, 309-317, 1956.

A convenient procedure, usable when the ionosonde trace width is sensitive to amplitude changes, has been given by W. R. Piggott, J. Atmos. Terr. Phys. 14, 175-180, 1959.

The alternative approach is to use equipment with very severe differentiation, i.e., a very short time constant. This is sensitive to very small signal levels and can give more accurate heights when the trace is due to a single ray and there are no interfering signals. It can, however, be very misleading and difficult to interpret when multiple rays or scattered reflections are present.

For some stations proper calibration is not practical. The average correction should be determined by comparison between the virtual heights of different orders of reflection and indicated on all height tabulations. Note that errors in height automatically imply errors in the M(3000) factors.

Ideally the objective is to measure virtual heights to the nearest one km interval. This was attained as early as 1935 but is not always possible with current ionosondes, many of which can only attain the nearest 5 km.

2.13. Reading accuracy: The measurements should be made to at least the reading accuracy specified in the following table:

Characteristic	Reading accuracy		
	E region		F region
	E layer	Es layer	
Height	2 km	2 km	5 km
Frequency	0.05 MHz	0.1 MHz	0.1 MHz
M(3000)			0.05

Note: If gain runs are made the heights should be obtained from the ionogram with the clearest trace. When expanded height ionograms are available every effort should be made to read the height characteristics as accurately as possible. Under these special conditions a reading accuracy of 1 km may be obtainable. When the reading accuracy of the equipment is better than ± 2 km, E-region heights should be given to the nearest odd km at least. When the reading accuracy is better than ± 5 km E-region heights should be given to the nearest 5 km. When the scaling accuracy is worse than ± 5 km h'E should not be recorded, but h'Es is still valuable for classification purposes and should always be tabulated. When the characteristics of the ionosonde only enable heights to be measured to the nearest 10 km no attempt to tabulate in 5 km intervals should be made. Such ionosondes are now obsolete.

Where the height accuracy of an ionosonde is limited to ± 5 km, little scientific value can be obtained from the E-height values. These may, however, still be needed for evaluating F-layer electron density height profiles and the F-region reading accuracy then applies to all heights. The value of profiles when the height accuracy is worse than ± 10 km, is rather small and measurements should only be made to meet specific purposes.

It is not, in general, worth-while to apply the more elaborate computer methods, with correction for valleys and underlying ionization, unless the frequencies and heights can be measured to at least the accuracy given in the table. The correction terms vary rapidly with the <u>difference</u> in height between corresponding points in the o and x traces which must therefore be determined accurately, and serious errors can be incurred with frequency errors of 1% for the measurements near critical frequencies.

2.14. <u>Timing</u>: The nominal time for a slow sounding is defined as the time when the ionosonde records the standard frequency of 3 MHz. The nominal time of a group of multigain recordings is that of the medium gain ionogram. The nominal and scheduled time of the recordings should not differ by more than 0.5 minute.

If for any reason data are not available exactly on the hour, a record obtained within five minutes of the hour may be used to scale the hourly value of the characteristic without qualification, provided that the sequence of ionograms indicates that conditions are varying slowly. (See Chapter 7 for details of tabulation.)

2.2 Accuracy Rules for Individual Measurements

2.21. <u>General</u>: The general accuracy rules give the desirable accuracy applicable when the structure of the ionosphere and characteristics of the ionosonde permit. They also indicate the extent of the uncertainty permitted for doubtful or extrapolated values and enable such values to be identified. The rules imply that, in general, the reliability of data is determined by the percentage inaccuracy allowed except when this percentage is less than the reading accuracy Δ. The general properties of the rules are illustrated in Fig. 2.1, which shows, in graphical form, the rules applicable to all critical frequencies with reading accuracies Δ = 0.1 MHz and Δ = 0.05 MHz.

It must be remembered that the accuracy rule limits apply to reasonable doubt, not to absolute certainty. Thus, if an F trace shows some scattered echoes beyond the limit range and is such that it is unlikely that foF2 is really above the limit range, the trace should be treated as if the scattered traces were not present.

2.22. <u>Conventions for assigning the level of accuracy</u>: The maximum reading unit Δ has been defined in the <u>table of recommended reading values given above</u> (section 2.13). Numerical values whose reliability is influenced by certain phenomena are qualified by symbols (section 2.3) according to the following rules.

(a) If the estimated uncertainty of a value does not exceed ± 2%, or ± Δ, whichever is greater, then the numerical value is unqualified.

(b) If the estimated uncertainty of a value exceeds ± 2%, or ± Δ, whichever is greater, but does not exceed ± 5%, or ± 2 Δ, whichever is greater, the value is considered doubtful and the qualifying letter U is used with the number together with the descriptive letter which most nearly represents the reason for the uncertainty.

(c) If one boundary is certain and the other possible boundary of uncertainty lies within ± 10%, or ± 3 Δ, whichever is greater from it, the most probable value is taken as being midway between the observed limits, and the qualifying letter U is used with the number and appropriate descriptive letter.

(d) When the possible error exceeds that in paragraph (b), but it is estimated that the true value lies within about 20%, or 5 Δ, whichever is greater, of an observed boundary of

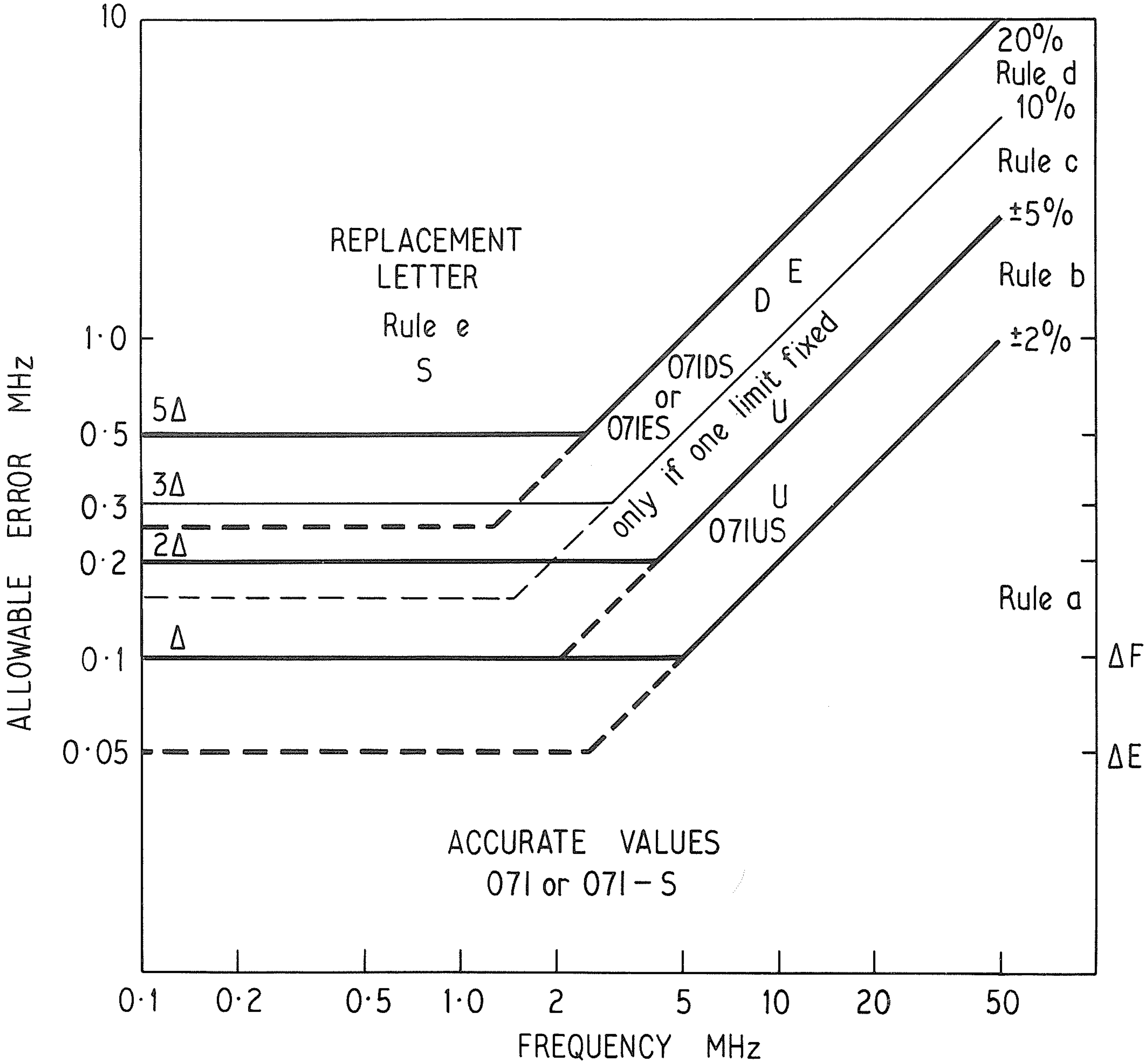


Fig. 2.1 Accuracy rules for frequencies

——— Δ = 0.1 MHz

- - - Δ = 0.05 MHz (2 Δ same as Δ for 0.1 MHz)

When the value of probable error lies between any pair of limits, use convention shown.

Note: When one limit is not fixed, D, E used for both zones c and d.
Arbitrary example foF2 = 7.1 MHz; interference present, S.
If one limit fixed .071 US in section c, otherwise .071DS or .071ES in section d.

possible positions of the principal echo, then this observed limit is tabulated with the qualifying letter D or E, whichever is applicable, and with the appropriate descriptive letter.

(e) When the extreme limit of the principal echo is judged to differ from the true value of the parameter by more than about 20%, or 5 Δ, whichever is greater, a descriptive letter only is tabulated without a numerical value.

The rules for frequencies are summarized in Fig. 2.1.

Note: Prior to 1970 the limits for use of D and E were 10%, or 3 Δ, and descriptive letters were used when the extreme limits exceeded these values. The need for numerical values for the study of particular events and to increase the value of the medians when the limits were often recorded has prompted this change.

A numerical value obtained by extrapolation (section 2.4) and not qualified by D or E should never differ by more than 5%, or 2 Δ, whichever is greater, from the extreme limit of the actually observed principal echo.

In many cases inspection of the second order traces can provide information on the reliability of the measurements. In particular, the presence of tilted layers may be established by comparing the virtual heights and critical frequencies deduced from the first and second order traces. The accuracy of the operations denoted by the qualifying letters J, O, Z is inherently not measurable and may be small or large compared with the limits imposed by the accuracy rules. The accuracy rules should not be applied when these letters are used.

It is particularly important that the accuracy rules are consistently applied when spread F is present since many researchers depend on counting the incidence of different levels as shown by the letter symbols.

Note: When the normal accuracy of the recorder is inadequate to enable the recommended intervals to be used, the ± 2%, ± 5% and ± 10%, + 20% or -20% may be changed proportionally so that the normal ionogram is unqualified. A note to this effect should be circulated with the data. Every attempt should be made to improve the equipment so that this is not necessary, as the value of the data depends largely on the accuracy rules being obeyed.

2.3 Qualifying and Descriptive Letters

Certain ionospheric, equipmental, or interference effects can be observed on ionograms and may make it difficult or impossible to obtain numerical values to the accuracy given in the table above. The qualifying and descriptive letter symbols listed below are used along with or in place of the numerical values to indicate these effects (all letters are descriptive if not otherwise designated). Qualifying letters indicate the nature of the uncertainty as explained below, and are always accompanied by a descriptive letter indicating the reason for the uncertainty. Descriptive letters not accompanied by qualifying letters indicate the presence of a phenomenon which may but need not affect the accuracy of the measurement.

A - Qualifying letter: less than. Used only with fbEs. (See section 3.1.)
Descriptive letter: measurement influenced by, or impossible because of, the presence of a lower thin layer, for example, Es.
B - Measurement influenced by, or impossible because of, absorption in the vicinity of fmin.
C - Measurement influenced by, or impossible because of, any non-ionospheric reason.
D - Qualifying letter: greater than.
Descriptive letter: Measurement influenced by, or impossible because of, the upper limit of the frequency range in use.
E - Qualifying letter: less than.
Descriptive letter: Measurement influenced by, or impossible because of, the lower limit of the frequency range in use.
F - Measurement influenced by, or impossible because of, the presence of spread echoes.
G - Measurement influenced or impossible because the ionization density of the layer is too small to enable it to be made accurately.
H - Measurement influenced by, or impossible because of, the presence of stratification.
I - Qualifying letter only: Missing value has been replaced by an interpolated value.
J - Qualifying letter only: Ordinary component characteristic deduced from the extraordinary component.
K - Night E layer present.
L - Measurement influenced or impossible because the trace has no sufficiently definite cusp between layers.

M - Interpretation of measurement questionable because ordinary and extraordinary components are not distinguishable.
Qualifying letter: Used with descriptive letter which shows why components not distinguishable.
Descriptive letter: Used when interpretation is doubtful and a qualifying letter needed for other reasons (e.g., U, D, E).
N - Conditions are such that the measurement cannot be interpreted.
O - Qualifying letter: Extraordinary-component characteristic deduced from the ordinary component. (Used for x characteristics only.)
Descriptive letter: Measurement refers to the ordinary component.
Q - Range stratification present.
R - Measurement influenced by, or impossible because of, attenuation in the vicinity of a critical frequency.
S - Measurement influenced by, or impossible because of, interference or atmospherics.
T - Qualifying and descriptive letter: Value determined by a sequence of observations, the actual observation being inconsistent or doubtful. (See section 6.9.).
U - Qualifying letter only: Uncertain or doubtful numerical value.
V - Forked trace which may influence the measurement.
W - Measurement influenced or impossible because the echo lies outside the height range recorded.
X - Measurement refers to the extraordinary component.
Y - Intermittent trace, or trace missing due to defocussing.
Z - Qualifying letter: Measurement deduced from the third magneto-ionic component.
Descriptive letter: Third magneto-ionic component present.

In Chapter 3 the use of each letter is discussed in detail.

2.4 Extrapolation

A trace may be extrapolated in height or frequency both when a characteristic is not clearly visible on the ionogram for instrumental or operational reasons and when the complexity of the ionospheric phenomena changes the meaning of the apparent value of the characteristic. Extrapolation is used to give the most probable value of the characteristic in these cases. Unqualified extrapolation is allowed only when the deduced value is within 5%, or 2 Δ, whichever is the greater, of the limit of the actually observed trace.

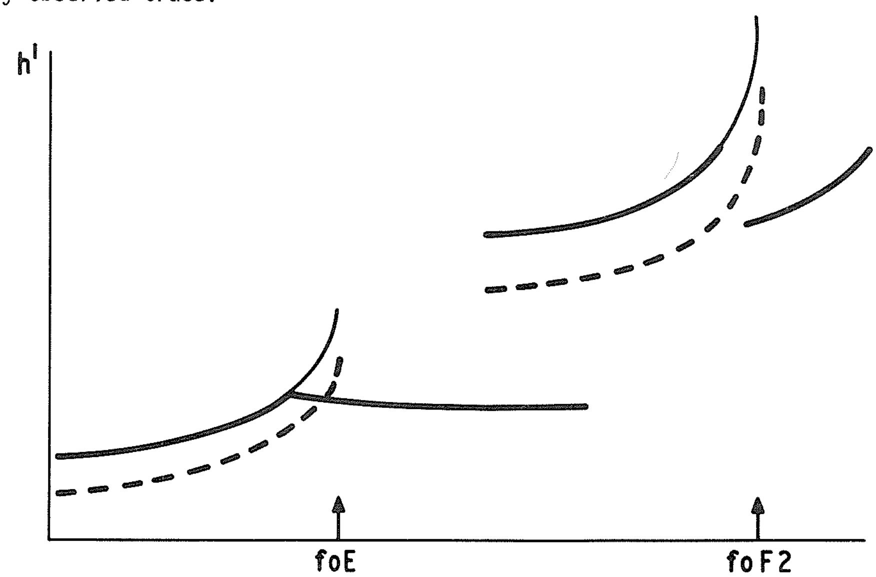


Fig. 2.2 Extrapolation to a critical frequency.

The shape of the normal trace (---) for similar conditions is traced and moved to fit the observed trace (thin line in figure). By this means the ionogram traces (shown thick) are extrapolated to give the critical frequency.

Use accuracy rules to decide if qualifying letter needed.
foE is (foE) - A or (foE) UA
foF2 is (foF2) - R or (foF2) UR

Extrapolation is not usually justified over greater frequency ranges, instead use limit value and D or replacement letter A or R. Similar rules apply for extrapolation due to C, S, etc.

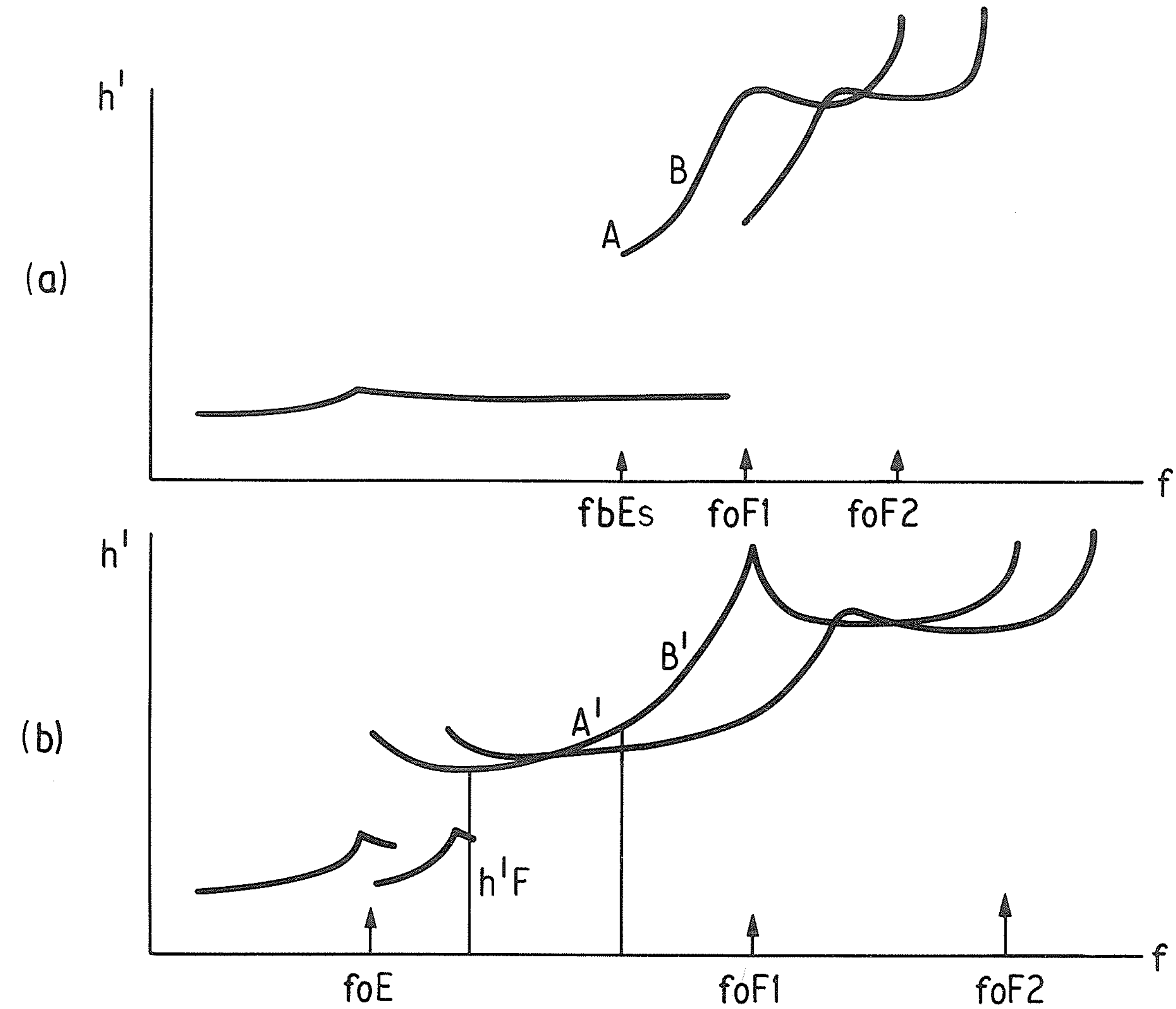


Fig. 2.3 Extrapolation in height

Estimation of error for use of E.
(a) h'F blanketed by Es.
(b) Ionogram taken at same time of day so foF1 and foE approximately the same.

AB matched to A' B' near A and A' so that difference between h'F at fbEs in (a) and correct value of (b) can be estimated.

Note: Error in foE can be determined similarly.

This is used to show when a limit value is likely to be useful (see section 3.2 letter G).

The most common extrapolation is the vertical extension of a trace near the critical frequency. This should be controlled by examining ionograms where the trace is more complete and the significant common parts are similar in shape. This applies also when the retardation at foE is decreased by the presence of sporadic E, Fig. 2.2. Extrapolation in height is also allowed, Figs. 2.3, 2.4.

Extrapolation has been allowed in order to avoid systematic error, for instance, the presence of transitory deformations, blanketing, or deviative absorption. Limits are prescribed so that the extrapolation is 'controlled'. These limits are determined by the general accuracy requirements (section 2.1, 2.2) and the permitted range of extrapolation is always limited by the accuracy rules given above. Within the limits it is important to obtain numerical values whenever possible as the usefulness of the tabulated data depends on the number of numerical values obtained.

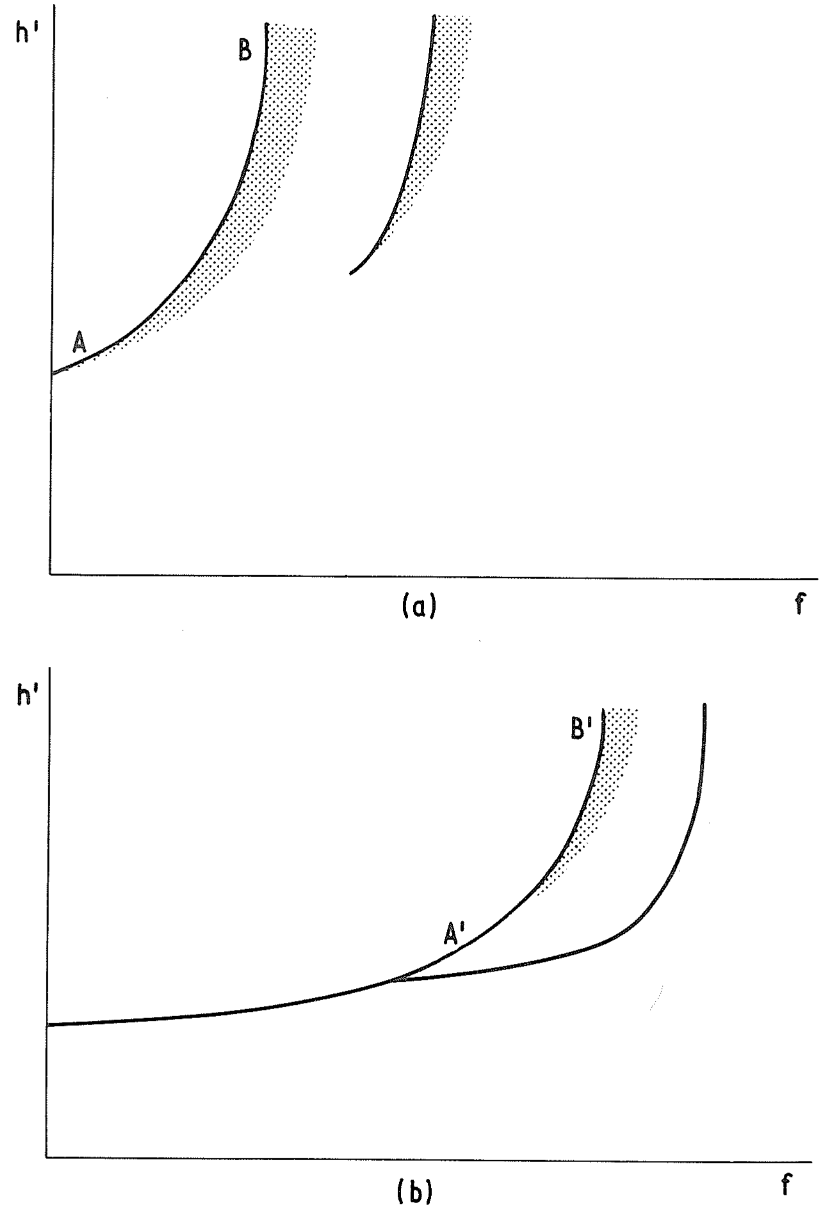


Fig. 2.4 (a)(b). Estimating error in minimum virtual height at night.

(a) h'F falling at lowest frequency seen.
(b) Ionogram taken when foF2 much greater than in (a) but curvature of trace similar AB, A'B'.

Estimate difference between true h'F in (b) and value at A. (This can be done by an overlaid tracing of the frequency scale if the ionogram is logarithmic. Otherwise compare at two ratios of sample to critical frequency).

Extrapolation is particularly important when it is desired to compute electron density with height profiles. Detailed rules are given in section 10.22. These procedures can be applied to improve the accuracy of standard parameters, e.g., h'F at night by providing standard reference patterns. (Fig. 2.4 a,b). Values deduced in this way should always be qualified with U and the descriptive letter which shows why extrapolation was needed. The work involved is appreciable and therefore such procedures are only used for training or when there is a local need for greater accuracy.

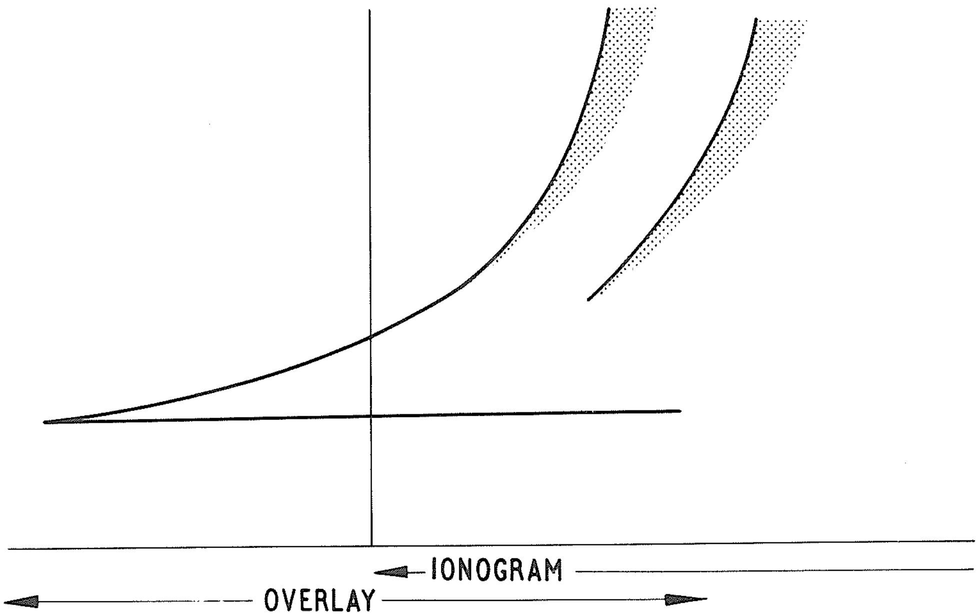


Fig. 2.4 (c). Estimating error in minimum virtual height at night or use of overlay based on Table 10.2

Alternatively Table 10.2 can be used to compute the expected shape (see section 10.22 for details).

For logarithmic frequency, card overlays are prepared for different thicknesses of layer and matched to the o trace. The vertical line shows the bottom edge of the ionogram and the horizontal line the extrapolated value of h'F.

2.5 Interpolation

Interpolation in time is allowed in order to make the tables of hourly values as complete and representative as possible. It is very important that these procedures be strictly controlled. Isolated missing hourly values can usually be replaced by an interpolated value using the rules given in detail in section 3.1 under the letter I.

2.6 Gain Runs

Frequently the receiver gain setting which is best for scaling one characteristic is not suitable for another. Thus, a gain run (a sequence of three soundings at low, normal and high receiver gain) taken at each hour provides more accurate information [A1001, Figs. 105, 106]. The steps in gain should always be kept the same and, whenever possible, the differences in gain measured and specified in the station operation log books. For many stations changes of gain of about ± 15 dB appear to be adequate but the best value must be found by experiment.

In high noise areas smaller changes, e.g., + 5 dB, - 10 dB, may be needed whereas in very quiet zones, e.g., the Arctic and Antarctic, much larger changes are advantageous.

Each characteristic is scaled from the sounding on which it is best displayed, except that:

(a) Gain sensitive characteristics fxI, foEs, fbEs and fm2 or fmin must be scaled from the normal gain sounding.

(b) When transient phenomena are present the most consistent value is tabulated. Gain runs are particularly valuable for interpreting ionograms when spread echoes (scatter) are present.

2.7 Scaling in the Presence of Oblique or Spread Echo Traces

2.70. Principles: The greatest difficulties in interpreting ionograms arise when the ionosphere is not horizontally stratified. This may be due to either localized or large scale phenomena. The ionosphere can be curved so that reflections from several directions are possible at the same time giving several traces. Field aligned irregularities can also give strong reflections and add to the complexity of the ionogram. These phenomena are particularly important at high and low magnetic latitudes. fxI, which always refers to oblique traces, is discussed in section 3.3.

The perturbations due to tilts are often used to study travelling disturbances and many examples will be found in the literature. For synoptic analysis purposes these cause perturbations in the values of standard parameters which are transient and the objective is to obtain the most probable value of the unperturbed parameter.

For most hours at temperate latitudes, except possibly near sunrise and sunset, and at some hours elsewhere large scale tilts are rare, so that it is justified to use interpretations which assume that the main reflecting structures are near horizontally stratified, any tilts being less than 5°. When this is not true, completely different rules are needed to identify the most nearly overhead trace. Thus, the first problem in analyzing complex ionograms is to find whether large tilts are likely to be present or not. In this context we use tilt to describe the form of the surfaces of constant ionization density, Fig. 2.5, responsible for reflecting the signals and giving the observed traces. These surfaces may be tilted as a result of a variation in electron density longitudinally, the height and thickness of the layer staying constant, to changes in height or thickness, the maximum electron density staying constant or to any combination of these effects. When two layers are present which vary differently with distance the surfaces can even be tilted in different directions at different heights, giving very complex ionograms. For most interpretation purposes it is adequate to assume that a given frequency is reflected by the same electron density whether the layer is horizontal or not. This is slightly incorrect for the second order reflections where the effective frequency, fcosi (i is the angle of incidence), is slightly less than the working frequency f. (For a layer tilted at 45°, cosi = 0.92). At high latitudes a tilt in the magnetic meridian approximately complementary to the angle of dip can cause the o-mode reflection to be transformed into a z mode of reflection.

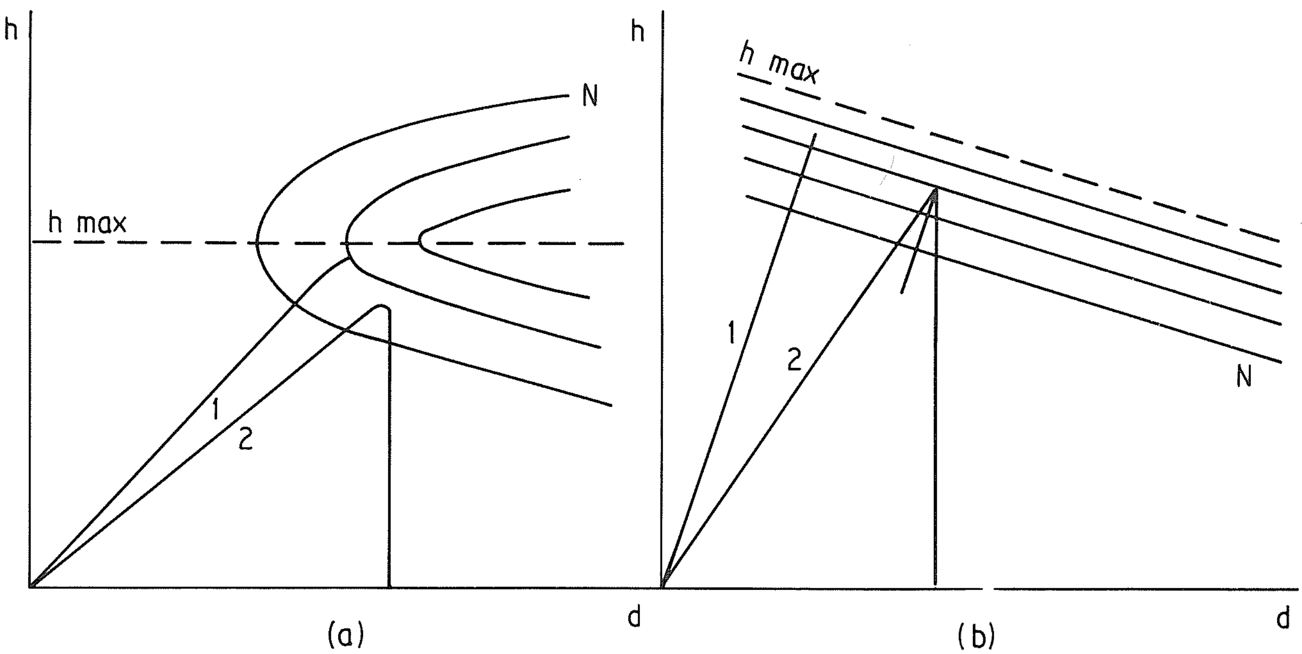


Fig. 2.5 Reflection from tilted layers.

(a) electron density increasing with distance
(b) tilted layer-height changing, electron densities constant

—— surfaces of constant electron density,N.
1. First order reflection
2. Second order reflection

When multiple traces are present the critical test is the consistency between the heights deduced from different order traces, Fig. 2.6. The family of traces showing the greatest consistency is nearest overhead. If the height values are consistent (after allowing for amplitude effects, section 2.1), the interpretation can be regarded as adequate.

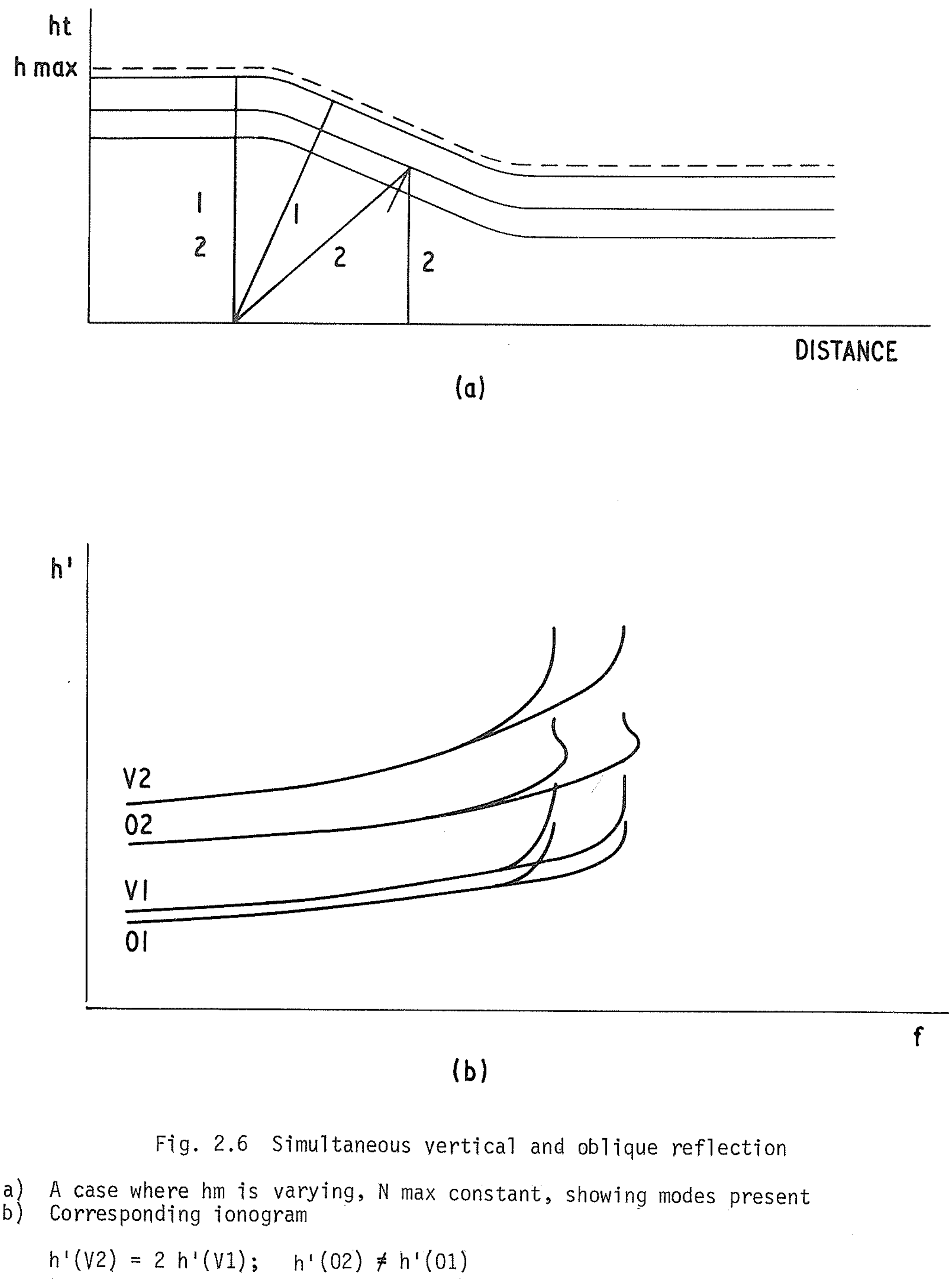


Fig. 2.6 Simultaneous vertical and oblique reflection

(a) A case where hm is varying, N max constant, showing modes present
(b) Corresponding ionogram

h'(V2) = 2 h'(V1); h'(02) ≠ h'(01)

Note: (i) Relative positions of V1, V2 (vertical first- and second-order traces), 01, 02 for corresponding oblique traces, depend on tilt present.
(ii) If N max varies also the critical frequencies of V traces will differ from those of 0.
(iii) MUF nose on 02 trace. The presence of this type of pattern (or this reversed in frequency) always means tilt is present.

The effects of irregularities giving rise to spread F traces also depend on whether large tilts are present or not and the optimum analysis rules change accordingly. Historically, the great predominance of almost horizontal stratified conditions has given rise to a set of 'normal' rules applicable to this case. In this edition we attempt to make the distinction clearer.

It is convenient to distinguish between the two main types of spread F traces though in some cases both may be present simultaneously and one can turn into the other. These are:

(a) Frequency spread

(b) Range spread

The former shows spread near the critical frequency, the pattern often showing frequency structure as though a number of normal traces were displaced in frequency and present simultaneously, (see Fig. 2.11 for details). [B. IIA 4 Sept; IIB 4 all; IIA 18 June; IIA 19 June; IIA 22 Dec; IIA 34 Sept; IIA 35 Sept; IIA 40 Sept; IIA 53 June; IIB 6 all; IIB 14 Dec. First and last 3 ionograms of III 20]. The latter shows little or no height variation with frequency, but often structure in height; in extreme cases it may look like a horizontal band across the ionogram, (see Fig. 2.14 for details). [B. Sequence III 19; IIA 41 Sept. Syowa; IIB 41. June Syowa; IIA 10 Sept; IIA 17 Dec; IIA 59 June; IIA 72 Dec; IIA 74 Dec; IIA 82 Sept; IIA 83 June; IIA 85 Dec]. Some examples of combined frequency and range spread are shown in the Atlas. [B. IIA 3 Sept; IIA 4 Dec; IIA 7 June Sept; IIA 8 June; IIB 3 Dec].

Classification of spread F types is considered in section 12.3.

2.71. <u>Identification of large scale tilt</u>: Usually large scale tilts take an hour or more to build up at a given station so that a study of the sequence of ionograms is the best way of identifying that these are likely to be present. In practice the time interval between ionograms should not exceed 15 minutes. Large scale tilts usually generate significant changes in the ionograms before and after the tilted section was overhead. When these are seen, the interpretation of the ionograms should be based on the probable presence of large tilts.

The first clear signs of the approach of a tilted structure are:

(a) The height intervals between higher order traces are altered relative to the interval between ground pulse and first order trace, and the shape of the traces can alter, Fig. 2.7.

(b) The sudden appearance of satellite traces. If these are seen first on a high order trace and later on the first order strong tilts are probable.

(c) The sudden appearance of range spread traces.

Note: It is possible for a tilted structure to be present near a station but not move overhead. In these cases the pattern shows tilt but does not change greatly with time.

(d) A rapid change of h'F with time, when accompanied by additional traces or spread F, is also a good indication that significant tilts are present.

The most reliable test for overhead tilt is to compare the virtual heights h_1 h_2 h_3 ... of the multiple traces. The height intervals (h_3-3h_1), (h_2-2h_1), etc. show measurable differences when the tilt exceeds about 10°.

The rule is:

If the virtual height interval ground pulse, G, to first order is different from that between the first and second order by more than expected from normal ionograms (see section 2.11) the reflection is not vertical. The pairs of traces for which the error is least identify the mode most nearly vertical and this trace should be analyzed, e.g., Fig. 2.6(b). The interpretation is based on the assumption that large tilts are present. If this is not true the alternative assumption is used (normal rules for little tilt).

When multiple reflections are present for either vertical or oblique traces, they should always be used to show whether the trace is oblique or not. It may happen that one of the traces not showing multiples is the vertical trace and it is then useful to know which traces were oblique in the sequence. In the situation when a trough and a ridge of ionization cross the station, reflections from the sides of the trough are often prominent until the ridge is overhead, when the multiple traces reflected from the ridge suddenly show vertical reflection, $h_2 - 2h_1 = 0$.

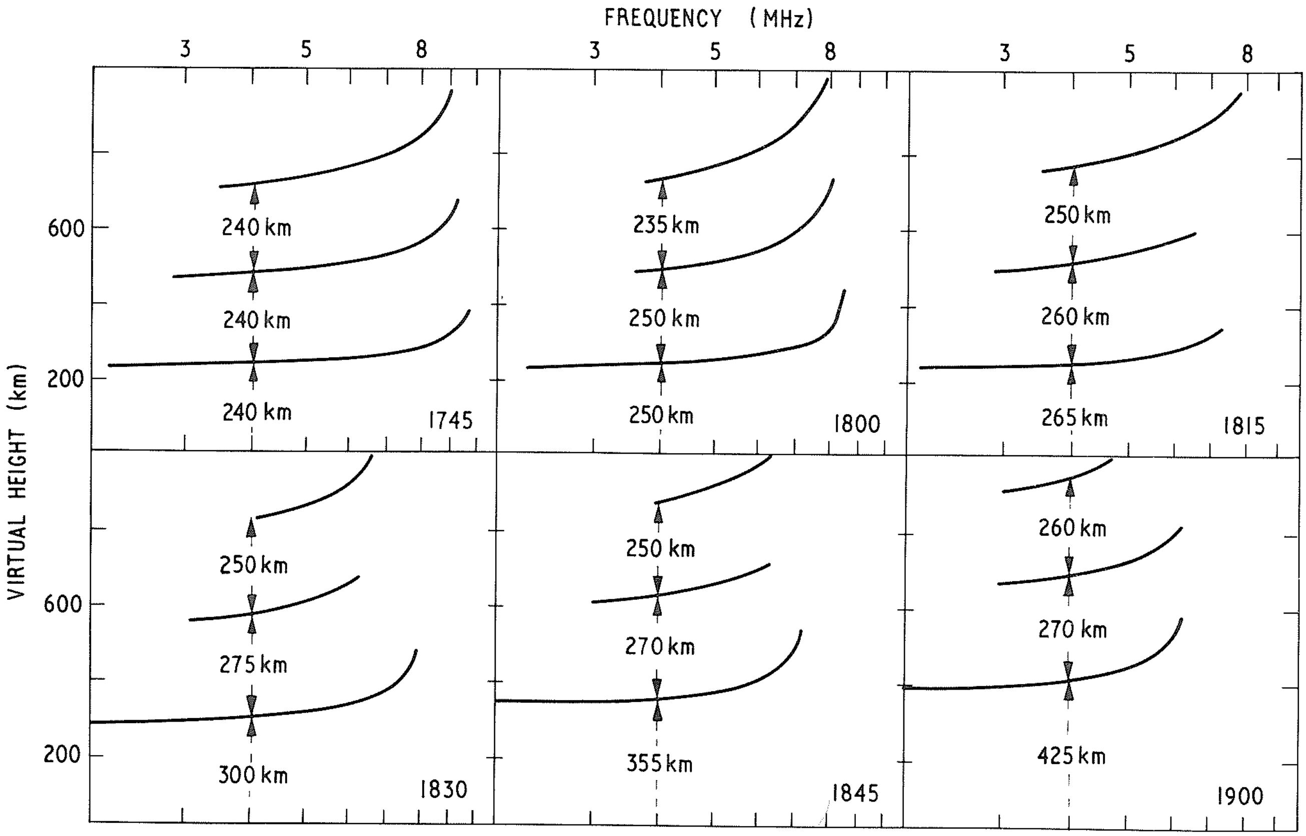


Fig. 2.7 Changes in pattern when large perturbation approaches station.

For this case hmF2 is increasing.

1745 Normal

1800 3F trace reflected at oblique incidence, note change of shape near foF2.

1815 All traces oblique, note characteristic decrease in curvature near foF2 and defocussing near foF2 (letter Y preferred but R acceptable).

1830 - 1900 All traces oblique but first order reflected from plane stratified tilted layer similar to Fig. 2.5(b) as is shown by shape becoming near normal.

Note: Only o-mode traces have been reproduced in this figure.

The sequence of events during severe tilt at a given station often tends to repeat from day to day, though not necessarily at the same speed or at the same time. Complex patterns can often be interpreted uniquely using several sequences.

When the critical frequency values given by the second order trace differ significantly (accuracy limits for U or more) from those given by the first order trace, large scale tilt is present (the converse of this rule is not always true).

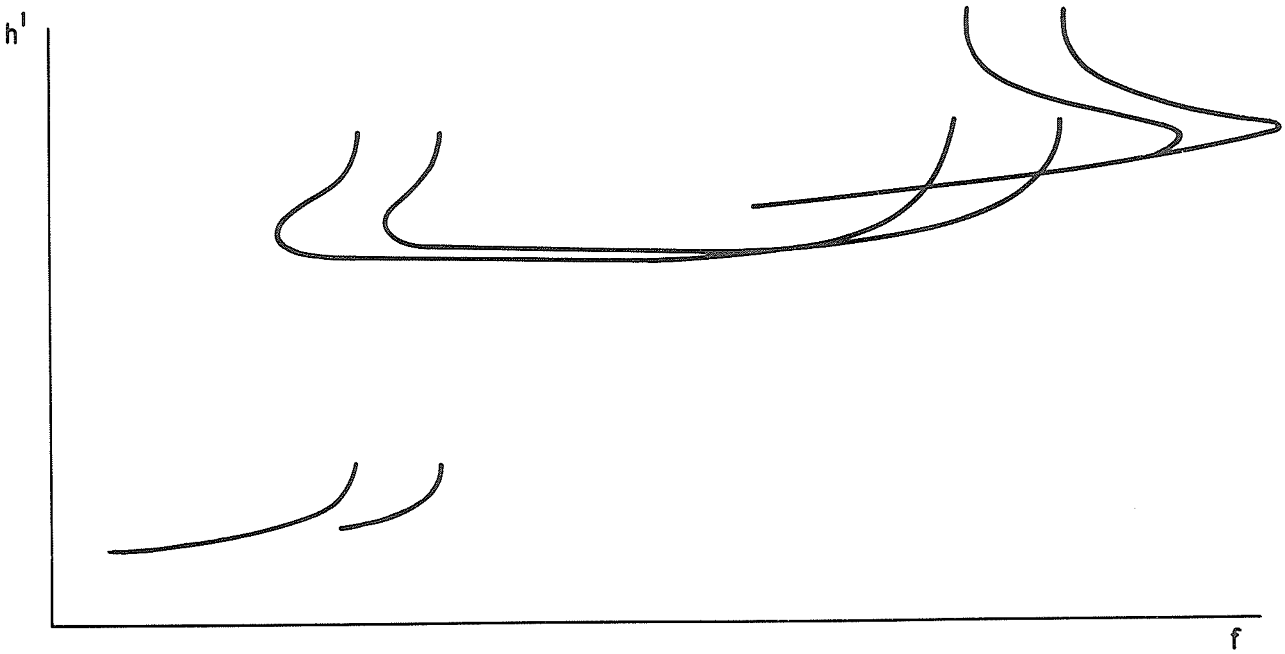


Fig. 2.8 Characteristic traces when tilts are large.

Patterns of the types shown indicate large tilts in the lower parts of the ionosphere. They can occur on any normal trace or on polar spurs.

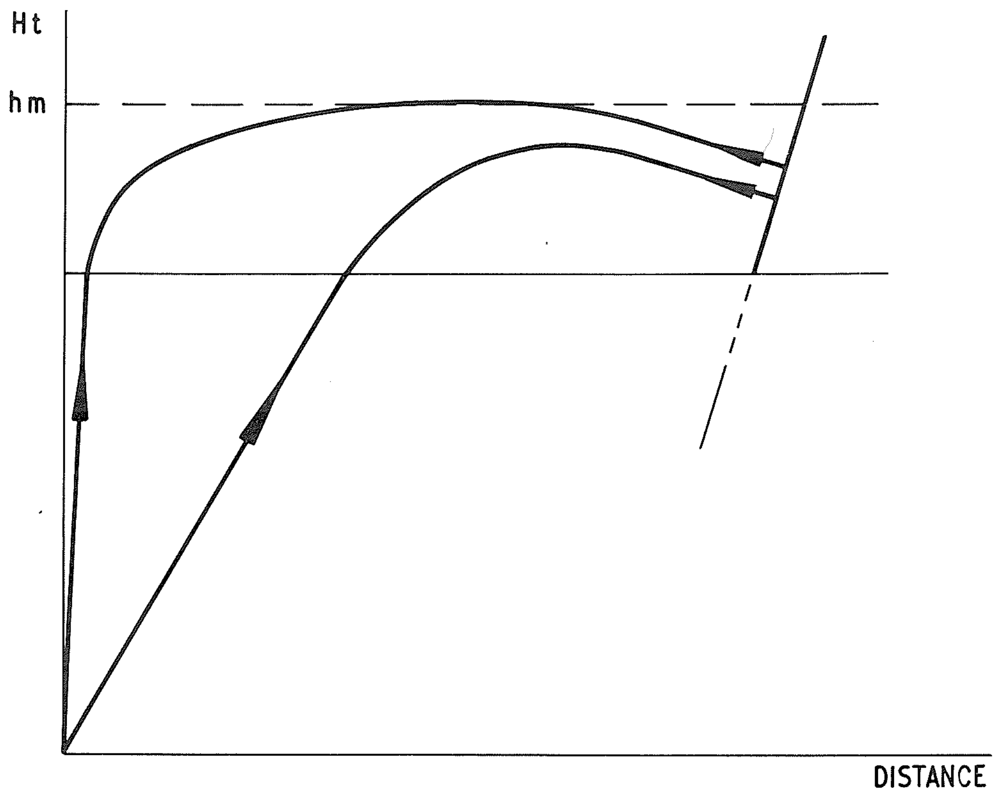


Fig. 2.9 Ray paths reflected from a field aligned irregularity showing high and low angle modes.

Always test that the development of the critical frequency in time, and the changes in virtual height with time, are consistent with the interpretation adopted. Thus, an abnormally large and rapid change in height would be inconsistent with no tilt even if the criteria given above were not seen.

Tilts in the lower ionosphere often show as oblique type traces (Fig. 2.8) for the upper layers. Field aligned reflection can give the same type of pattern when the rays are bent in a normal layer to be perpendicular to the irregularities (Fig. 2.9).

2.72. Normal interpretation - tilts small: The normal rules apply to the interpretation when average sized travelling disturbances, diurnal changes, or similar phenomena cause only slight tilt effects, and to spread F patterns seen when tilt of the main layer is probably small.

Tilts and irregularities can modify the interpretation of the traces for any layer but are most common and most important when modifying F-layer characteristics. The rules are given for the determination of foF2, M(3000)F2 and h'F, analogous rules apply to the parameters for other thick layers. For the interpretation of letter symbols see Chapter 3, for f plot symbols see Chapter 6. Tilts and irregularities modifying Es characteristics are considered in Chapter 4. They are important in generating Es types a, r and s.

When tilts are small, oblique reflections will give traces at apparent greater virtual heights than the near vertical reflection. Also denser clouds of ionization which are not overhead can give reflections on frequencies above the critical frequency. Analysis shows that such reflections give traces which have a different shape from normal reflections, Fig. 2.10.

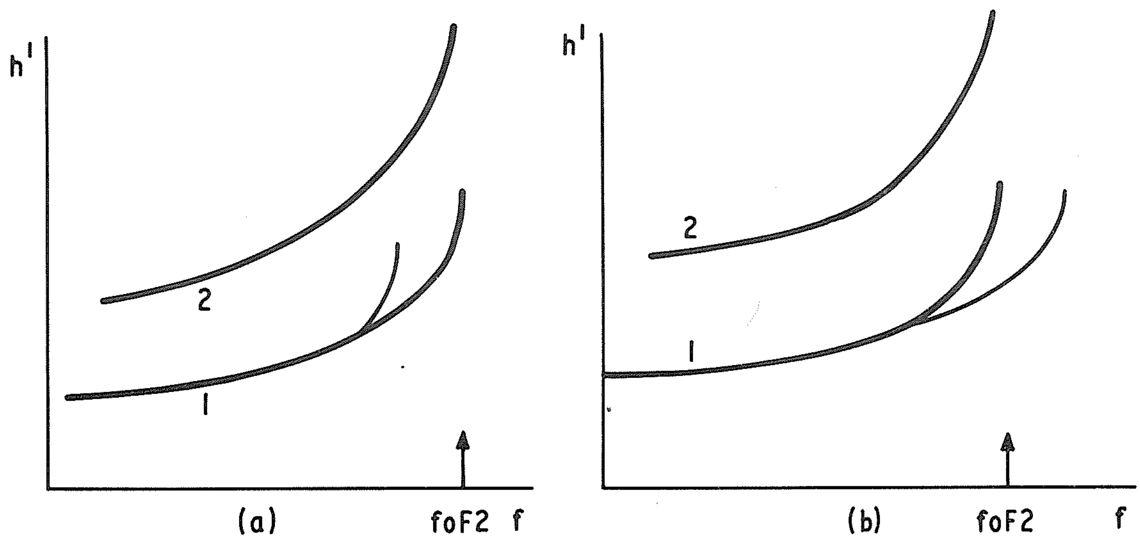


Fig. 2.10 Reflection from a cloud, o mode only

(a) N in cloud less than N layer.
(b) N in cloud more than N in layer.

1 - First order trace, 2 - second order trace.
o mode only shown in this figure. x trace often helps distinguish principal trace using fxF2 - foF2 = fB/2 and relative solidity of traces.

Any small gradients causing the average ionization density to be greater at oblique incidence will tend to give traces similar to the normal trace but displaced towards higher frequencies. For these conditions:

(a) The trace with the lowest virtual height is most likely to be overhead.
(b) The strongest trace is most likely to be overhead.
(c) The inner edge of the spread F pattern (Fig. 2.11) is most likely to give the best value of foF2 and M(3000)F2 in the presence of spread.

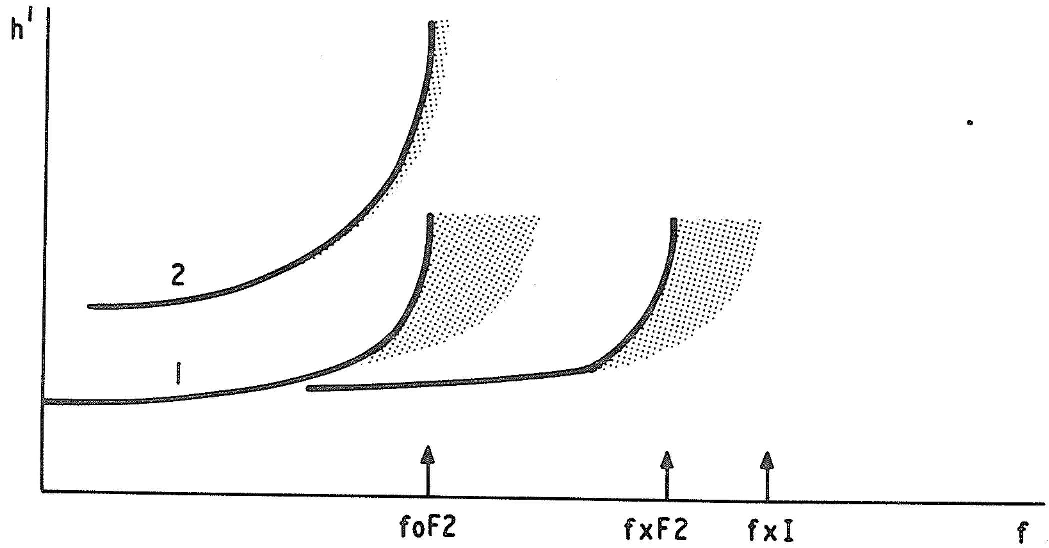


Fig. 2.11 Frequency spread

Note: (I) Second order trace twice height of first order
(II) Main trace clearer on second order
(III) Inner edge strong and clear
fxF2 - foF2 = fB/2
foF2 given by inner edge of trace

(d) The strongest traces in the multiple reflections are most likely to be overhead (check height intervals).

When range spread is present (a) takes precedence over (b) unless the lowest trace is weak or scattered.

(e) The critical frequency can be deduced from the second order trace.

These criteria should be used to confirm each other whenever possible. Note that parameters deduced using (c), the inner edge, should always be regarded as uncertain (qualifying letter U) for interpretation reasons. However, when more than two multiples are present in spread F conditions and give consistent values of foF2 within the accuracy rule limits, the value can be regarded as certain although not measurable on the first order trace.

Common cause of small tilts is the presence of travelling disturbances. For these sequences of ionograms show in time sequence some or all of the following [BIII 11, 12, 13]:

(a) a perturbation of foF2 and fxF2

(b) a forked trace, V

(c) a perturbation of h'F2

(d) a perturbation in foF1

(e) formation of a F0.5 transient layer with perturbation in h'F

(f) high type Es or E2 layer

(g) often an increase in foEs and fall in h'Es. Es type changing from h to c or in extreme cases to ℓ

(a) and (b) are usually accompanied by significant sideways movement of the wave causing the layer to look thicker. M(3000) and the height of the maximum are altered and are therefore not reliable, use UV or UH.

When the tilt is mainly East-West the o- and x-mode traces are modified in a similar way, when mainly North-South the shapes of the traces are dissimilar or displaced in frequency relative to their normal separation. Some typical examples are shown in Fig. 2.12, where it should be remembered that mixed and intermediate cases also occur. The separation of critical frequencies fxF2-foF2, fxF1-foF1, or fxE-foE is a very sensitive index for changes in critical frequency along the magnetic meridian. Tilts in the region near hmE can give patterns which can be confused with the effects of stratification in the same zone. The characteristic differences are contrasted in Fig. 2.13 (a)(b)(c)(d) tilt effects and (e) stratification effects.

At any frequency the oblique incidence reflections may appear either above or below the vertical incidence trace. The former is more common as the apparent virtual height for a constant real height of reflection will increase with the secant of the angle of incidence

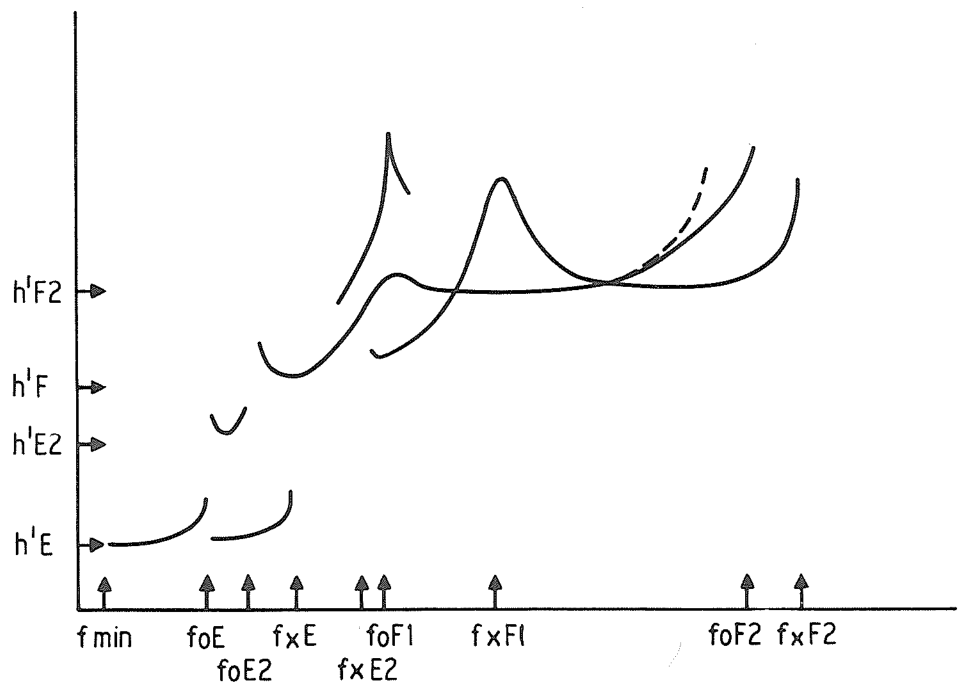


Fig. 2.12 North-South tilts showing distortion of traces

Typical effects at different levels have been combined - usually only one or two will be seen on any given ionogram. E trace normal.

fxE2 - foE2 = fB/2. Lacuna present on fxE2
F1 o and x traces dissimilar
F1 satellite trace present
F2 o and x traces dissimilar
F2 o trace showing strong tilt distortion (normal trace shown as dashed line)

Interpretation: (see Chapter 3, characteristic enclosed in parentheses means apparent value of the parameter)

fmin, foE normal
For foF1. Measure (foF1), (fxF1-fB/2) and satellite trace and tabulate (average value) UH
For foF2. As x trace apparently not badly distorted tabulate (fxF2-fB/2) JH.
If x trace distorted tabulate (foF2) EY
h'E normal
h'E2 tabulated if needed for local or regional purposes (h'E2) UH
h'F tabulated (h'F) UH
h'F2. Check second order, if this agrees use (h'F2), if not or if satellite present and no second order tabulate (h'F2) UH

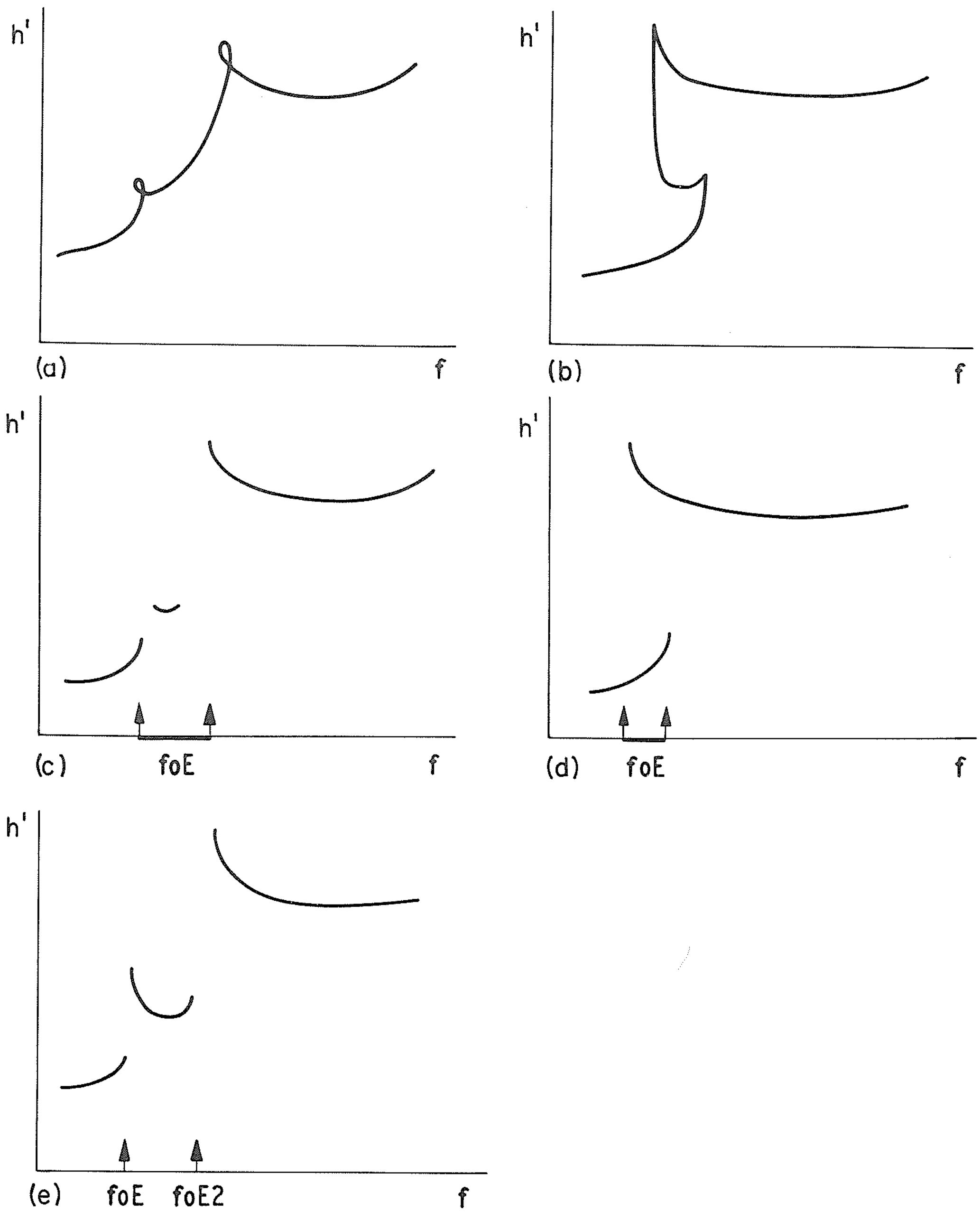


Fig. 2.13 Distinction between effects of layer tilt and intermediate thick E layer
(a)(b) The critical forms of o- or x-mode traces when tilts are present near hmE.
(c)(d) Traces after allowing for focus phenomena.
(e) Thick E2 layer.

Note: Strong trace due to positive focusing at frequencies just above foE in case (e), weak trace due to negative focusing in cases (c) (d).

The interpretation of foE in (c) (d) depends on the uncertainty shown by the bar relative to the limits given by the accuracy rules. As this increases we have

(i) (mean value of foE)
(ii) (mean value of foE) UH
(iii) case (c) (lowest value of foE) DH
(iv) case (d) (highest value of foE) EH
(v) replacement letter H

The intermediary trace in case (c) may be missing.

2.73. Interpretation when large tilts are present: At high and low latitudes large tilts can be quite common at certain times of day, sometimes exceeding 45°. For these conditions the normal rules, section 2.72, can be highly misleading. For example rapid changes in hmF2 with position can cause oblique traces to have apparent lower virtual heights than the vertical incidence trace, and curvature of the reflecting surfaces can cause these traces to be much stronger than the most nearly vertical trace. Such conditions are often accompanied by field-aligned irregularities which can give range and frequency spread which also do not obey the normal rules. Thus, the main problem is to identify the near vertical trace in the presence of other, often stronger and lower traces with or without the aid of multiple reflections. Many examples have been given by G. G. Bowman and G. A. M. King (Planet Space Sci., 1969, 71, 777-796; Aust. J. of Physics, 1968, 21, 695-714), and it is hoped to collect these and other examples in a high latitude supplement to this Handbook to be published separately.

The most useful tool is usually the sequence of ionograms, the significant properties of the most nearly vertical reflection trace being:

(a) that the height is varying regularly with time over periods of the order of an hour.
(b) that the critical frequency is varying regularly with time.

Note: Changes in height or critical frequency of the near vertical trace can often be used to predict the most probable position of this trace on the next ionogram whereas the oblique traces tend to show more irregular appearance and disappearance.

Special difficulties can arise at sunrise when rules (a) (b) can break down. The new F layer can be formed at a different height from that of the residual night layer, and the E and F1 layers are first formed at great heights and rapidly move down to their normal positions. An F-layer sequence near sunrise will be found in the Atlas [BIII p23]. The best way to learn to interpret sunrise ionograms is to make some sample sequences at short intervals, preferably every five minutes. The phenomena change with season and with the latitude and longitude of the station. For these periods, f plots can be very helpful in deciding on the correct interpretation.

When hmF2 is not varying much with position, the critical frequencies for the higher order traces usually show systematic shifts relative to those for the first order trace. This is often accompanied by excess range spread for these traces (the normal range spread for an nth order trace is n times or less the spread for the first order trace). [BIII 23 first 6 frames; BIII 24].

2.74. Range spreading: Range spreading, Fig. 2.14, is usually associated with the presence of field-aligned structures. When these are present the surfaces of constant ionization are corrugated approximately along and perpendicular to the field, Fig. 2.15. The type of pattern produced depends on whether the difference in electron density in the field-aligned structures is large or small compared with the ambient electron density. In the former case the structures act as reflectors, often to frequencies high compared with the local critical frequency. Some typical computed traces, (after Bowman, Aust. J. of Physics, 1968, 21, 695-714) are shown in Fig. 2.16.

When the perturbations due to the field-aligned structure are small as in Fig. 2.15, the layer approximates to two tilted layers present simultaneously. Usually the electron density is varying with distance in the magnetic meridian in these cases and two families of traces are generated.

Group 1. Traces reflected from the direction along the field. This gives a family of traces similar to the normal trace but with the critical frequency decreasing when the electron density decreases towards the magnetic pole, increasing when it increases in this direction.

Group 2. Traces reflected from the direction transverse to the field (often from field-aligned irregularities dense compared with the ambient density).

The former show simultaneous range and frequency spread, the most nearly vertical trace often showing the largest critical frequency (the opposite to the normal-low tilt condition), Fig. 2.17. The latter show range spread, usually with little or no retardation at the higher frequencies.

It should be noted that the relative strengths of the o and x traces are often abnormal in these cases and one or other may be missing.

Particle generated layers at high latitudes often show widely different critical frequencies to normal and are usually first seen as a range spread trace superimposed on the normal ionogram. To facilitate study of these phenomena their presence should be indicated by descriptive letter Q.

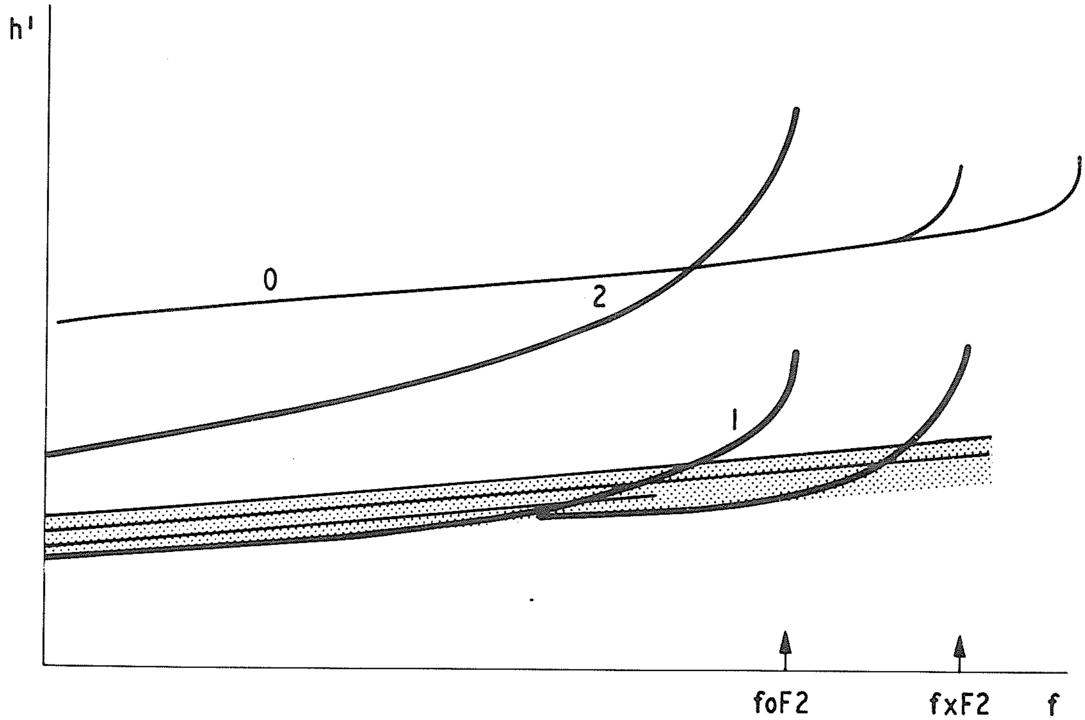


Fig. 2.14 Range spreading

Note: (i) Second order at twice height of first order except possibly near foF2.
(ii) When trace similar to 0 present, strong tilt likely to develop. (0 can be above or below 2F trace).

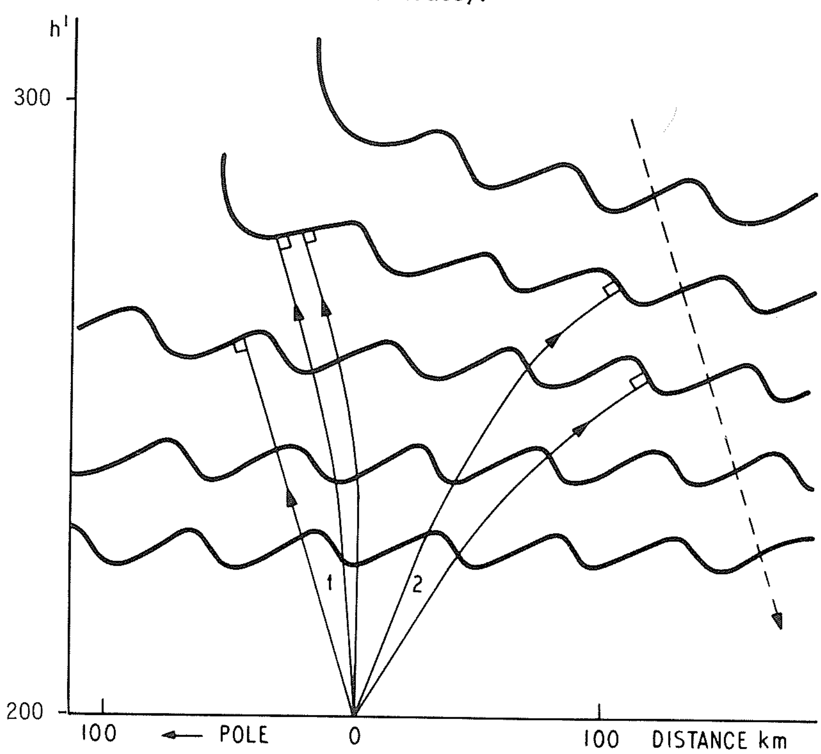


Fig. 2.15 Reflection from irregular ionosphere

Note: Electron density decreasing towards pole.

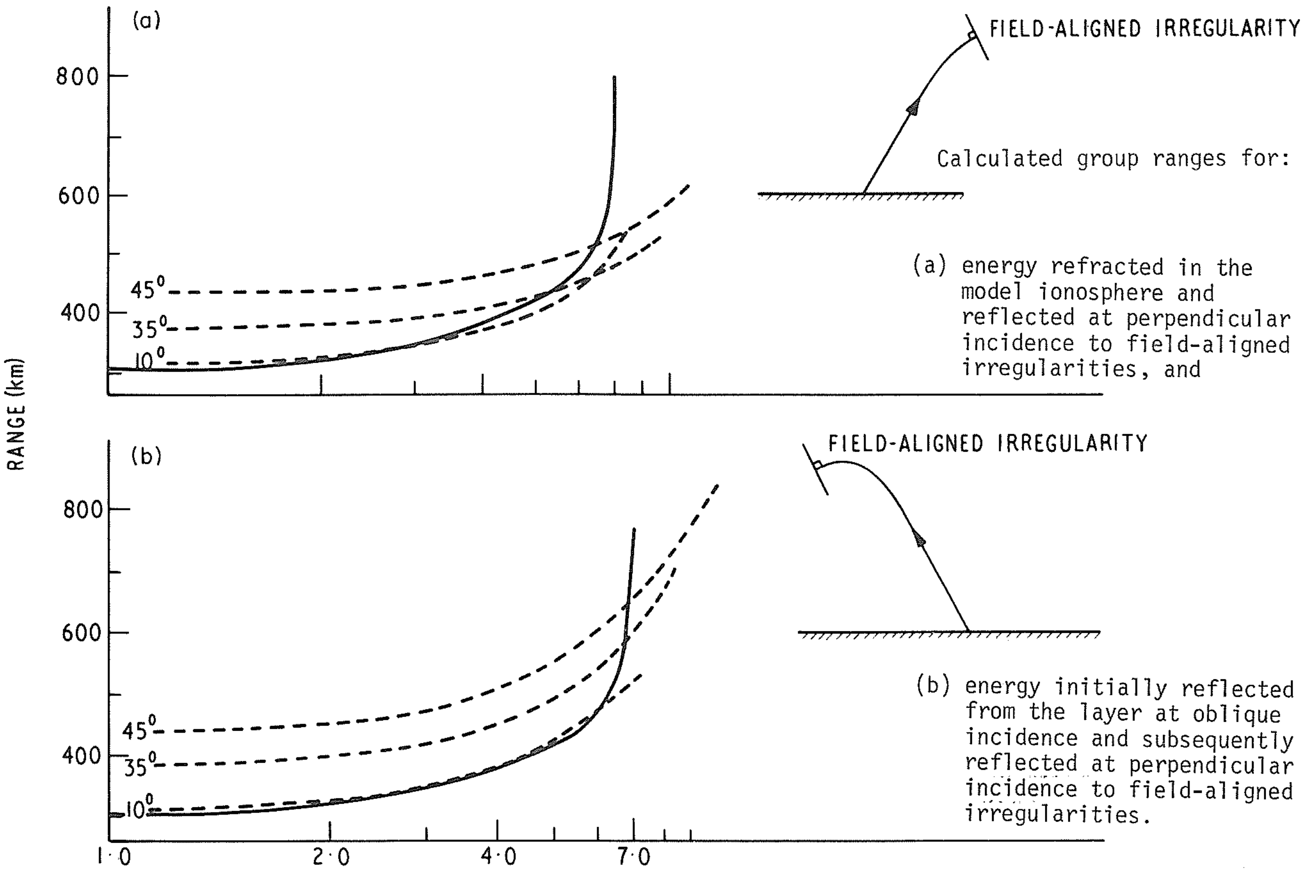


Fig. 2.16

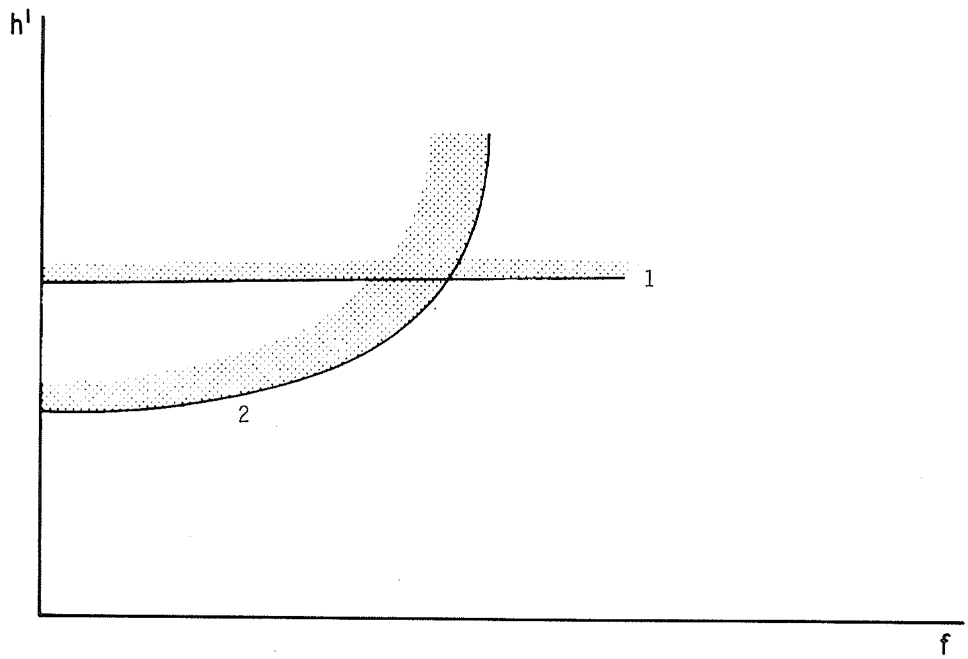


Fig. 2.17 Traces reflected in mode 1 (parallel to field) and mode 2 (perpendicular to field) in Fig. 2.15.

2.75. Lacuna phenomena: Under certain circumstances, traces reflected from a certain range of true height disappear although the remaining traces show that the absorption is either normal or only slightly increased. The name Lacuna (lacune in French) has been proposed for this phenomena, Lacuna being the Latin word for 'gap'. The explanation of Lacuna is still controversial though it is generally agreed that the reflected signal is greatly weakened by scattering or defocussing processes occurring over a limited range of reflection heights. When the equipment sensitivity is high or the phenomenon weak it is possible to see weak reflections spread in frequency and height over parts of the range where normal reflections have disappeared.

Lacuna appears to be closely associated with activity along the auroral oval and are also found at the magnetic poles. It may therefore prove to be a useful tool for studying activity in these zones. It is also closely associated with slant Es seen at high latitudes and has been discussed under the title Slant E condition. [e.g., J. K. Olesen, AGARD, CP 97, 1972, p 27.1-27.19, NATO Paris].

The distinguishing feature of Lacuna is that the amplitude of signals reflected from a certain range of heights is abnormally small. In contrast absorption causes greater losses on the lower frequencies and on the x-mode relative to the o-mode traces. Similarly, when lacuna affects a trace near a critical frequency the signal suddenly disappears or reapprears at normal strenght, abnormal absorption would cause a gradual change with frequency.

When absorption is low, slant Es is common during Lacuna.

The F traces disappear suddenly when Lacuna occurs and reappear suddenly, with relatively little change in shape over the interval.

In practice the lacuna is most often seen on the F1 trace, Figure 2.18, causing a gap from foE to foF1 (cometimes the E trace retardation is also cut off giving a trace at normal E height but looking like an Es trace). This is called F1 lacuna. It can also affect all F-layer traces - total F lacuna. When the sensitivity is high, weak diffuse traces can be detected over part or all of the perturbed height range.

The presence of lacuna phenomena is indicated by letter Y (see Chapter 3). Care must be taken to distinguish between lacuna and the effects of increased absorption, and blanketing by Es. (Section 3 Y).

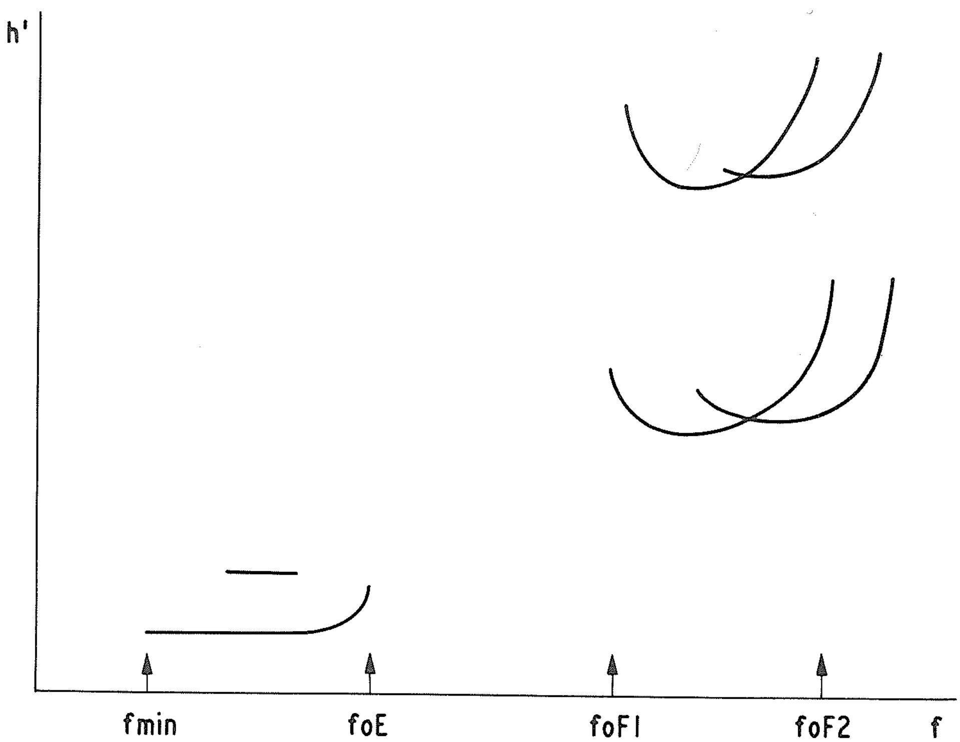


Fig. 2.18 F1 Lacuna

Note:
(a) fmin and multiple traces normal. Therefore not due to abnormal absorption.
(b) Sudden appearance of F2 trace. Therefore not due to retardation absorption.
(c) Retarded part of E trace usually missing but E trace height normal. This is not Es.
(d) A weak diffuse o-mode trace may also be visible over part of the missing F1 trace when sensitivity is high or the lacuna is weak. It is usually strongest near foF1.

NOTES

3.0 Use of Qualifying and Descriptive Letters

Letters are written exclusively in capital (block) letters. They are grouped into two classes, qualifying and descriptive. The distinction between these classes must always be kept clear and letters must be entered only in the appropriate position on the daily tabulation sheet (qualifying letters in the first letter column, descriptive letters in the second).

The letters A,D,E,M,O,T,Z are defined both as qualifying and descriptive letters and the meaning is made clear by the conventional position of the letter on the tabulation sheets.

Wherever doubt arises, the international definitions given under the appropriate letters in sections 3.1, 3.2, or 3.3 should be consulted.

When the data are tabulated by computer methods it is possible to compute the desired characteristic from a measured value for another mode. The International conventions for descriptive letters O and X have been modified to permit this. Thus, a tabulated value (fxEs)-x can then be read by the computer to give (fxEs-fB/2)JX. Similarly for fxI when no scatter is present, a tabulated value (foF2)-O can be read to give (foF2+fB/2)OX (no scatter but value deduced from o trace). It is very undesirable to use these conventions when tabulation is done by hand.

3.1 Qualifying Letters

The qualifying letters give an indication of the reliability of the measurement of a tabulated value. These letters cannot be used to replace a numerical value and must always be accompanied by a numerical value and by a descriptive letter.

Qualifying letters are used for two purposes: as algebraic symbols, and to show that the tabulated value has not been deduced directly from the trace which is normally considered.

When no qualifying letter is used, it is implied that there was no serious difficulty due to interference, noise or instrumental defects in making the measurement; that the interpretation of the ionogram is clear and unambiguous; and that the values tabulated are within the limits of accuracy required for the characteristic.

If no qualifying letter applies, the space provided on the tabulation sheet is filled with a dash (—) or left blank, as may be appropriate to avoid ambiguity and according to the format of the table.

The qualifying letters are: A,D,E,I,J,M,O,T,U,Z. They have the following meanings:

A - Less than. Used only when fbEs is deduced from foEs because total blanketing of higher layers is present. This must be ignored when computing medians - xxx AA is treated as xxx, i.e.fbEs = foEs.

D - Greater than.

E - Less than.

D and E are used as qualifying letters when only limiting values are observed. Accuracy rules for the use of D and E are given in sections 2.2 and 2.7.

When D and E are used in conjunction with ionosonde limits (descriptive letters D,E,W) or limits due to fmin, foE, foF1, descriptive letters B,G, it is essential that the numerical limits should be readily available. Since data are often handled by computer, notes in station booklets can be lost. It is therefore recommended that limit values be written out in full, e.g. xxxEE, unless it is certain that the missing values are easily available. Since median tables are often separated from other data all median values should be written in full whenever a numerical value is available.

I - Missing value has been replaced by an interpolated value.

Interpolations may be performed over a period not exceeding two hours provided that the sequence of records indicates that conditions are varying slowly. Interpolations should be done on an f plot or a diurnal curve since the characteristic need not vary linearly with time. If the gap in the observations is more than 2 hours, or if the characteristic is not believed to be smoothly and slowly varying, no interpolation is permitted. For example, interpolations for h'F and h'F2 should not be made over a height interval exceeding 50 km.

Interpolation may not be used to provide a numerical value in the following cases: (1) when the observed value is replaced by D,E,F,G,L,N or W, (2) for any Es parameter or for fmin.

Interpolation should be used whenever possible to provide a numerical value when the observed value is replaced by C, R or S. The same is true for B in the case of a SID but not in the case of polar black-out.

J - Ordinary component characteristic deduced from the extraordinary component.
This letter applies only to measurements involving critical frequencies and assumes fo = fx-1/2fB [A112I, Fig. 138, A114D]. Whenever the letter J is used, the reason for not scaling the ordinary trace must be indicated by the appropriate descriptive letter.

M(3000) may be obtained even when the ordinary critical frequency is deduced from the extraordinary, provided that the point of tangency of the transmission curve and the ordinary trace can be located. M(3000) is scaled using the deduced ordinary critical frequency, but is not qualified by J. The possible error in deducing fo is normally very small.

M - Mode interpretation uncertain.
This letter is used when there is not enough evidence from the ionogram or sequence of ionograms to show whether the mode was ordinary or extraordinary. It is mainly (but rarely) used with parameters fxI, foF2, foEs or fxEs (where tabulated). The reason for the diffculty is given by the most appropriate descriptive letter. The observed value is treated as if the interpretation was correct but M implies a possible error of fB/2 for frequency characteristics and an undefined error in height and factor characteristics.

O - Extraordinary component characteristics deduced from the ordinary component.
This letter applies whenever it is necessary to deduce the extraordinary characteristic from the ordinary wave trace. It can only be used with characteristic frequencies defined for the x trace, in particular fxI and fxEs. fx is deduced by assuming fx = fo + fB/2.

When the qualifying letter O is used the reason is given by:

(a) The descriptive letter which best shows why the extraordinary characteristic could not be measured.
(b) The descriptive letter M, when there is doubt about whether the ordinary or extraordinary characteristic was measured. The characteristic is treated as O.
(c) The descriptive letter O, when there is no doubt that the ordinary wave characteristic was measured but the reason for the absence of the extraordinary characteristic is complex, doubtful, is near fB, or the x mode could be seen but was not used (see O under descriptive letters, 3.2).

T - Value determined by a sequence of observations, the actual observation being inconsistent or doubtful.
The letter T is applied only to numerical values obtained by 'smoothing' from the f plot and always shows that the actual ionospheric conditions differ from the representative value given in the table. Its use is mainly confined to high-latitude stations where the actual value may be found from the f plot. T is never used to replace a missing value. In such cases interpolations should be performed if possible. See section 6.9.

U - Uncertain or doubtful numerical value.
A tabulated value may be uncertain because the trace is obscured by interference, noise, instrumental defects, spread echoes, deviative absorption, etc., which make the ionogram difficult to interpret. See section 2.2 for the criteria for use of the letter U.

Z - Measurement deduced from the third magneto-ionic component.
The letter Z, used as a qualifying letter, is analogous to the letter J. It applies only to critical frequencies and indirectly to M(3000). Whenever Z is used the reason for not scaling the ordinary trace must be indicated by a descriptive letter.

M(3000) may be obtained even when the ordinary critical frequency is deduced from the third magneto-ionic component, provided that the point of tangency of the transmission curve and the ordinary trace can be located: M(3000) is scaled using the deduced ordinary critical frequency and is qualified by Z. The qualification is necessary because the z trace is always oblique and therefore the deduced ordinary critical frequency is uncertain.

Additional qualifying letters are used in topside soundings and are given in section 5.65.

3.2 Descriptive Letters

Descriptive letters give the main reason for uncertainty in, or absence of a numerical value or indicate the presence of certain phenomena. Although two descriptive letters may be used when the form provides space for three letter symbols, mechanical methods of analysis can handle only one descriptive letter. Therefore only the first descriptive letter can be recognized as an international parameter and it is most important that this letter be consistent with the rules.

The descriptive letters are: A,B,C,D,E,F,G,H,K,L,M,N,O,Q,R,S,T,V,W,X,Y,Z. The following selection rules should be invoked when two letters seem equally applicable:

(a) Always use the letter which most nearly represents the cause of the difficulty.
(b) Always use a letter with a restricted meaning in preference to one with a more general meaning. (This particularly applies to the ambiguity between C and S, or between E and G.)

The descriptive letters have the following meanings:

A - Measurement influenced by, or impossible because of, the presence of a lower thin layer, for example, Es.

This letter is used when a higher layer (such as the F layer) is 'blanketed' by a thin layer (such as Es). Blanketing occurs when an Es layer prevents the observation of echoes from a higher layer (Figs. 3.1, 3.2, 3.3).

Es can blanket the normal E trace also in which case foE, h'E are replaced by A, Fig. 3.2.

When complete blanketing occurs (i.e. no reflections from higher layers appear at all), it is not possible to evaluate fbEs with certainty. However the statistics of fbEs lose much value if these high values are not numerical. The solution is to use fbEs = (foEs)AA in these cases. This can be misleading if foEs is deduced from a weak trace. When the Es does not vary with position, the top frequencies of the multiple order traces decrease slowly with order and the top frequency of the second order trace corresponds approximately with the frequency at which an F trace could have been seen. The first order E trace is also often stronger below than above this frequency. When the Es is varying with position the second order trace (or more seldom higher order traces) can be seen at frequencies higher than the top frequency of the first order trace. In practice when total blanketing is found, the difference between foEs deduced from the solid trace and fbEs is negligible compared with the variability of fbEs in space and time. Thus rule (a) below is usually applicable.

(a) If the trace is solid to foEs, tabulate foEs AA (Fig. 3.1).

(b) If the trace is not solid to foEs, or if two or more multiple traces are present with the value of the top frequency of the second order trace much smaller than foEs (Fig. 3.2) tabulate the value of foEs deduced from the top frequency of the second order trace with qualification AA respectively. (Note: If these values have to be deduced from the x-mode trace, AA should be used in preference to JA in cases (a) (b).). Values of fbEs deduced using foEs deduced from the solid part of the trace and rule (a) should usually agree with the value deduced from rule (b) within the accuracy rules for limit values. Otherwise rule (c) is more appropriate.

(c) When rules (a) (b) cannot be used, the best estimate of foF2 gives fbEs, fbEs = (foF2)DA. This should be found from the sequence of foF2 values near the time involved or from corresponding values on other days.

Es traces may blanket over the lower part of their frequency range and not over the higher part, Fig. 3.3, [A88I, Fig. 77; A96I, Fig. 87], [B IIB 54 Johannesburg noon, IIB 55 Dec., IIB 57 June, IIB 66 June].

Blanketing differs from the occultation of a normal layer (e.g. F1) by a lower thick layer (e.g. E) in that the traces of the higher layer will not show any additional group retardation near the blanketing frequency [A88I, Figs. 76, 77, 78; A96I, Fig. 90]. Compare Fig. 3.3 and Fig. 3.4.

Normally a blanketing Es trace is strong but when the non-deviative absorption is great - fmin large - the trace may appear to be weak. Comparison of the Es trace with that of the higher layer shows clearly when blanketing is present, Fig. 3.5.

When the minimum frequency reflected from higher layers is greater than foEs, descriptive letters C, R, S or Y should be used to describe fbEs as appropriate. The use of A should be restricted to cases where blanketing is clearly indicated. Y is most commonly the most appropriate, Fig. 3.6. (see also section 2.75, Fig. 2.18).

A difficult situation to handle is when the only trace appearing on the ionogram is a weak Es echo over a rather small frequency range with a comparatively high value of fmin (Fig. 3.5). In such cases one should study the series of preceding and following ionograms to determine where the F-layer critical frequencies are likely to be, to decide whether the F-region characteristics should be scaled as missing because of blanketing (A) or absorption (B). Another helpful guide in this situation is a knowledge of the expected range of frequencies of the F-region echoes, obtained from the previous day's scaling or from monthly median values. If the Es echo first appears in a range of frequencies well above the expected range of F-region echoes, the letter B should be used. If the virtual height is below 95 km, the weak trace is probably Es type d, the absorption is great and letter B should be used for all parameters except Es type.

Frequently in equatorial regions and sometimes at higher latitudes Es echoes are recorded in the same height range as regular E-region echoes, the latter being 'obscured' by the Es traces. This frequently occurs with the q type of Es. Though blanketing is probably not taking place the use of the letter A to describe this obscuration is permitted [A96I, Fig. 98].

Letter A is also used when a multiple order Es trace prevents accurate measurement of h'F or h'F2.

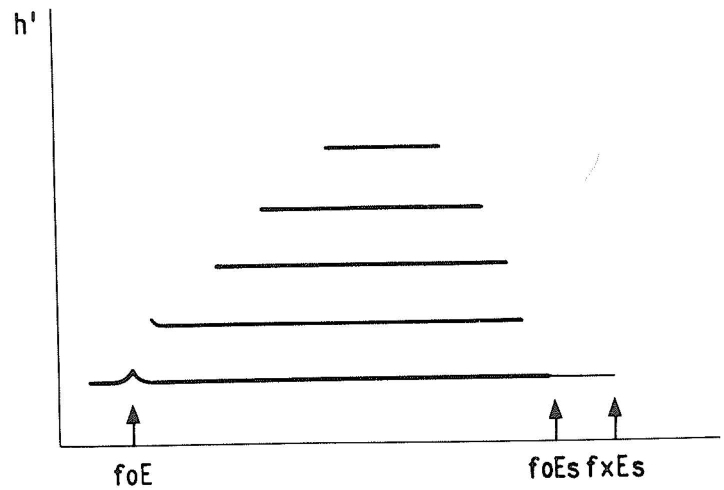


Fig. 3.1 Complete blanketing

(i) All F-layer parameters replaced by A .
(ii) If x trace distinct as shown here foEs can be read directly, fbEs = (foEs)AA .
(iii) If x trace not distinguished, foEs = (fxEs - fB/2)JA.
Deduce fbEs from second order as in Fig. 3.2.
(iv) foE should be extrapolated if possible to give (foE)-A, otherwise use cusp value and UA, (foE)UA.

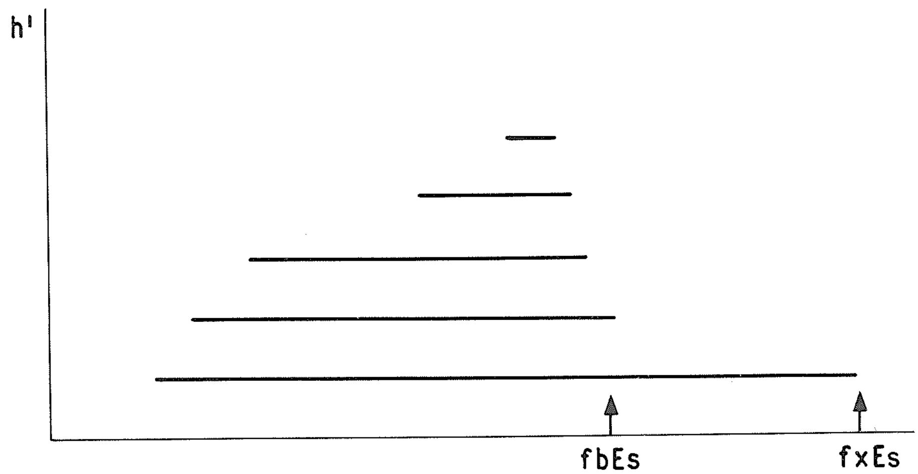


Fig. 3.2 Complete blanketing with consistent multiple traces

(i) All F-layer and normal E-layer parameters replaced by A.
(ii) Deduce foEs from fxEs, foEs = (fxEs - fB/2)JA.
(iii) Deduce fbEs from multiples, fbEs = xxxAA.
(iv) If multiples not consistent, e.g. top frequency >fxEs, use most probable value of foF2 deduced from sequence or other days with DA; fbEs = (foF2)DA. Discrepancies less than those allowed by the accuracy rules for limit values are ignored in applying this.

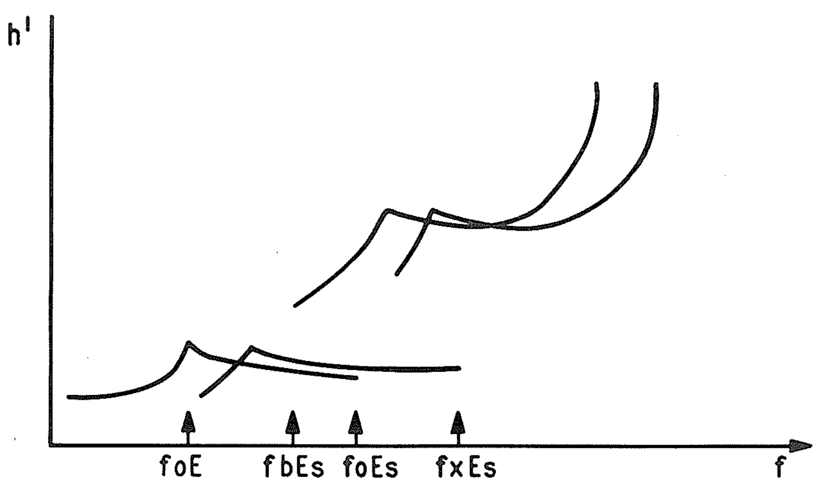


Fig. 3.3 Partial Blanketing

h'F replaced by A. Note if F trace nearly horizontal (see extrapolation) use lowest value of h'F with EA (h'F)EA. h'E = xxx h'Es = yyy.

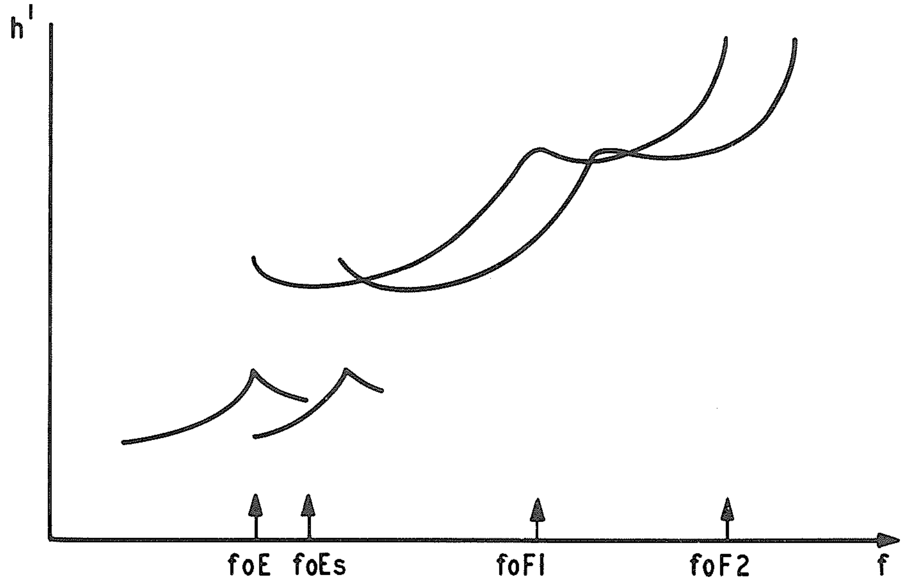


Fig. 3.4 Occultation of F by a thick E Layer

fbEs = (foE)EG
Note: In this case h'E is given as (h'E)EB
h'Es is given as (h'Es)EG

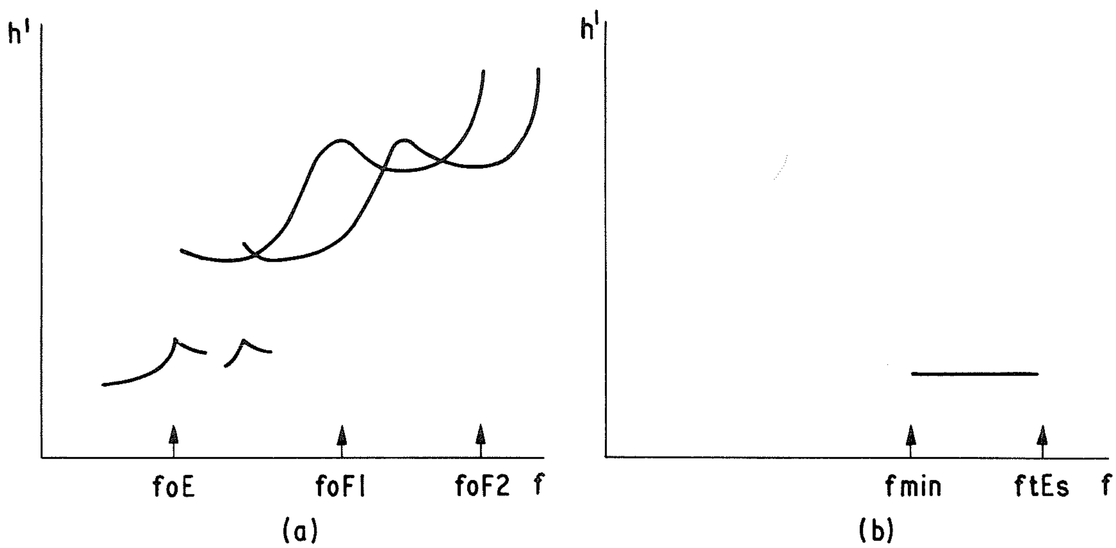


Fig. 3.5 Distinction between A and B

(a) absorption normal, corresponding time of day to (b)
(b) absorption high

(i) If in (b) fmin >foE in (a), h'E and foE replaced by B
<foE in (a), h'E and foE replaced by A

(ii) If in (b) fmin >fofl in (a), h'F and foF1 replaced by B
<foF1 in (a), h'F and foF1 replaced by A

(iii) If in (b) fmin >foF2 in (a), h'F2 and foF2 replaced by B
<foF2 in (a), h'F2 and foF2 replaced by A

(iv) For this case: foEs = (ftEs)MB
fbEs = (foF2)DA

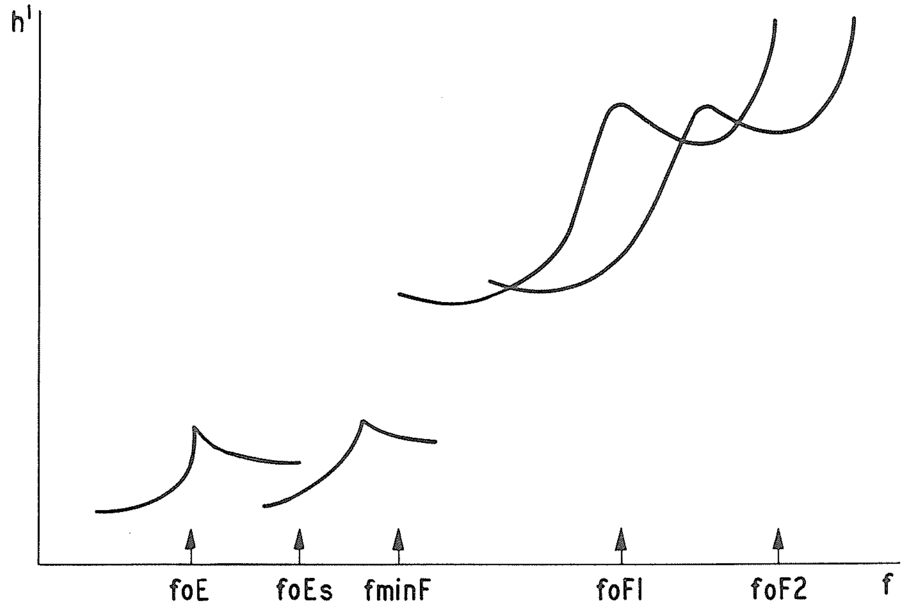


Fig. 3.6 Lacuna Case

fminF >foEs
fbEs = (foEs)EY

Note: Same convention applies if x trace is missing or if the F trace shows no retardation at lowest frequency.

B - Measurement influenced by, or impossible because of, absorption in the vicinity of fmin.

This letter applies only to the effects of non-deviative absorption. Absorption of this type is roughly measured by fmin (Figs. 3.5, 3.7, 3.8, 3.9) [A101I, Fig. 111; A112I, Figs. 128, 129, 144].

If the trace is well defined at lower frequencies and missing at a higher frequency, the letter B must not be used. In such cases the letter R may be applicable (Fig. 3.9) [A112I, Fig. 137; A88I, Fig. 81].

When neither Es nor E echoes are observed but fmin is above the lower limit of the ionosonde and absorption is clearly indicated, foEs and fbEs are tabulated as less than the numerical value of fmin with descriptive letter B [A88I, Fig. 67]. h'Es is replaced by B (Fig. 3.7).

During total black-out or SID, use B for all characteristics including fmin. This is the only instance when letter B can be applied to fmin.

At stations using gain runs, it may happen that the medium-gain ionogram is blank because of absorption, so that fmin must be recorded as B. If traces appear on the high-gain record they should be scaled for all characteristics except foEs, fbEs despite the entry B in the fmin table.

When fmin is within about ± 10% of a critical frequency, the numerical value is perturbed by the relatively large retardation (deviative) absorption present. The fact that fmin is no longer a reliable measure of non-deviative absorption can be indicated using the convention (fmin) UR for these cases. [This local rule should be used when fmin is a measure of non-deviative absorption.]

Care should be taken to distinguish between high absorption at night (letter B) and absence of traces due to foF2 being below the lowest recorded frequency (letter E). The interference and noise level on the ionogram is usually detectably less than on normal ionograms in the former case but is unchanged in the latter. The time variation of foF2 also usually suggests when an E condition is likely to occur, Fig. 3.10.

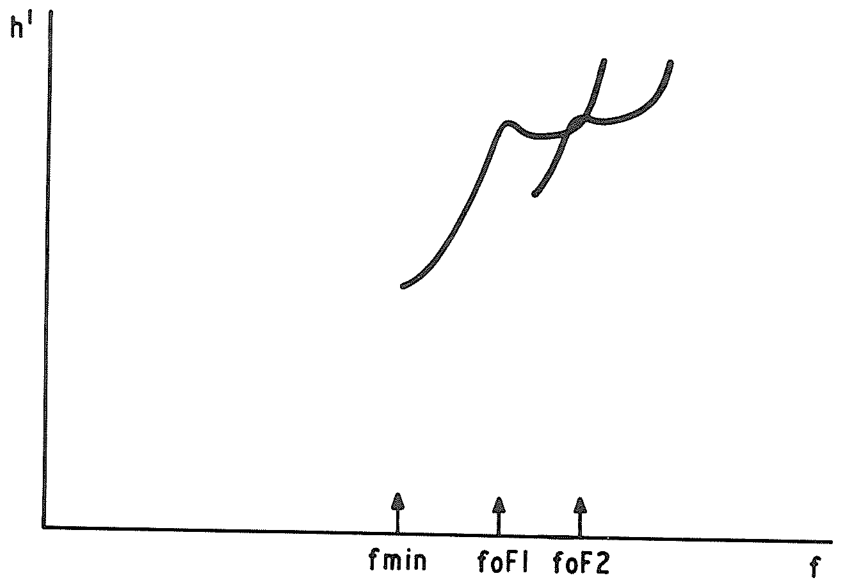


Fig. 3.7 High absorption in daytime

Use of B, foE, foEs, fbEs tabulated as (fmin)EB
h'E, h'Es replaced by B
h'F replaced by B unless within accuracy limit of normal value, then use (h'F)EB

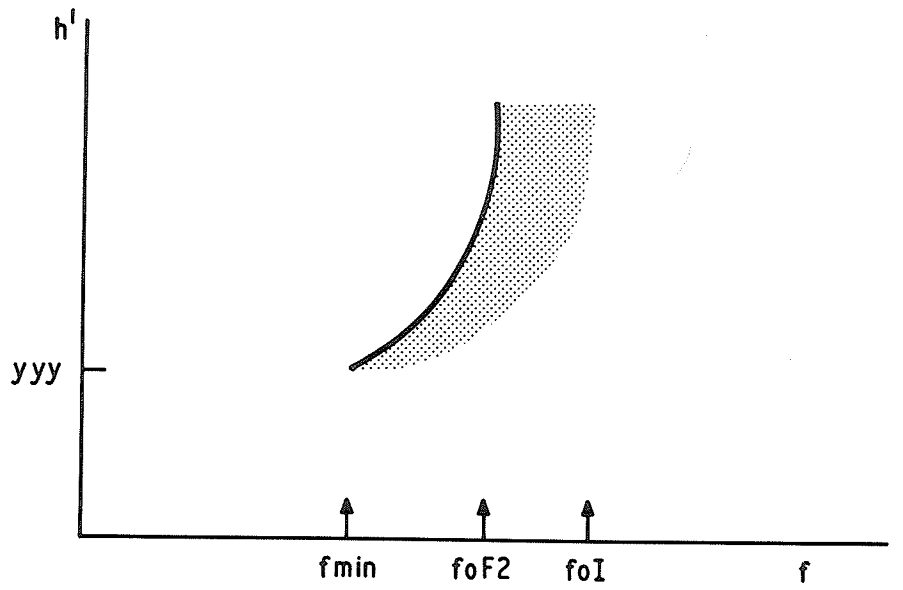


Fig. 3.8 High absorption at night

Use of B, foEs, fbEs tabulated as (fmin)EB
h'Es replaced by B
h'F tabulated as (yyy)EB
fxI tabulated as (foI + fB/2)OB

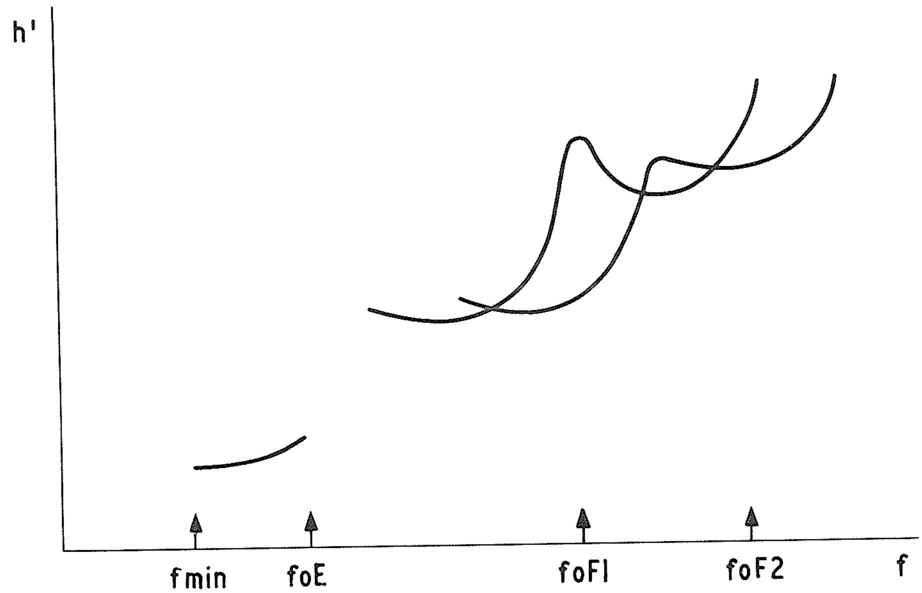


Fig. 3.9 Distinction B and R

foE is (foE) -R or (foE)UR depending on gap width (see accuracy rules)
Note: fmin determined by E not F trace.

C - Measurement influenced by, or impossible because of, any non-ionospheric reason.

C is used to explain missing records due to equipment or power failure, interference due to other local equipments (e.g. transmitters), or when it becomes necessary to take the ionosonde off the air to prevent interference with other installations. It is used to explain a doubtful measurement where there is uncertainty regarding the frequency or height scale (unusual expansion or compression of the record, poor identification of frequency markers, etc.) such that the measurement is in doubt by more than the nominal accuracy required of the measurement.

C is used to explain a doubtful measurement when there is uncertainty regarding the time of observation (poor legibility or absence of print-time, clock errors) such that the time of the record is uncertain by not more than 5 minutes. It may be used to explain a doubtful measurement due to poor equipment response in part of the frequency range. Finally, C is used to explain doubtful or missing values because of some failure or omission on the part of the operator (fogged or streaked film, out of film, etc.).

When part of the ionogram is unusable because of an instrumental fault, C, the rules for extrapolation or interpolation are the same as for letter, S.

D - Measurement influenced by, or impossible because of, the upper limit of the normal frequency range.

Care should be taken in the daily and monthly tabulations to distinguish the descriptive letter D from the qualifying letter D. When the upper limit is adjustable and is less than the published upper limit of the normal frequency range, the actual upper limit frequency, xxx, should be recorded, xxxDD.

E - Measurement influenced by, or impossible because of, the lower limit of the normal frequency range.

If foF2 is presumed to be at a frequency below the lower limit of the ionosonde, the descriptive letter E is used in place of values foF2 and h'F. Figs. 3.10a,b show an example where no principal F trace was present and the f plot suggests foF2 is below the lower limit. The absence of the F trace is not in itself enough justification to use the descriptive letter E. Always judge from a sequence of records and from the noise and interference present on the ionogram; the letter A, B, or S is frequently the appropriate one [A112I, Fig. 135].

If foF2 is so close to the lower frequency limit of the ionosonde that the trace does not become horizontal, then the height of the echo at the lower frequency limit of the recorder is tabulated for h'F with the qualifying letter E (less than) and the descriptive letter E (Fig. 3.11). [A112I, Fig. 143].

During night hours when no Es echoes appear on the ionogram and fmin is below the lower frequency limit of the ionogram, the descriptive letter E alone is tabulated for foEs, fbEs, h'Es and fxEs where tabulated (Figs. 3.10b, 311). The descriptive letter E is not used in this way when a trace from a thick E layer is present on the ionogram (e.g. during daylight hours) (see letter G). The descriptive letter E may not be used if fmin is greater than the lower limit of the ionosonde.

When the lowest frequency of the ionosonde is changed at different times of day (as is usual for ionosondes employing switched bands), it is important that the actual lowest frequency in use be tabulated at least in the fmin tables whenever a limit value, (fmin)EE, is present, preferably this should be done for all parameters qualified EE.

When the critical frequency is lower than the lowest frequency of the ionosonde the appropriate symbol is E not G.

Care should be taken in the daily and monthly tabulations to distinguish the descriptive letter E from the qualifying letter E.

Where the ordinary characteristic is below the lower limit of the ionosonde but the corresponding extraordinary characteristic is present, this should be measured and the corresponding ordinary characteristic deduced and qualified by J and described by E.

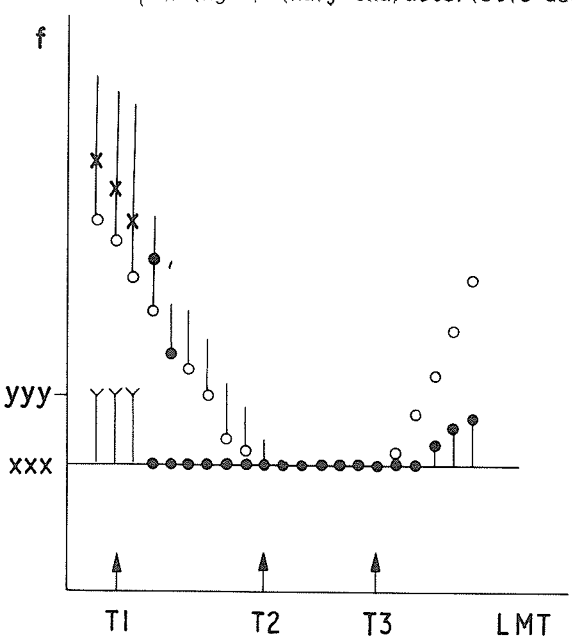


Fig. 3.10(a) Section of f plot showing use of EE

Lower limit frequency of ionogram xxx
Near T1 fmin is yyy ES
foEs yyy ES
fbES yyy ES
Between T2 and T3 all parameters replaced by E
(more accurately xxx EE)

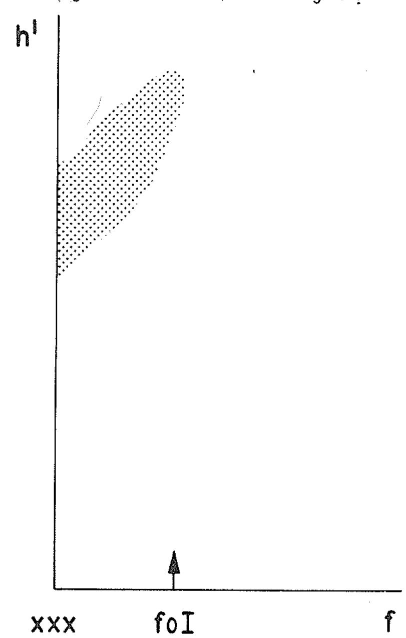


Fig. 3.10(b) Ionogram at time T2, Fig.3.10(a)

fxI = (foI + fB/2)OE
All other parameters replaced by E
(more accurately xxx EE)

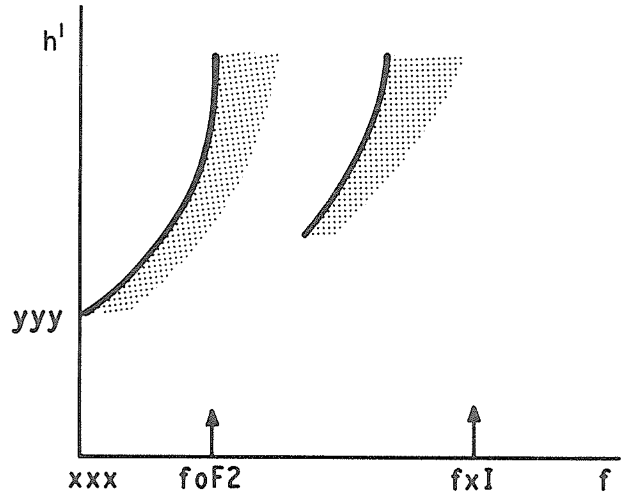


Fig. 3.11 Use of EE

Lowest frequency on ionogram is xxx
fmin (xxx)EE or less accurately E
h'F (yyy)EE
foES, fbES, fxEs and h'ES - - - E

F - Measurement influenced by, or impossible because of, the presence of spread echoes.

The critical frequency or virtual height of a layer is usually modified by the presence of spread echoes at appropriate heights, even when the reading accuracy of the characteristic is unaffected, and the descriptive letter F should be used in these cases. Whenever possible, a numerical value for the critical frequency should be tabulated, but caution should be used not to scale traces which are likely to be oblique (see section 2.7). Letter F may also be used to describe or replace values of virtual height when severe spread echo occurs.

The procedures have been fully discussed in section 2.7 and are therefore only summarized here.

The first step is to decide whether the main traces are due to a horizontal or a tilted layer, section 2.7, Figs. 2.6, 2.7, 2.8, 2.10. If the former, as is most usual except at high latitudes or during storms:

(a) the first choice is the principal trace (Figs. 3.12(a) and 2.10) [A98I, Fig. 101; A100I, Fig. 105; A104I, Fig. 122; A112I, Fig. 136].

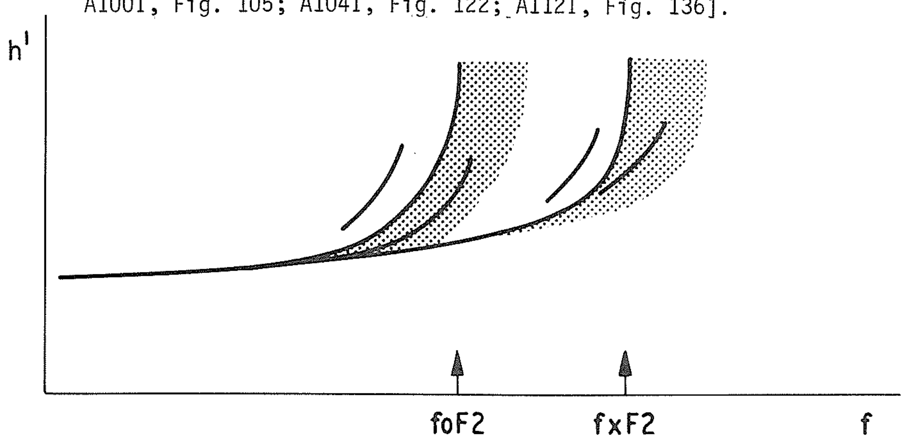


Fig. 3.12(a) Principal trace

(i) The principal trace is usually more solid than other traces.
(ii) For the principal trace fxF2 - foF2 = fB/2. This is not always true for subsidiary traces.

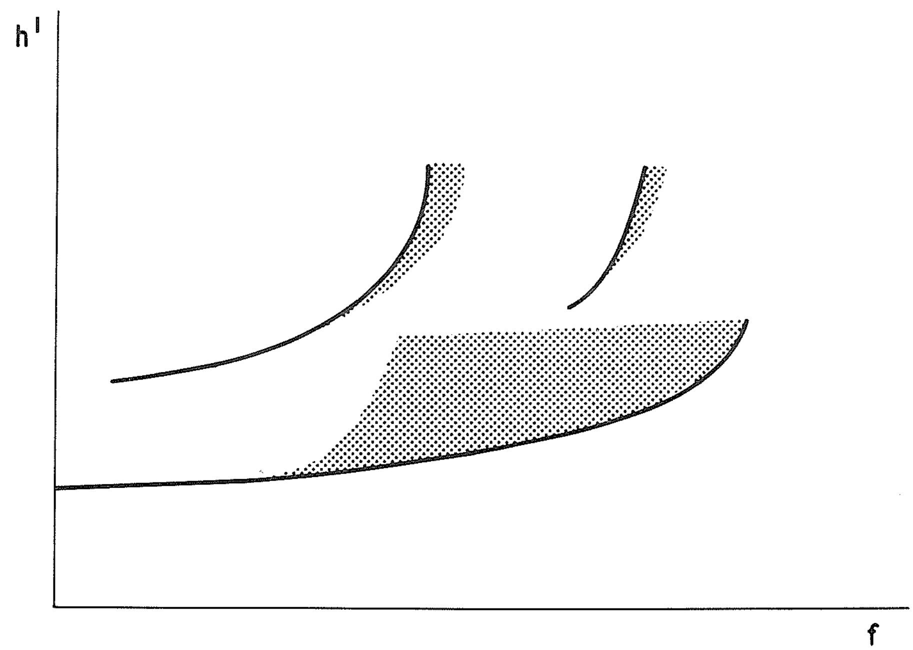


Fig. 3.12(b) Use of multiple orders

A principal trace can often be seen in the second or higher order when not visible on the first order. Again it is usually relatively solid and fxF2 - foF2 is often close to fB/2. The latter, when true, confirms the interpretation but is not essential.

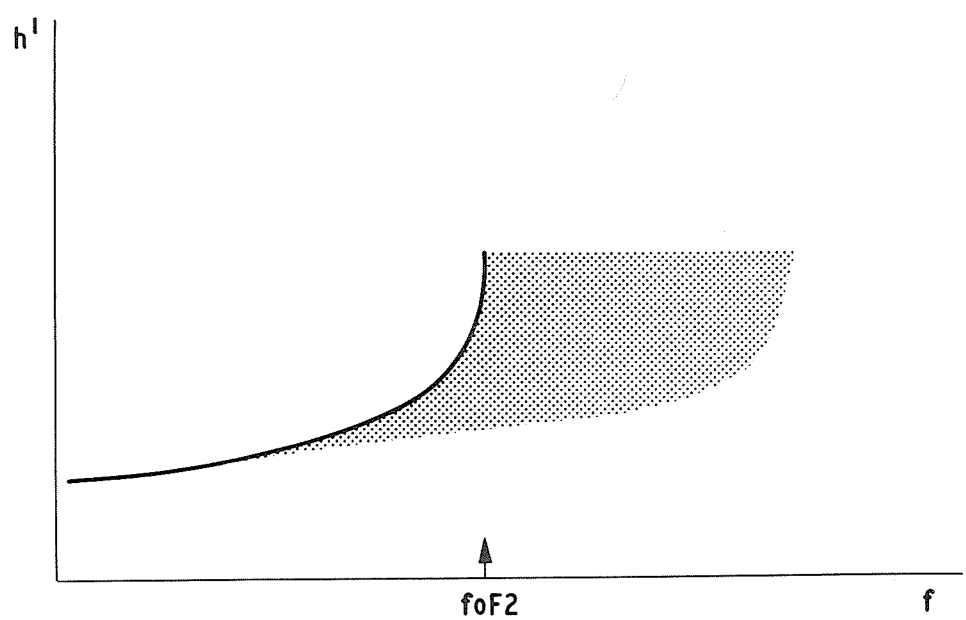


Fig. 3.12(c) Use of limit edge

When the main trace is due to a horizontally stratified layer, the lower frequency edge of the spread gives foF2. Very often a principal trace can be seen to define this edge. (see also Figs. 2.4, 2.11).

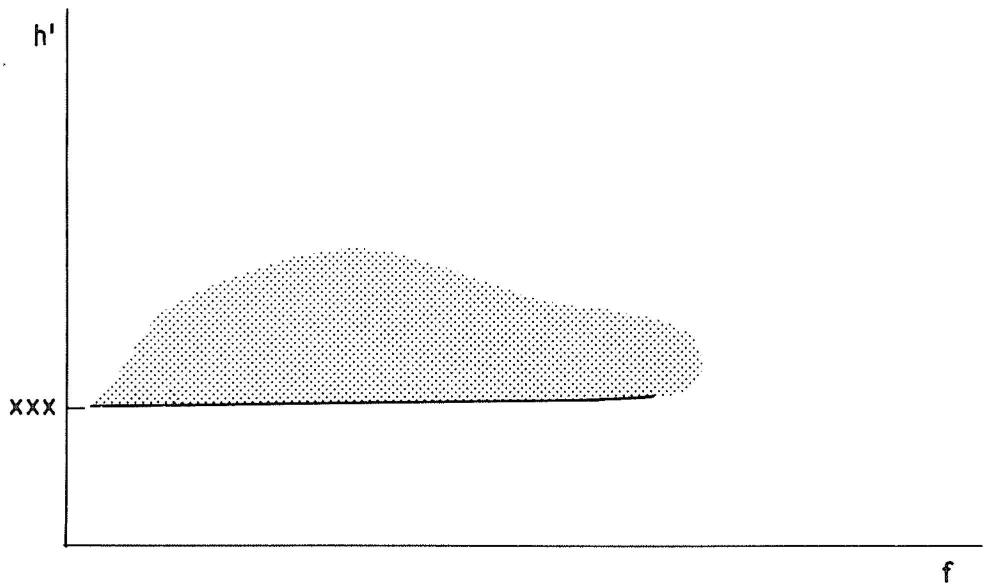


Fig. 3.13 No principal trace

Use of F foF2 replaced by F
h'F xxx-F or xxxUF depending on whether or not lower edge clear.

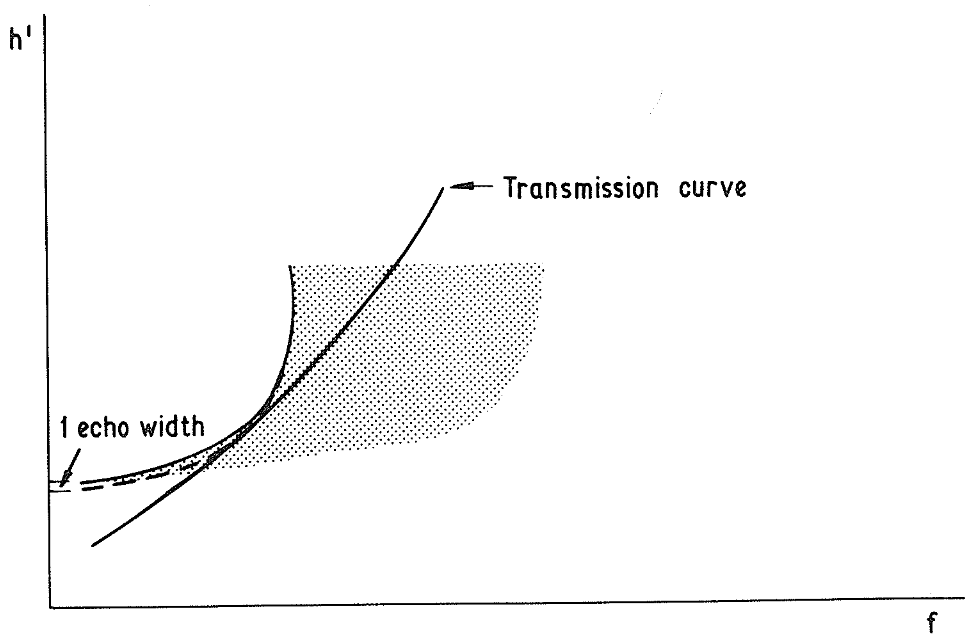


Fig. 3.14 Scaling of M(3000)

from Ionogram with well defined inner edge to scatter pattern

—— observed inner edge
- - -constructed trace edge

(b) the second choice is guidance from the multiples (Figs. 3.12(b) and 2.11) [A104I, Figs. 123, 124].
(c) the third choice is a well-defined 'inside edge' of the spread (Fig. 3.12(c) [A40I, Fig. 29; A88I, Figs. 68-70].
(d) the fourth choice is a limiting value used with the qualifying letters D or E (see section 2.22, paragraph c).
(e) the fifth choice is the descriptive letter F without any numerical value (Fig. 3.13) [A104I, Figs. 124 and 125]. For tilt cases see section 2.7.

Procedures to be followed in scaling M(3000) when spread echoes are present are as follows:

(a) The first multiple echo may be used as a guide to help determine the location of the main echo.
(b) If there is a well-defined 'inside edge' to the trace, proceed as follows: construct a curve, each point of which is one echo width below the corresponding point of the inside edge. Scale the factor from the reconstructed trace, Fig. 3.14.
(c) If these methods fail, the descriptive letter F without any numerical value is tabulated.

Letter symbol F can never be used with parameters fxI, h'I, dfS, as these characteristics are most important when spread F is present.

G - Measurement influenced or impossible because the ionization density of the reflecting layer is too small to enable it to be made accurately.

This letter is used when foF2 is equal to or less than foF1. In this case tabulate the numerical value of foF1 for foF2 and use the qualifying letter E (less than) and the descriptive letter G [A88I, Fig. 84; A100I, Fig. 108]. For M(3000) F2 and h'F2 tabulate the letter G with no numerical value (Fig. 3.15).

The same conventions apply when foE is equal to or greater than foF2, foF2 = (foE)EG, (usually a night E case).

The letter G is used for Es characteristics in all cases when no Es traces are observed although regular E-layer traces are present. The ionogram must show regular E or retardation at the low frequency end of the ordinary wave F-region trace (Fig. 3.16) [A112I, Fig. 132; A88I, Fig. 72].

A numerical limit should always be given with EG when night E is present and is helpful to the user when foE varies greatly in a month. Usually, however, the variability of foEs is so much greater than that of foE that a median foE is adequate and this minimizes work.

All median and quartile values of foEs or fbES should be numerical, the value of median foE is inserted if these would otherwise be G.

If, because of interference, it is not possible to obtain numerical values for foE, yet the presence of the E trace is observable, it is proper to use G for the missing Es characteristics (Fig. 3.17).

G is used to explain a doubtful or limiting value of h'Es when the low frequency end of the Es trace is affected by group retardation and the trace does not become essentially horizontal (Fig. 3.18) [A112I, Fig. 134]. This applies in the case of Es type c and Es type h.

For Es type ℓ, when foEs is less than foE, the numerical value of foEs and fbEs should be described by the letter G (Figs. 3.19 and 3.20). This is necessary for median determination.

Note: Two common difficulties concern the proper use of G or B and of G or E. For G to be used there must be positive evidence of the presence of a reflecting lower thick layer, i.e., any group retardation due to its critical frequency is visible on the ionogram. If the trace is missing because of high absorption the appropriate letter is B; if the critical frequency falls below the lowest limit of the ionosonde the associated characteristics are replaced by E. Stations making gain runs should use the high-gain sounding to determine whether the letter G applies.

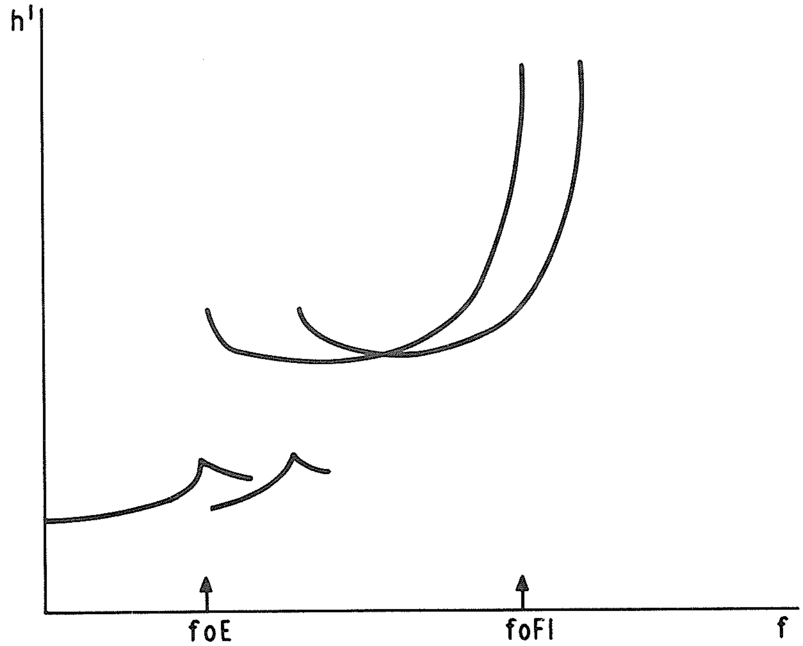


Fig. 3.15 G condition. No F2 trace visible

foF2 is given by (foF1)EG (less accurately by G)
h'F2 is given by G
M(3000)F2 is given by G
Note foF1/foE will be approximately given by the normal ratio when foF2 is present.

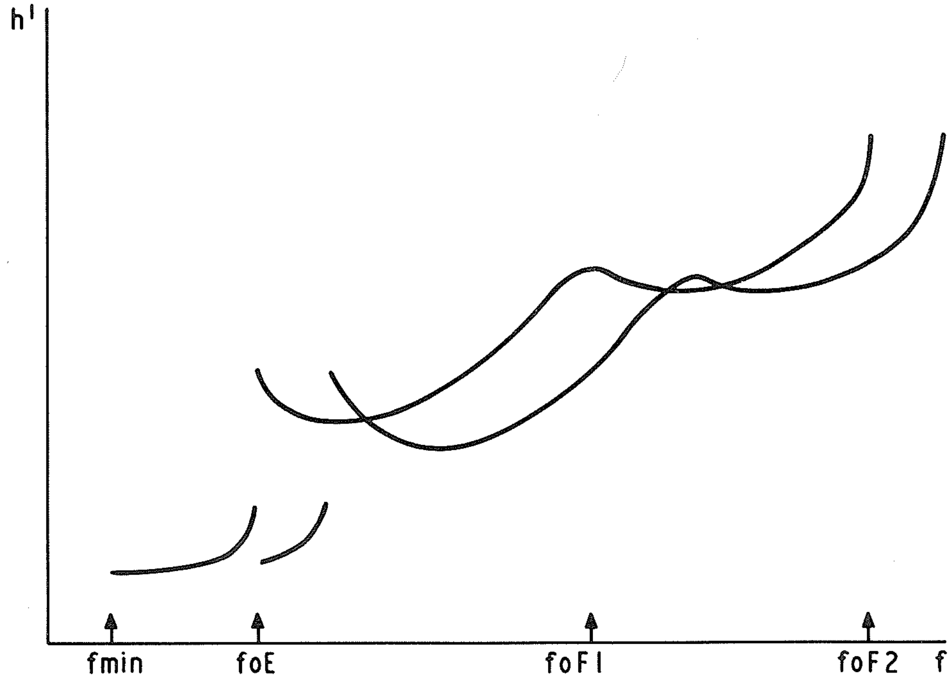


Fig. 3.16 G condition. No Es trace visible

foEs given by (foE)EG
fbEs given by (foE)EG
h'Es replaced by G

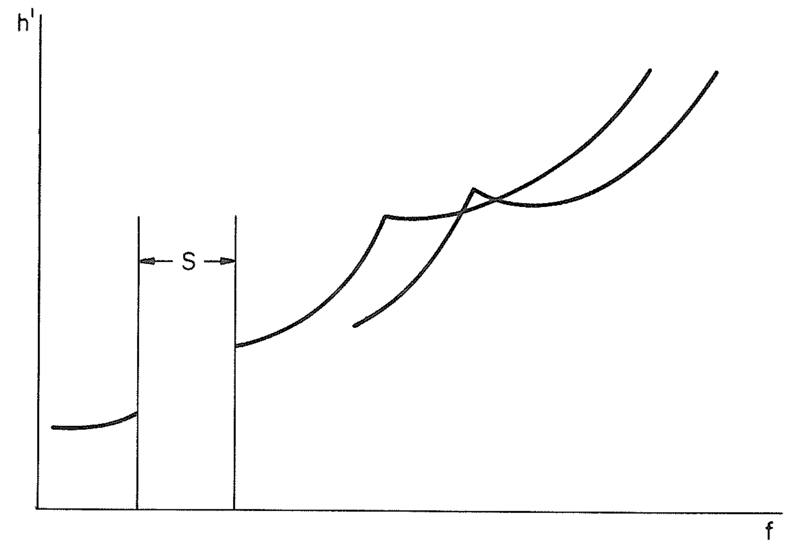


Fig. 3.17 Use of G,S when interference is present

foE = S, foEs = G, fbEs = G

More accurately use median values of foE to give
foEs = (foE)EG, fbEs = (foE)EG.

h'Es = S or G, former preferable.

A similar pattern due to instrumental fault would show C instead of S.

Fig. 3.18 Use of G with h'Es

h'Es = (h'Es)EG

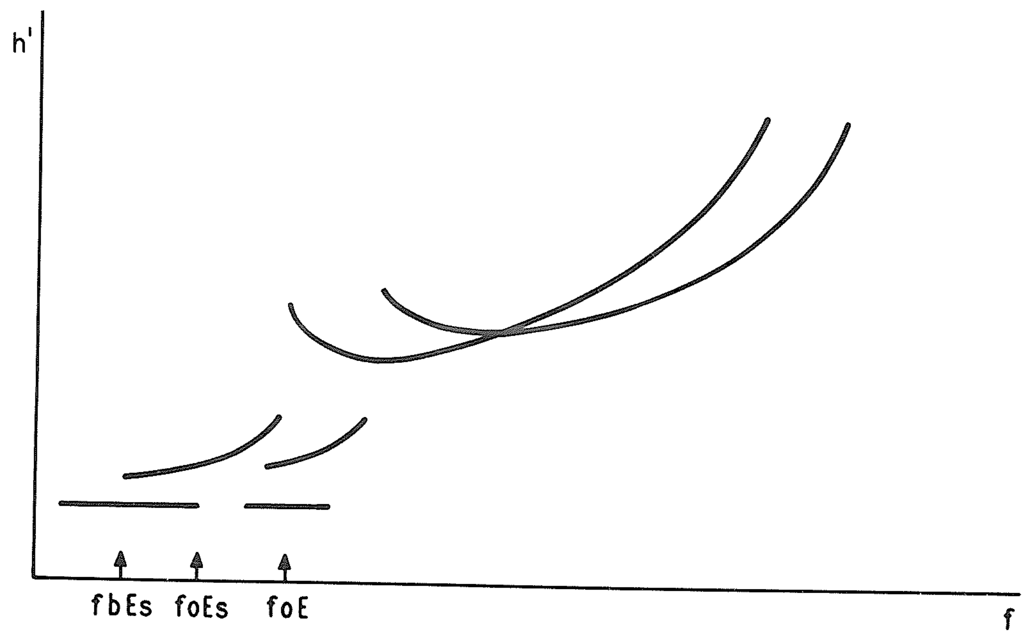


Fig. 3.19 Use of G to show foEs less than foE

foEs is written (foEs)-G
fbEs is written (fbEs)-G

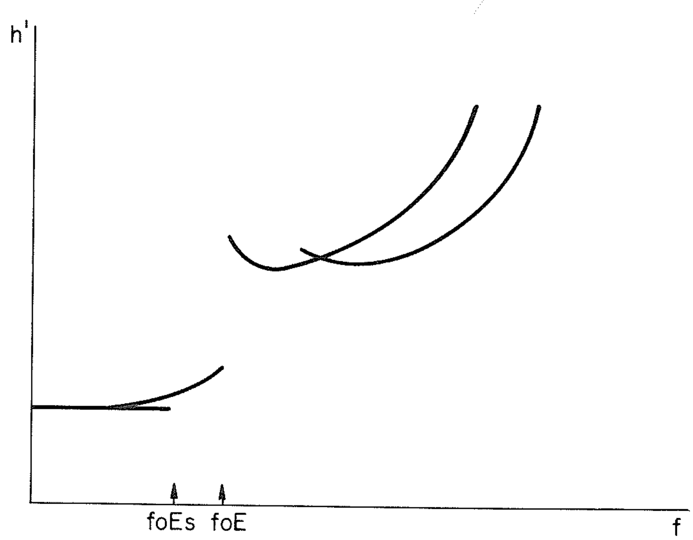


Fig. 3.20 Use of G to show fbEs less than foE

foEs is written (foEs)-G

In this figure fbEs is less than the lowest frequency recorded xxx. fbEs is written (xxx)EG or, in approximate form, E.

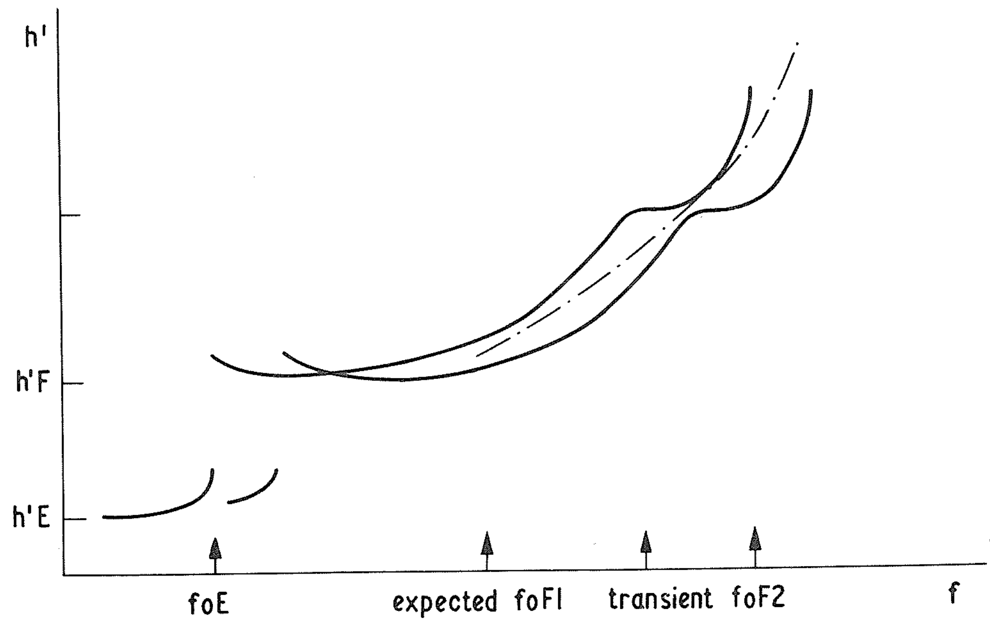


Fig. 3.21 Stratification H influencing foF2 and M(3000)F2

— · — · — · transmission curve touches abnormal trace
foF2 given by (foF2)-H
M(3000)F2 given by (M(3000)F2)UH
h'F2 is transient and not recorded

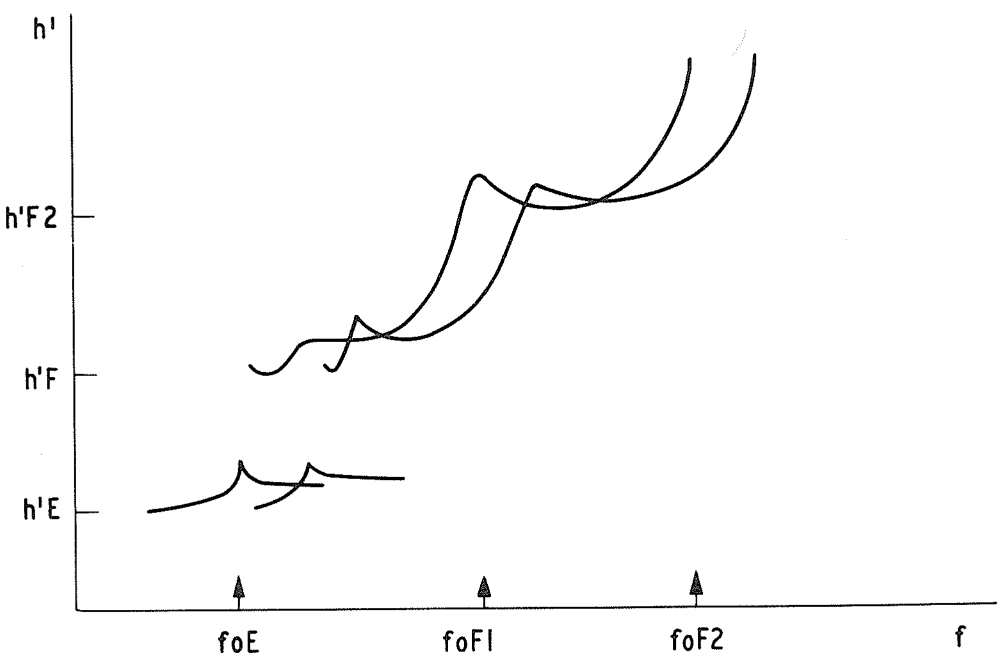


Fig. 3.22 Stratification influencing h'F

h'F given by (h'F)UH.
(when the transient can be easily seen U is needed.)

H - Measurement influenced by, or impossible because of, the presence of stratification.

This letter may refer to the traces of any regular layer. It is used when the trace shows a retardation cusp or point of inflection not normally scaled at the station (Fig. 3.21). In most cases the phenomena are transient [A88I, Figs. 81, 83; A98I, Fig. 91; A128I, Fig. 148]. In Fig. 3.21 the expected value of foF1 is at a much lower frequency than the stratification shown.

The presence of abnormal stratification usually modifies the critical frequency or virtual height of the layer, as can be seen from the f plots or h' plots respectively. The descriptive letter H is therefore necessary in these cases, even when the reading accuracy of the characteristic is unaffected, Fig. 3.22.

The qualifying letter U should be used when comparison of different components, orders of reflection or a sequence of ionograms shows that the uncertainty of interpretation exceeds the allowed limit. The definitions of the normal characteristics should be used to identify the appropriate value in doubtful cases. Thus, for the F2 trace, the highest critical frequency and lowest virtual height should be tabulated.

M(3000) should always be determined using the trace of the regular layer as a whole (e.g., F2, F1 or F1.5 when scaled systematically) (Fig. 3.21; point-dash line: transmission curve).

K - Presence of a night E layer.

This letter is used to distinguish cases where foE is determined by a 'night E' layer - a thick layer in the E region generated by particle precipitation and having a critical frequency significantly higher than the normal solar controlled E layer. This letter has been devised primarily to draw attention to particle-generated thick E layers found at hours when foE due to the normal E layer is also present; e.g., for low frequency ionograms and for stations at high latitude in summer months. Night E is seen only on disturbed days. Lower case k is inserted in the Es type table also when night E is present.

When the E trace is totally blanketing the distinction between a thick layer (night E) or a thin layer with apparent retardation at the top frequency (Es type r) cannot be certain. In cases of complete doubt classify as Es type r. The following criteria should be used:

(a) When absorption is small, night E gives both o and x modes and one or more multiple traces extending to near foE; whereas, Es type r either shows no multiple traces or multiples which stop at a frequency appreciably lower than foEs. When any of the multiple traces are within the accuracy rule limits for use of U with foEs, the distinction type r or night E is not significant; scale as night E, foEs = fbEs = foE, entry (foE)-K.

(b) When absorption is high a solid trace is more likely to be due to night E than to Es type r, and a weak trace or trace showing spread is more likely to be Es type r than night E.

L - Measurement influenced by or impossible because the trace has no sufficiently definite cusp between layers.

The letter L is used for F-region characteristics (Fig. 3.24). The criterion for deciding the use of L is the relative slope of the F1 and F2 traces. (See also section 6.4 for detailed rules).

The conventions given below are intended to give a quantitative guide as to when L should be used by comparing the slope of the F1 trace with the slope of the transmission curve. If the latter always cuts the former L must be used. If a tangent point can be found (equal or greater slope of F1 trace relative to transmission curve) a numerical value is possible.

(a) The conventions for using L when scaling foF1 are:

(i) When the shape of the F trace shows that no F1 stratification is present no entry is made. (F traces never concave downwards) (Fig. 3.23).

(ii) When the transition from the F1 trace to the F2 trace is smooth and ill defined the probable error in estimating the true value of foF1 will

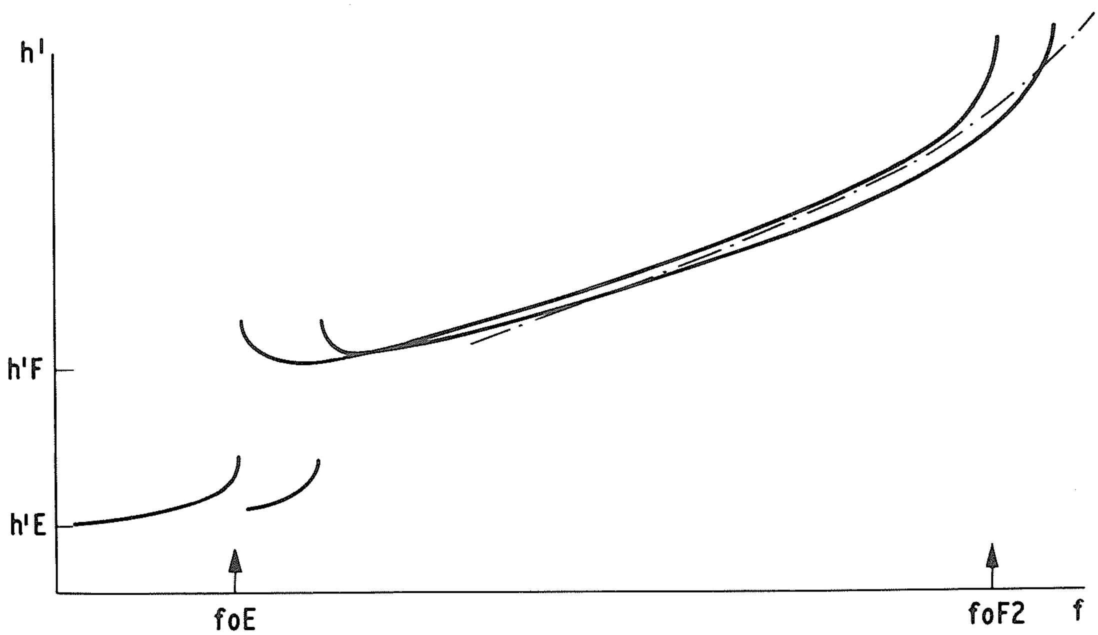


Fig. 3.23 Use of L

— · — · — · transmission curve touches o trace at one point only.
foF1, h'F2 no entry in tables. foF1 no entry on f plot.

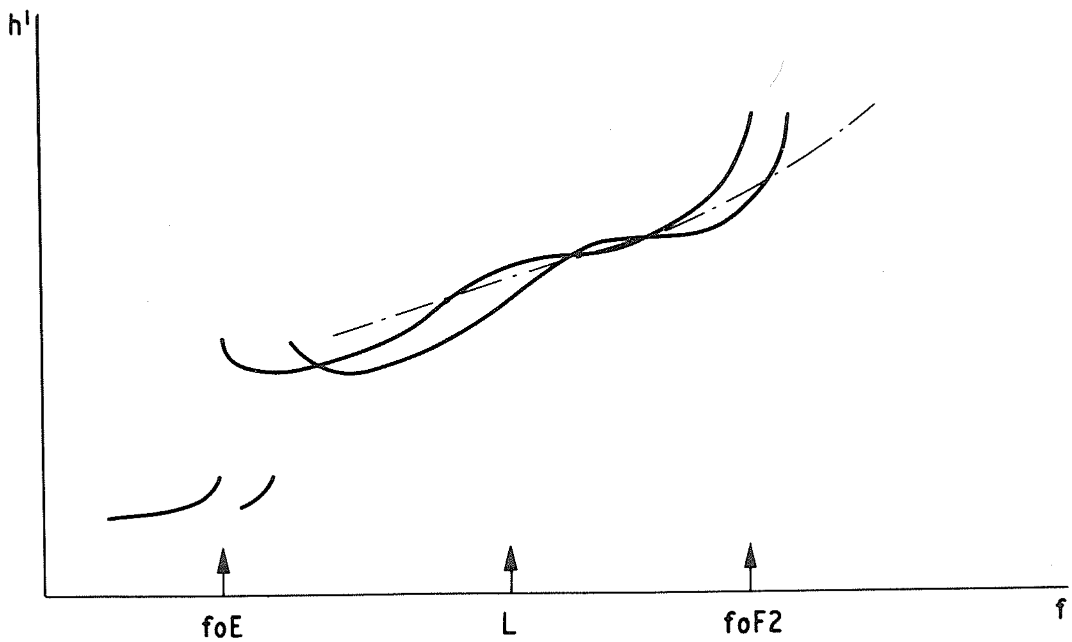


Fig. 3.24 Use of L

F2 trace not horizontal
foF1, M(3000)F1, h'F2 replaced by L
L is placed on f plot at frequency shown

exceed 20% and the numerical value is replaced by the letter L (Fig. 3.24). The M(3000) transmission curve will not give a point of tangency with the F1 trace in these cases, cutting the F1 trace at an angle, [A100I, Fig. 110], (Fig. 3.24).

(iii) When the M(3000) transmission curve gives a point of tangency with the F1 trace but the F2 trace does not become horizontal, scale with qualifying letter D and descriptive letter L [A100I, Fig. 109]. (Fig. 3.25a).

(iv) When the M(3000) transmission curve gives a point of tangency on the F1 trace and the trace shows an ill-defined maximum or one which is only clear on a multiple reflection, scale with the qualifying letter U and the descriptive letter L (Fig. 3.25(b)).

(v) When the cusp is sufficiently well defined for foF1 to obey the criteria for an accurate measurement do not use L.

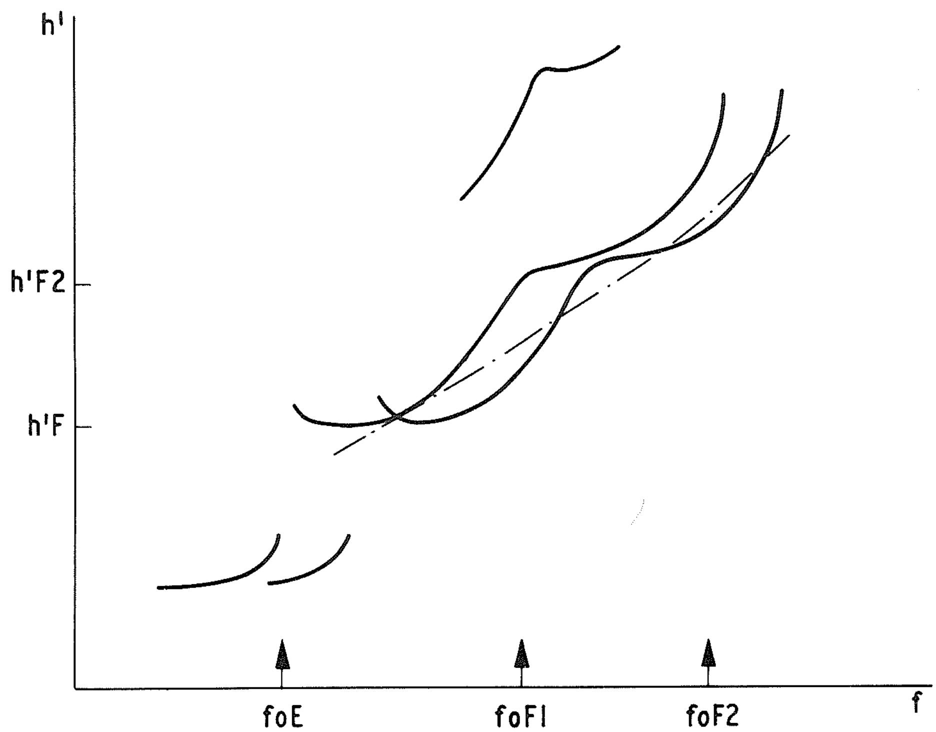


Fig. 3.25(a) Use of DL

F2 trace is not horizontal
foF1 given by (foF1)DL measured at frequency at which F1 trace slope most rapidly decreasing (see section 6.4 for f plot representation).
h'F2 given by (h'F2)EL, (h'F2)UL or by L depending on minimum slope of F2 trace.

(b) The conventions for determining M(3000)F1 are based on the fact that the main source of error is usually the determination of foF1. For this case, the five foF1 cases given above give:

(i) M(3000)F1 left blank
(ii) M(3000)F1 replaced by L
(iii) M(3000)F1 deduced at the numerical value of foF1 and qualified EL
(iv) M(3000)F1 deduced from the numerical value of F1 and qualified UL
(v) M(3000)F1 unqualified. Do not use L.

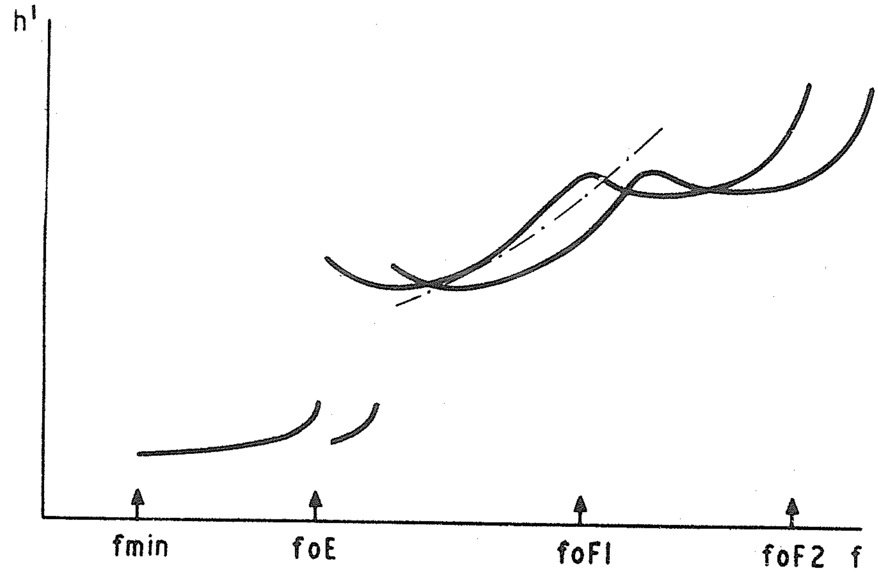


Fig. 3.25(b) Use of UL

For foF1 cusp equal to or less than that shown and transmission curve can be made to touch F1 trace use (foF1)UL.
Note when o-and x-mode traces less similar than that shown (foF1)UH would be preferable.

(c) The conventions for using L when scaling h'F2 are:

(i) When the shape of the F trace shows that no F1 stratification is present, no entry is made (Fig. 3.23).

(ii) When the F2 trace does not show an almost horizontal section the numerical value is replaced by the descriptive letter L (Fig. 3.24) [A96I, Fig. 88; A100I, Fig. 109].

(iii) When the F2 trace is almost horizontal h'F2 may be tabulated with qualifying letter U and descriptive letter L [A96I, Fig. 86].

(iv) L is not used when the F2 trace has a horizontal tangent [A96I, Fig. 87].

Similar conventions may be used when additional characteristics are tabulated for local purposes, e.g., the intermediate layer F1.5 (see chapter 12).

It should be noted that there can be occasions when the appropriate letter symbols can be different for all three F1 parameters, e.g., h'F below fmin, entry B; M(3000)F1 tangent point blanketed by Es, entry A; foF1 a good cusp, unqualified entry; h'F2 hidden by interference, entry S. The appropriate letter symbols take precedence over L whenever they represent the more important source of inaccuracy or ignorance.

In most cases, M(3000)F1 and foF1 will show the same usage of L. In borderline cases, h'F2 will usually be more exact than foF1 or M(3000)F1 and the conventions are therefore given separately.

M - Interpretation of measurement uncertain because ordinary and extraordinary components are not distinguishable.

Descriptive letter M is used to show that it was not possible to distinguish which component was present. It is mainly used when the presumption is that the required characteristic was not seen and the numerical value has been deduced. It is preferable to use

M as a qualifying letter wherever possible giving the descriptive letter showing why interpretation was not possible.

This letter is used primarily for the characteristics foEs and fxEs. Its use for these is discussed fully in sections 4.4 and 4.5 (Es characteristics).

The letter can also apply to foF2 and fxI when there is real doubt of whether the o or x mode is observed. It should not be used if the doubt can be resolved by using a sequence of ionograms or by comparison with other ionograms. The most common case occurs when foF2 is varying irregularly in time and is close to or below the lowest frequency of the ionogram.

M should be used as a descriptive letter when a qualifying letter such as D, E, U is appropriate and the interpretation is also doubtful and may be used when there is no main reason for the doubt, e.g., (   )MM or (   )-M implies several causes with equal weight.

Letter M always implies an uncertainty of fB/2 in frequency characteristics, an uncontrolled uncertainty in height parameters, and M(3000) factors should not be computed for data described or qualified by it. It should be used as sparingly as possible.

N - Conditions are such that the measurements cannot be interpreted.

Use this letter as sparingly as possible. Be certain no other letter describes the difficulty. Usually a careful examination of a sequence of records will provide a logical interpretation [A88I, Figs. 66, 67; A96I, Figs. 91, 92; A104I, Fig. 115]. The most common use of this letter is when oblique echoes prevent unambiguous interpretation of the ionogram.

N is used when traces of different orders are superimposed so as to prevent an unambiguous interpretation of the traces. In general the reason for using N should be shown in the remarks column.

O - Measurement refers to the ordinary component.
(See section 4.5 for use when fxEs is tabulated.)

Descriptive letter O shows that an o-trace characteristic has been tabulated in an x-mode table without correction. Where suitable programs exist, the computation foX + fB/2 = fxX can be more accurately done than by hand. This should only be used when it is known that the final tabulation will include the correction. The most common application is when fxI = fxF2 and only foF2 is evaluated, use (foF2)-O. Note: O must take precedence over all other descriptive letters in this case and the procedure is therefore less useful than the direct measurement of fxI or its calculation from foI. Also this cannot be done when foI is not equal to foF2, i.e., spread is present; it is then necessary to calculate fxI manually using qualifying letter O and the appropriate descriptive letter. For example, with foI near the gyrofrequency fB, calculate fxI = (foI + fB/2) and tabulate (foI + fB/2)OB.

Similar rules apply for descriptive letter X. The qualifying letter corresponding to X has always been J. Section 1.04 gives more exact rules which should be used where necessary.

Q - Range spread present.

Q is used to show the presence of a range spread trace, see section 2.74, Figs. 2.14, 2.17. It is tabulated with the value of h'f and takes precedence over F when a distinct range spread structure is present. A general broadening of the trace (see section 12.34, Mixed types of spread F) is better described by letter F. The main objective of this letter is to identify cases where a range spread structure is observed at oblique incidence and cases where no main trace or frequency spread is present. It is mainly used at high and low latitudes but may be important anywhere during major ionospheric storms.

R - Measurement influenced by, or impossible because of, attenuation in the vicinity of a critical frequency [A88I, Fig. 81; A112I, Fig. 129].

The letter R may be used to replace or describe a numerical value of any characteristic (example: see Fig. 3.26). The attenuation must be associated with retardation, the trace starts to move up towards the critical frequency and then disappears. Wide gaps in the trace which cover frequencies where retardation would be expected to be small are due to layer tilt, letter Y; to instrumental causes, letter C; or interference, letter S. When R is applicable the trace weakens gradually, when Y is applicable the trace is strong and stops suddenly (see Y).

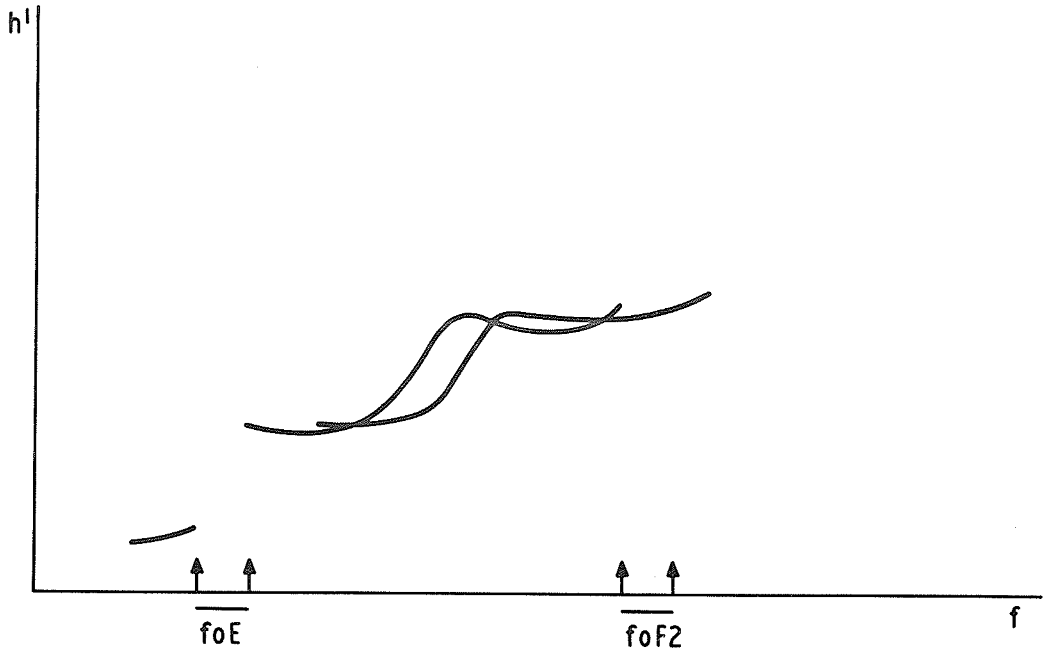


Fig. 3.26 Use of R

Traces show beginning of retardation near critical frequencies and then disappear. If no retardation is seen, Y is likely to be more appropriate (see letter Y).

The accuracy rules determine whether entry should be (foE)--, (foE)-R, (foE)UR, (foE)DR, (foE)ER or R, and (foF2)--, (foF2)-R, (foF2)UR, (foF2)DR or R.

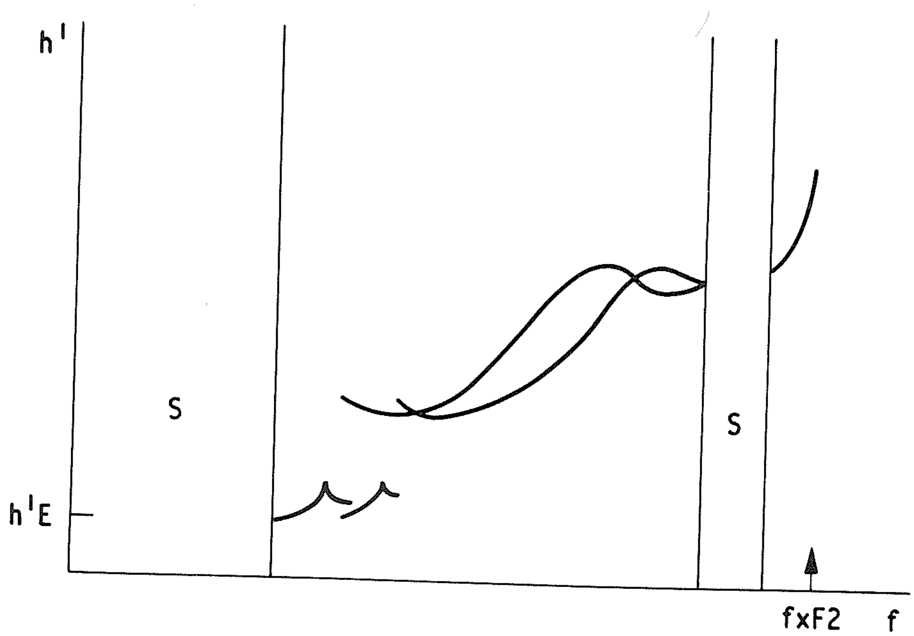


Fig. 3.27(a) Use of S

foF2 given by (fxF2 - fB/2)JS
h'E given by (h'E)ES

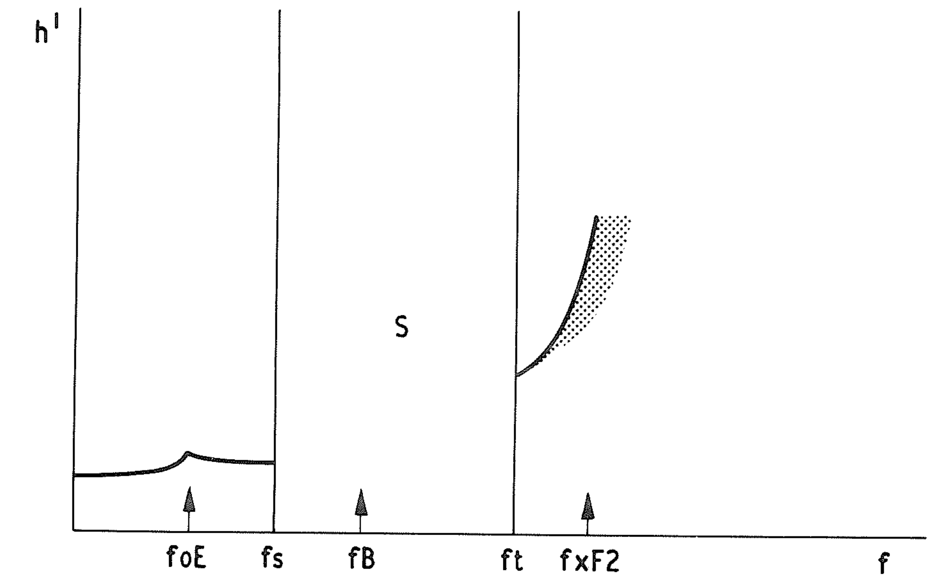


Fig. 3.27(b) Use of S on low frequency ionogram

foF2 given by (fxF2 - fB/2)JS
foEs and fbEs given by (fs)DS
h'F given by (h'F)ES

Note: This should not be used if foEs is usually above ft at this time of day. Then (ft)ES is more useful. This is occasionally found in summer months.
If an F trace is seen below fs and no F traces above ft, foF2 is best given by (ft)ES.

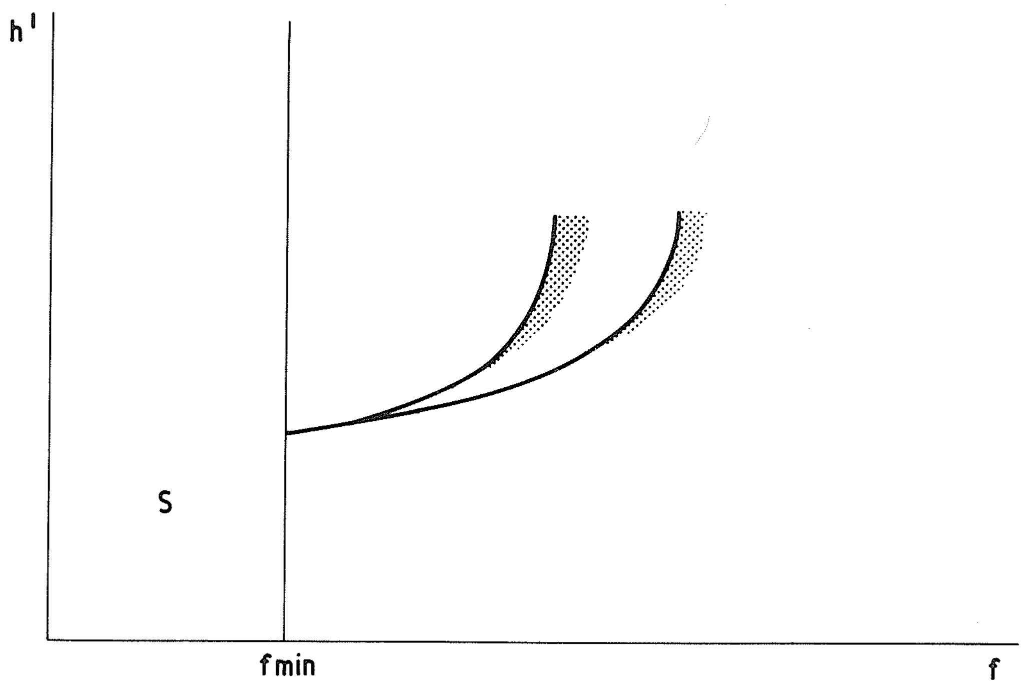


Fig. 3.28 Use of S at night

h'F is given by (h'F)ES
foEs, fbEs and fmin given by (fmin)ES
h'Es replaced by S

R can only be used when there is evidence for the existence of a principal ray trace. The top frequency for a scattering layer cannot be a true critical frequency even when the scatter pattern rises in height near the top frequency; the proper letter to use in this case is F.

S - Measurement influenced by, or impossible because of, interference or atmospherics.

This letter should be used only when considerable difficulty from either of these causes affects the reading of the characteristic in question; i.e., only to explain a missing, doubtful, interpolated, or 'J' value (Figs. 3.17 and 3.27) [A88I, Fig. 81; A112I, Fig. 138; A113I, Fig. 145].

When the low frequency portions of the traces are obscured by broadcast band interference, the value of fmin should be tabulated, qualified by letter E (less than) and described by letter S (Fig. 3.28). Accuracy rules do not apply in this case.

A special difficulty arises with low frequency ionograms where there is often a wide band of broadcast interference present for many hours. As the limits of this are usually rather constant and clearly recognizable in the data, the accuracy rule can be relaxed without danger of confusion. When an E or Es trace disappears into this interference band and does not appear at the upper frequency limit, it is allowed to use (limit value) DS without applying an accuracy rule. In the case of F-layer traces, the corresponding rule is to take the upper limit of the missing band with ES. These values are usually abnormally small relative to the median for foF2 and high for Es, so that they add to the median count without greatly increasing the difference between first and second medians (Chapter 8).

During night-time hours when fmin is tabulated with the qualifying letter E and the descriptive letter S, and no Es is present, foEs and fbEs are tabulated in the same way as fmin and h'Es is replaced by S (Fig. 3.28).

In general, interference known to be due to local causes, e.g., faulty generators, motors or lamps, snow or rain static, should be regarded as an instrumental fault (letter C rather than S).

T - Value determined by a sequence of observations, the actual observation being inconsistent or doubtful.

The descriptive letter T should only be used in those rare cases where an isolated numerical value is so unrepresentative that it has been replaced by an interpolated value from the smoothed f plot. Such values are qualified by the letter T also. This procedure is not allowed for fmin or for Es characteristics.

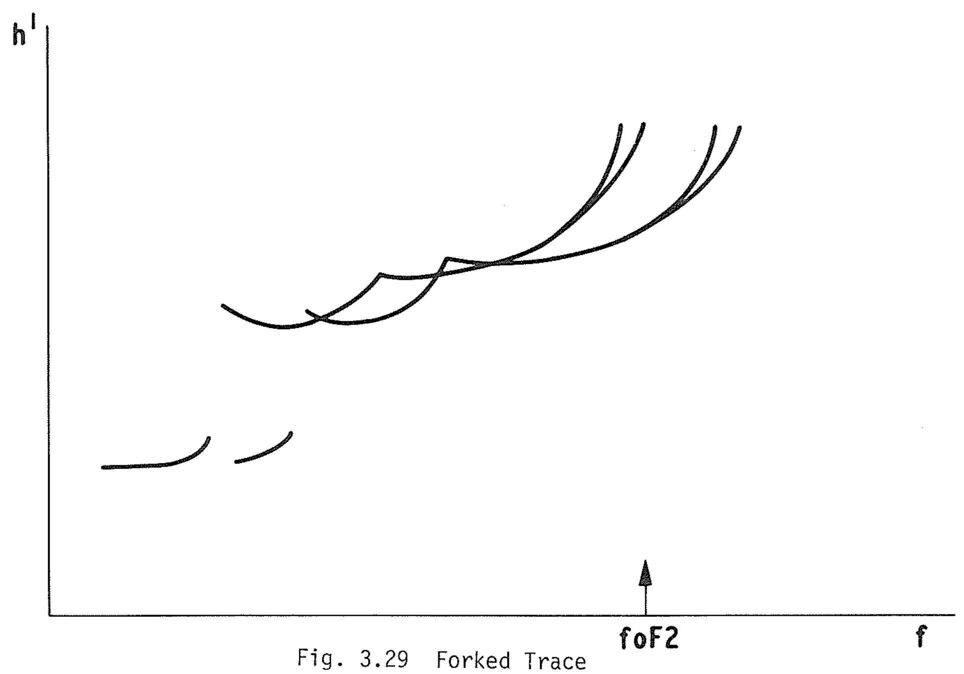


Fig. 3.29 Forked Trace

V - Forked trace, which may influence the measurement.

Scale the high frequency branch of the ordinary wave component (Fig. 3.29) [A128I, Fig. 149]. Do not confuse obvious oblique echoes, spread echoes or stratifications with forked trace [A88I, Figs. 66, 67, 70, 71; A96I, Fig. 91b; A100I, Fig. 105; A104I, Figs. 115, 122, 124].

W - Measurement influenced or impossible because the echo lies outside the height range recorded [A128I, Fig. 150].

With a normal height range (about 1000 km) cases where the letter W applies to any ionospheric characteristic are extremely rare. Care is needed to avoid using W for F2 characteristics when G is more appropriate. This can be best decided by examining a sequence of ionograms or from the f plot. In general if foF2 is close to foF1, G applies, whereas if the F2 trace moves bodily with little change of shape, W applies.

When W is used, a numerical value should be tabulated with the qualifying letter D, and described by W (Fig. 3.30).

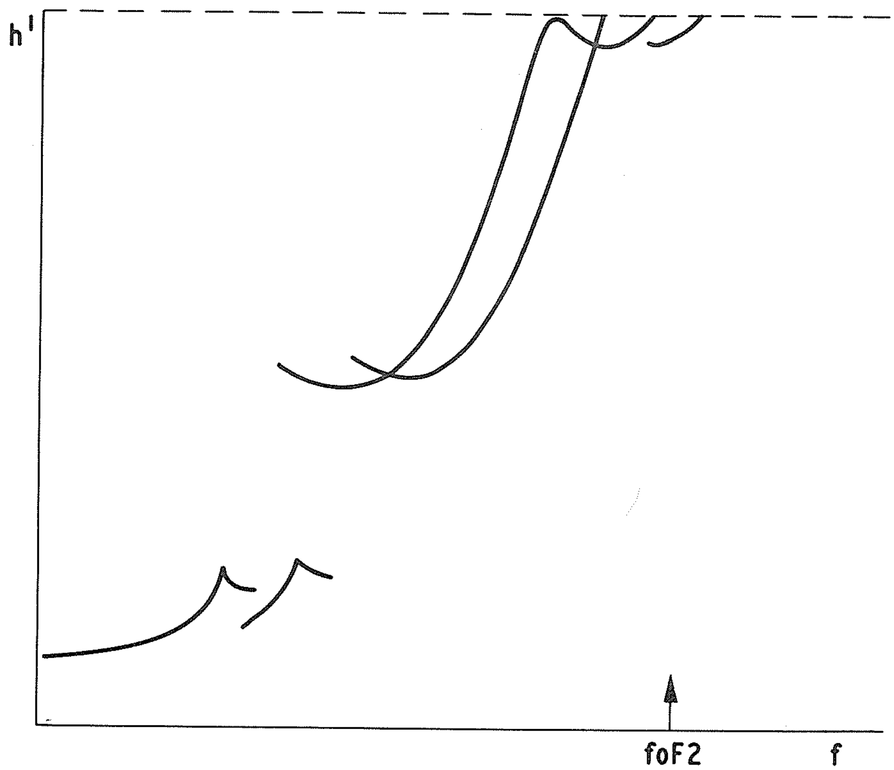


Fig. 3.30 Use of W

If h'F2 as shown but foF2 cannot be extrapolated, foF2 replaced by W.
If extrapolation possible, use (foF2)UW or (foF2)DW as given by accuracy values.
If h'F2 trace not seen and F1 trace goes above upper height limit, foF1 may need qualifying by W, foF2 replaced by W, h'F2 replaced by W.

X - Measurement refers to the extraordinary component.

Letter X shows that the measurement was made using the x trace. It is mainly used to show the presence of an x-mode characteristic in an o-mode table and is analoguous to descriptive letter O in an x-mode table. JX is equivalent to O. O as the qualifying letter is J, not X, for historical reasons, see descriptive letter O above. It is mainly used with computer processed data. The entry ( )JX states that the o-mode characteristic was deduced from the x-mode measurement by subtracting fB/2 and implies that the o-mode characteristic could have been measured. (Otherwise some other descriptive letter would be more appropriate). For use of X with Es characteristics see Chapter 4.

Y - Lacuna phenomena, severe layer tilt.

Letter Y is used to show the presence of wide gaps in the trace pattern due to the Lacuna phenomenon (see section 2.75). When the parameter is missing, Y is used as a replacement letter. Examples of the use of Y when Lacuna is present are shown in Figs. 3.31, 3.32 which represent total F Lacuna and F1 or partial Lacuna, respectively. It is necessary to distinguish the proper use of Y from that of A, B, F, H and R.

The provisional rules are:

A. When blanketing sporadic E appears to be present always use A.

B. The distinction between the presence of high absorption (B) and Lacuna (Y) is based on the fact that absorption causes greater weakening on the low frequencies than on the high and affects the x trace to a greater extent than the o trace, whereas Lacuna causes an abnormal weakening of traces reflected from a given range of heights only.

(a) If fmin is given by an E trace and there is a wide gap in the traces at higher frequencies or they are missing, Lacuna is present use letter Y (see H below).

(b) If fmin is approximately equal to foF1 and any of the following conditions are obeyed, Lacuna is present.

(i) The x-mode trace is visible.
(ii) The second order o-mode trace is visible.
(iii) fmin, the value of fmin for the second order F trace is the same as fmin within the accuracy rule for an unqualified reading, (strong confirmation).

In this case -

All E parameters are replaced by B
h'F1 and M(3000)F1 are replaced by Y
fmin is given by (fmin)EY
foF1 is given by (foF1)UY.

(c) If no traces are seen use letter B even when sequence suggests Y may be present.

F. When weak scattered F layer traces are seen but there is evidence that Lacuna is present Y should be preferred to F:

(a) If the upper end of the E trace is suddenly cut off below the normal value of foE and the F traces simultaneously become weak and scattered use Y not F.

(b) If the F2 trace is normal but the F1 trace is weak and scattered use Y not F. The E trace is most likely to be cut off but may be nearly complete.

(c) If part of the F1 trace is missing, fmin being given by an E trace, and the remainder is weak and scattered use Y not F.

(d) The presence of slant Es with any of above conditons confirms that Y should be used.

H. When there is a gap between the normal E trace and the F trace, Fig. 2.13(c), the lower part of the F trace showing retardation, use H not Y. (This restricts the use of Y to cases where large tilts are present and may be reconsidered later by INAG).

<u>Severe layer tilts present</u>

There are two important cases:

(a) Large tilts affecting apparent value of fbEs: If fbEs is greater than foEs, Fig. 4.22, use fbEs = (foEs)UY.

(b) Abnormal pattern near foF2: When the F layer is very tilted, the trace rises in the normal manner to a frequency near the expected value of foF2 (as shown by sequence) and then turns over so as to run horizontally, Fig. 3.34. When the signal-to-noise ratio is good it stops suddenly. In this case the wave has been reflected at oblique incidence and the value of foF2 overhead is certainly less

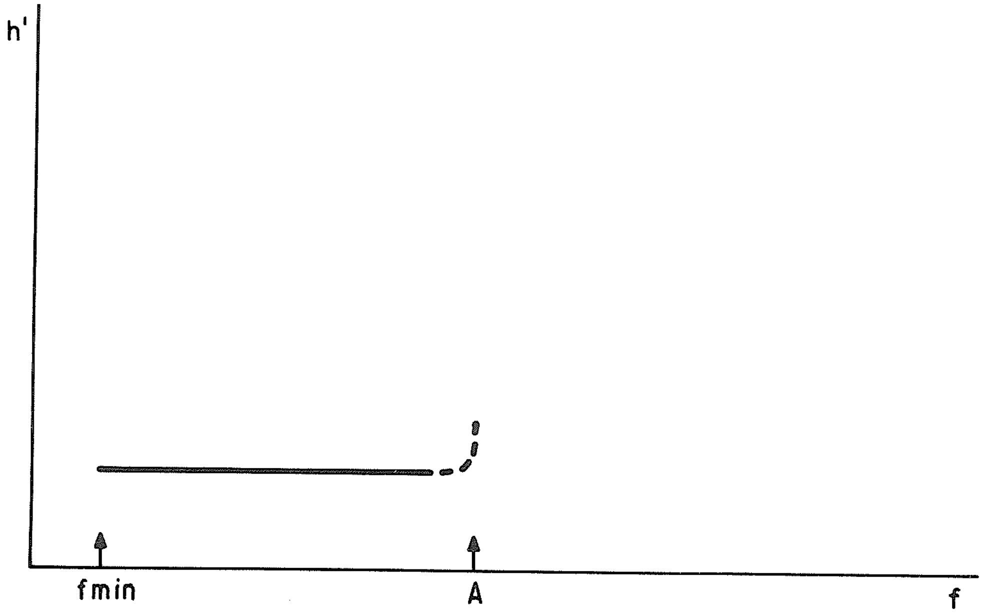


Fig. 3.31 Total F Lacuna
The F1 and F2 traces are missing.

fmin is given by an E trace
foE would be expected at A
h'Es: G. foEs, fbEs: G (preferable (foE)EG)

All F parameters replaced by Y. foE replaced by Y

Note similar pattern can occur with group retardation on
E trace as shown by dots in which case foE is tabulated as (foE)UY.

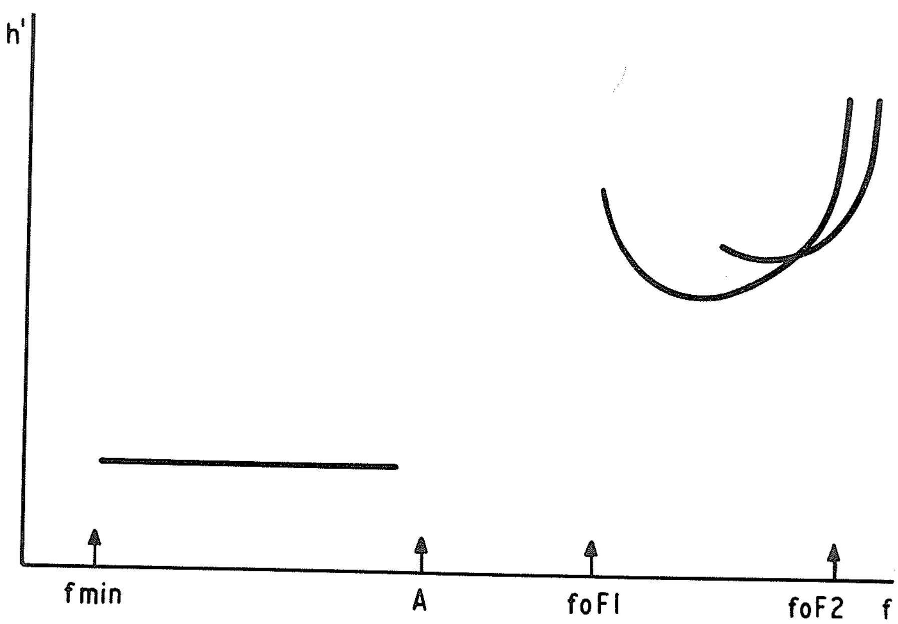


Fig. 3.32 F1 or partial Lacuna

F1 trace is missing
fmin given by E trace
foE would be expected at A
(if foE is observed use (foE)UY).

foE replaced by Y (unless observed)
h'F replaced by Y
foF1 given by (foF1)UY
M(3000)F1 replaced by Y

Note: F2 trace appears suddenly at approximately foF1.

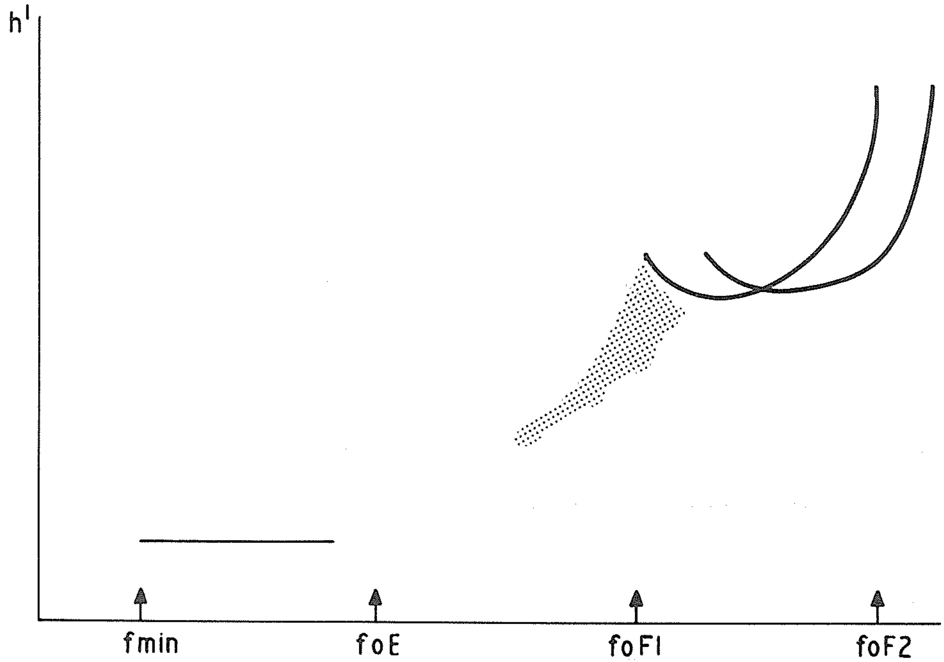


Fig. 3.33 Weak F1 Lacuna

The F1 trace becomes weak and scattered but is still visible.
fmin given by E trace
foE cusp not seen — foE replaced by Y
foE seen — foE given by (foE)UY
h'F replaced by Y
foF1 given by (foF1)UY
M(3000)F1 replaced by Y
Note: F1 trace often shows spurs in these conditions.

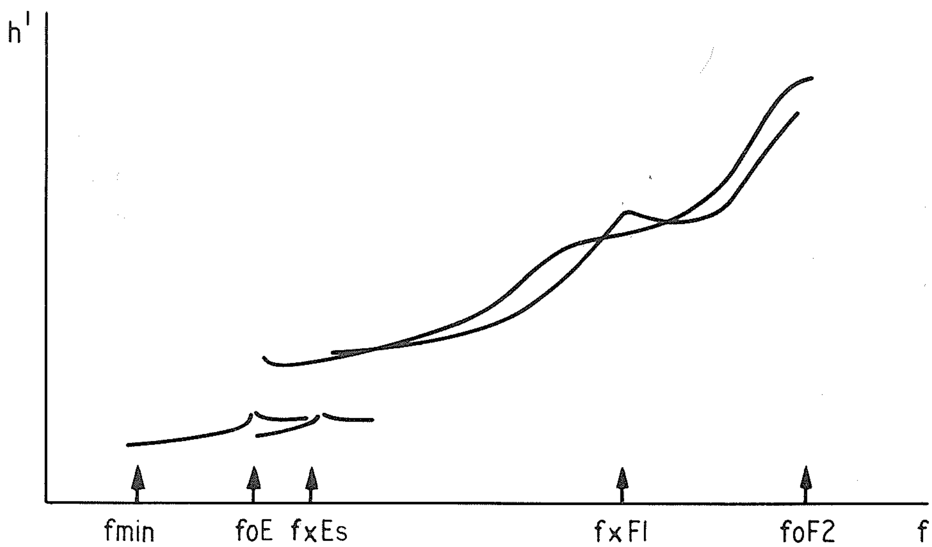


Fig. 3.34 Tilted layer, critical frequency increasing rapidly with distance. Use of Y.

foF2 is (foF2)EY — foF1 is (fxF1 - fB/2)JL
fxF2 is (foF2 + fB/2)OY — h'F2 is L
fbEs = (foE)EG

Note: x-mode trace can be similar to o mode or not depending on whether tilt is N-S or E-W.

than the limit frequency observed. This is probably true in all cases when the trace is concave downwards: the residual doubt is less important than obtaining a numerical limit. Use the top frequency observed qualified by E and described by Y. These conditions may last several hours but are usually short lived. This procedure can only be used when there is independent evidence of tilt or curvature (section 2.7). Convex or linear traces are more likely to be normal traces which are absorbed, UR, DR or R, when tilt is not present. A similar effect can be caused by inadequate antennas or ionosonde, letter symbol C, and this possibility should be considered if the condition is seen regularly.

Z - Third magneto-electronic component present.

The critical frequency or height parameter is described by Z or a note made in the remarks column of the daily worksheet (Chapter 7), Fig. 3.35, 3.36. Descriptive letter Z is preferred to F when either are appropriate since Z is usually only seen when spread is present.

When a z-mode trace extends to fmin, the value of fmin should be described by Z. This applies to all coupling cases (section 1.05).

Letter Z is used also as a qualifying letter when the o-mode parameter is deduced from the z trace, e.g., foF2 = (fzF2 + fB/2)ZF. This is valuable when there is no main trace or a series of main traces (Fig. 3.35). Note h'z < h'o < h'x so it is not possible to use qualifying Z for height parameters.

M(3000)F2 can be deduced if, with the aid of the z-mode trace, an o-mode trace can be identified at the point of tangency of the transmissiion curve.

The z-and x-critical frequencies differ by very nearly the gyro-frequency and the o-critical frequency is approximately half-way between them (Fig. 3.35). In general, the z trace is less spread than the other components (Fig. 3.35) [A38I, Figs. 23, 24; A104I, Fig. 118a,b,c]. It is most commonly observed at high-latitude stations, and may appear in all layers showing magneto-electronic splitting -- F2, F1, E (Fig. 3.36) and certain types of Es.

The letter Z should be recorded as a descriptive letter with the frequency characteristic of the appropriate layer. At high latitudes, the critical frequency fzF2 should be plotted on the f plot whenever observed.

The low frequency end of the F region z trace is often mistaken for stratification in F1, resulting in erroneous scaling of h'F (Fig. 3.37) [A104I, Fig. 118a,b]. Sometimes it is also confused with multiples of the E or Es layers.

Since the z component is reflected obliquely, except at the magnetic pole, there is always doubt whether or not conditions have changed with the position, and values based on deductions using this component are regarded as doubtful and are therefore qualified by qualifying letter Z (section 3.1).

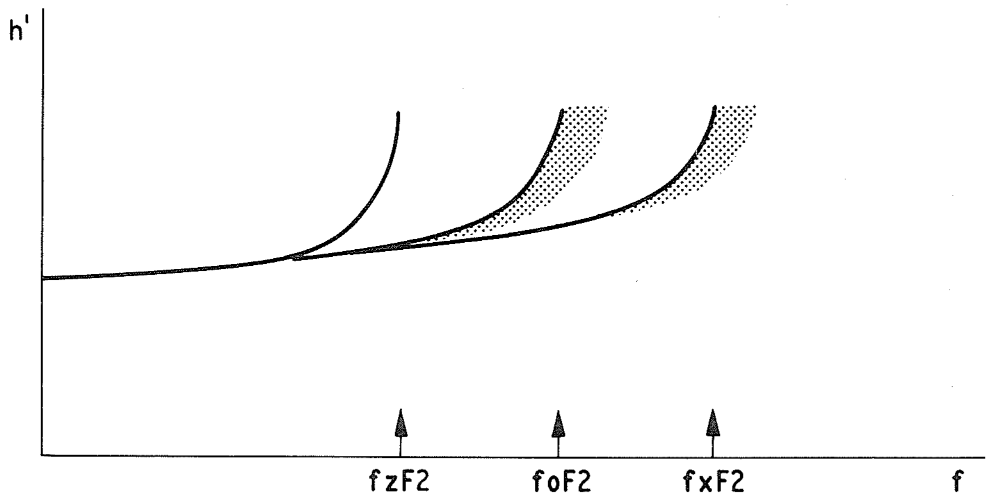


Fig. 3.35 z mode in F region

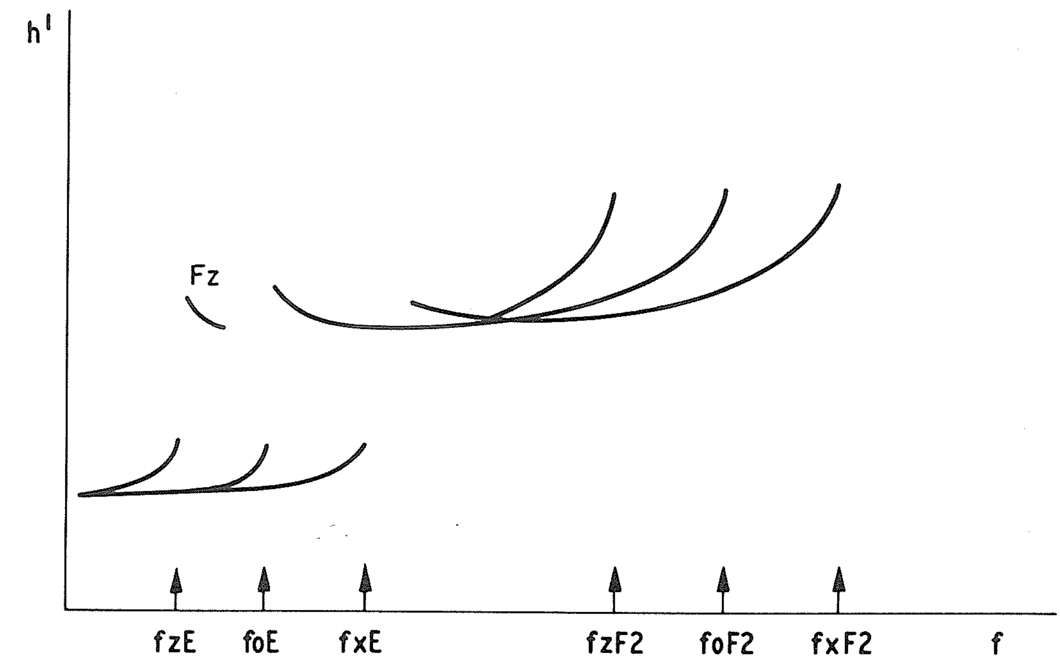


Fig. 3.36 z, o, and x modes in E and F regions

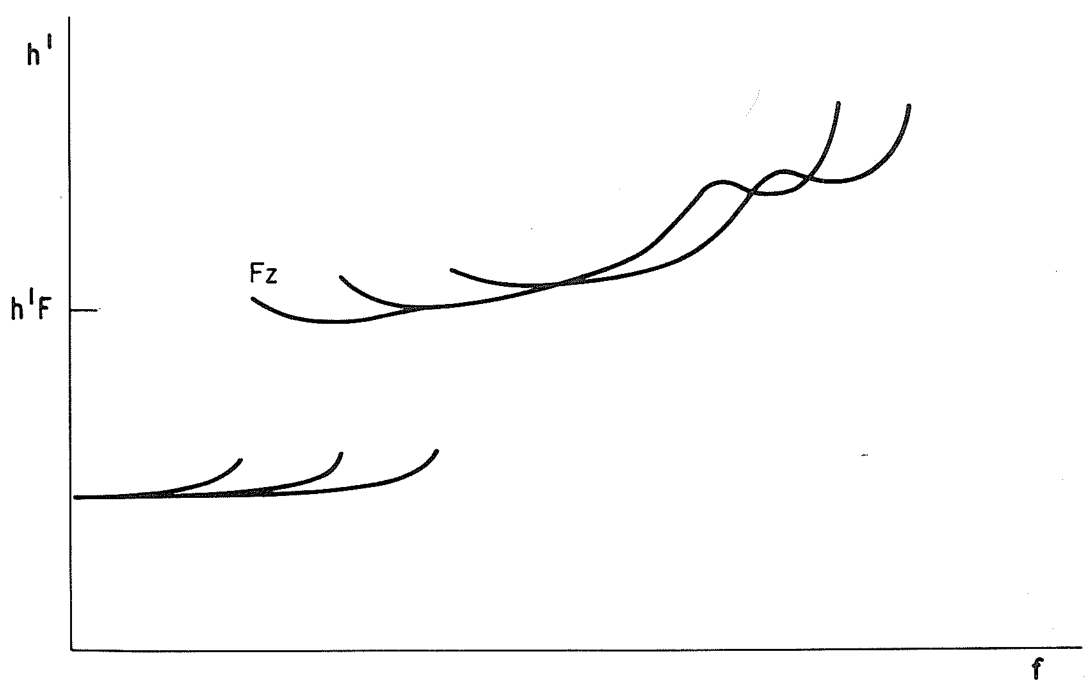


Fig. 3.37 z mode on low frequency end of F trace

3.3 Rules for the Analysis of fxI

3.30. Definition: The parameter fxI is defined as the highest frequency on which reflections from the F region are recorded, independent of whether they are reflected overhead or at oblique incidence. Thus, fxI is the top frequency of spread F traces including polar or equatorial spurs, but not including ground backscatter traces.

In practice it is given by the highest frequency at which F traces are seen on the ionogram with two exceptions:

(a) Traces due to ground or sporadic-E backscatter are ignored, Fig. 3.38.

(b) When the top frequency is likely to be due to an o-mode reflection.

Typical examples of fxI measurement are shown in Fig. 3.39. In general the shapes of the patterns can change rapidly and considerably, e.g., in some cases there is no apparent retardation at fxI or near foF2 and h'I can be either greater or less than h'F2.

fxI should be scaled from the normal gain ionogram except when this shows total blackout, (fmin replaced by B).

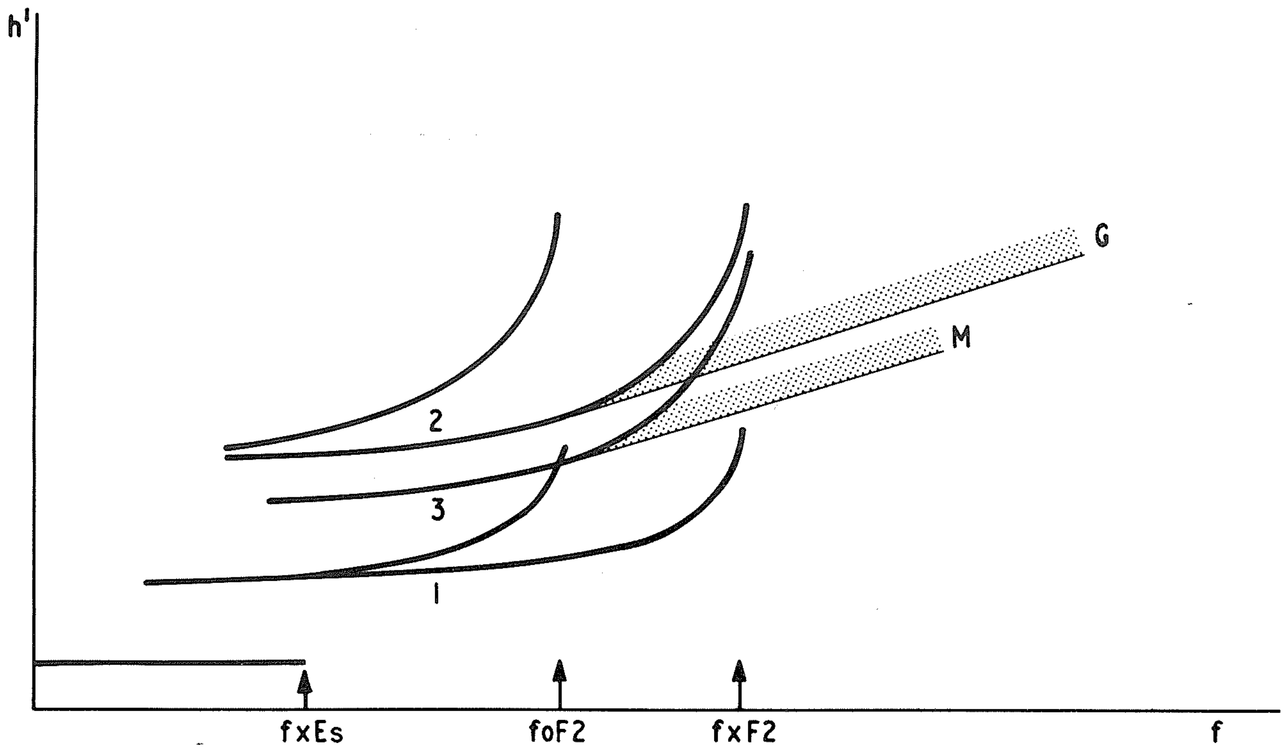


Fig. 3.38 Ground backscatter

The ground backscatter trace G is tangential to the second order x-wave trace (2). Es backscatter is tangential to the M (2FE) trace (3)
In this case fxI is written (fxF2)-X.

3.31. Accuracy rules: Accuracy rules only apply to fxI for distinguishing between cases when D or E should be used instead of replacement letters C or S. If the possible error is less than 20% or 5Δ whichever is the greater use D or E as appropriate (see D, E) together with the descriptive letter. If the possible error is greater than this, use the descriptive letter as a replacement letter.

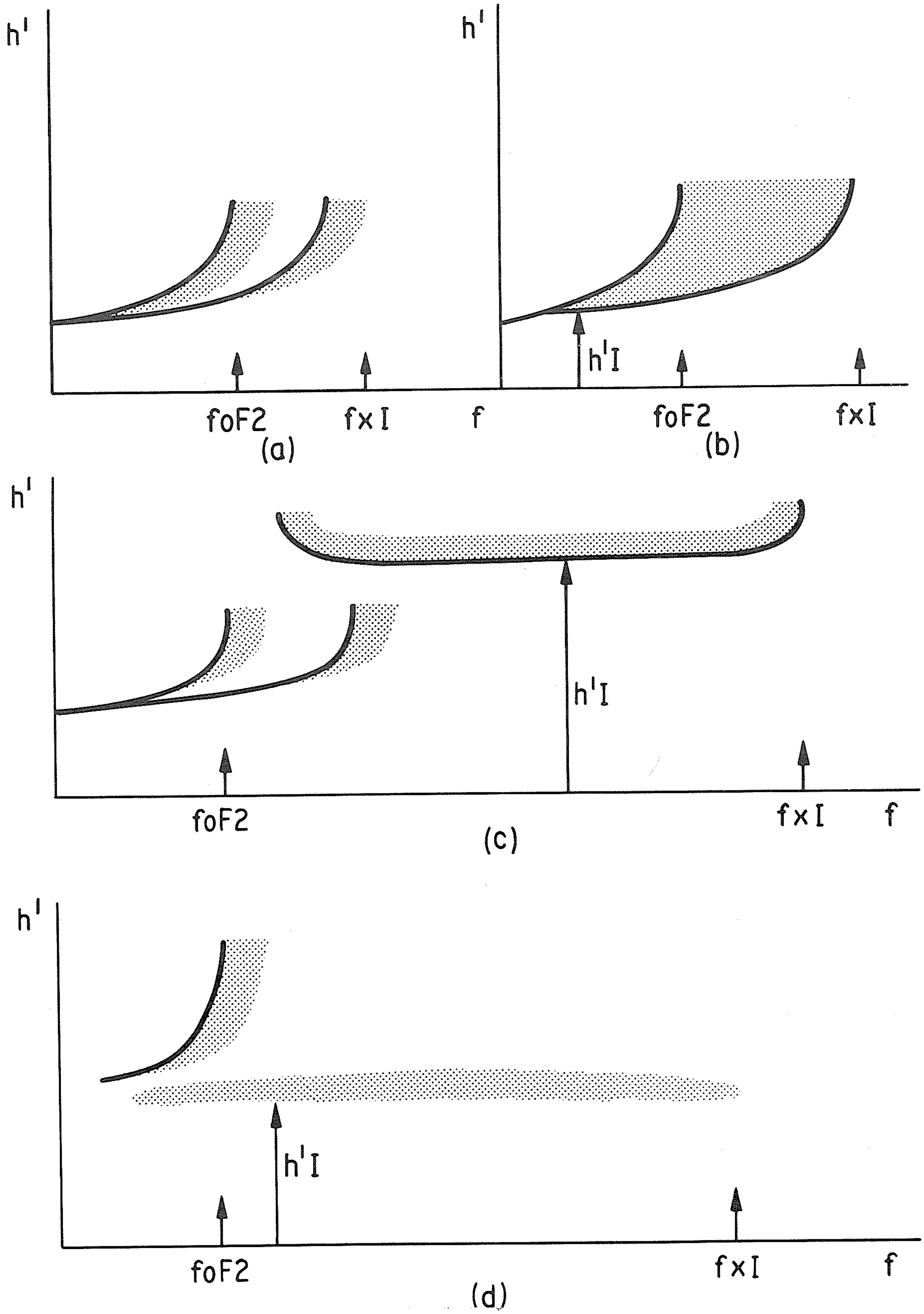


Fig. 3.39 Typical examples of fxI

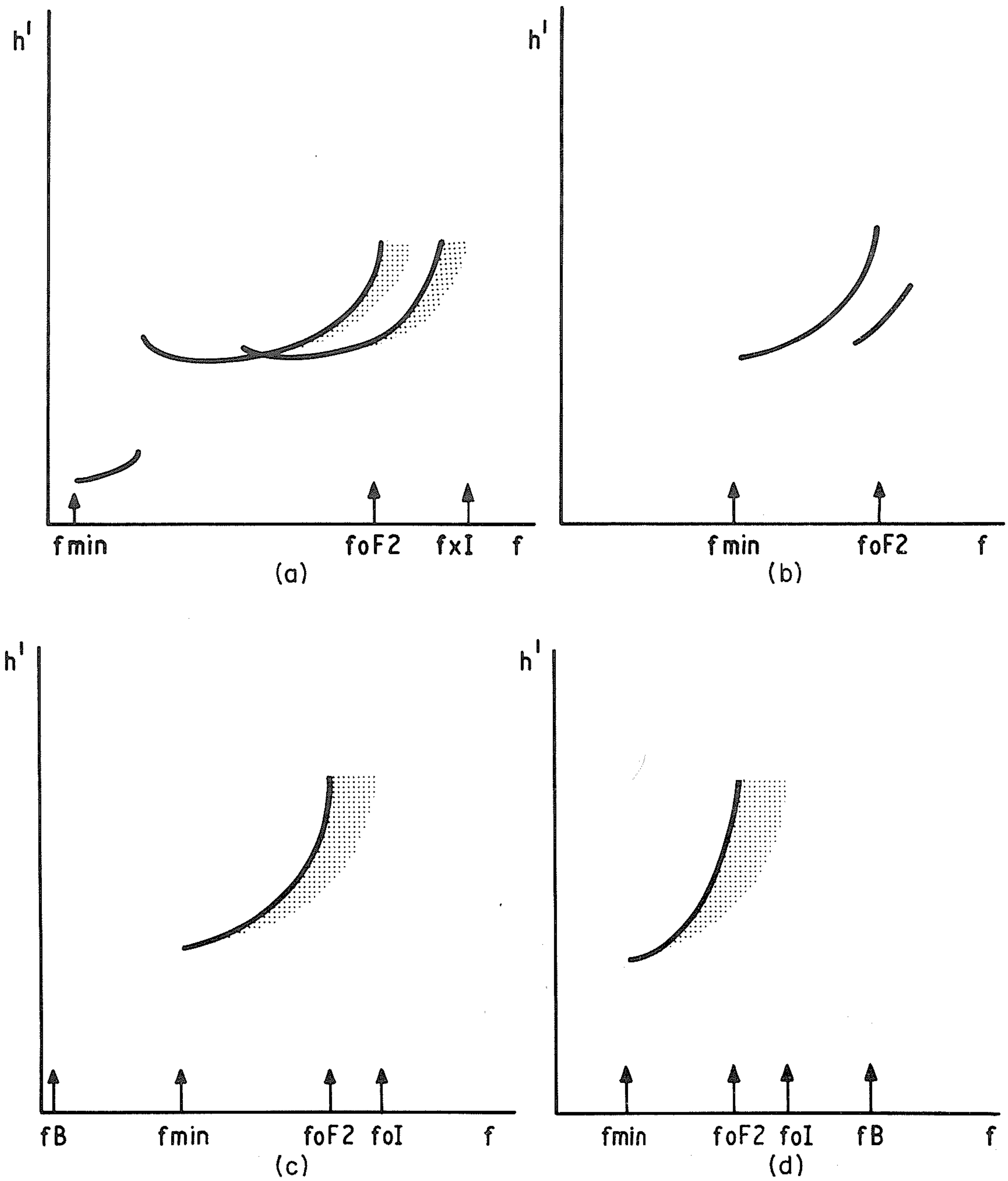


Fig. 3.40 High Absorption Conventions for fxI

(a) Normal fxI = (fxI)
(b) High fmin, only main traces visible
fxI = (foF2 + fB/2)DB
(c) High fmin, x traces missing
fxI = (foI + fB/2)OB
(d) foF2 near or below fB
fxI = (foI + fB/2)OB

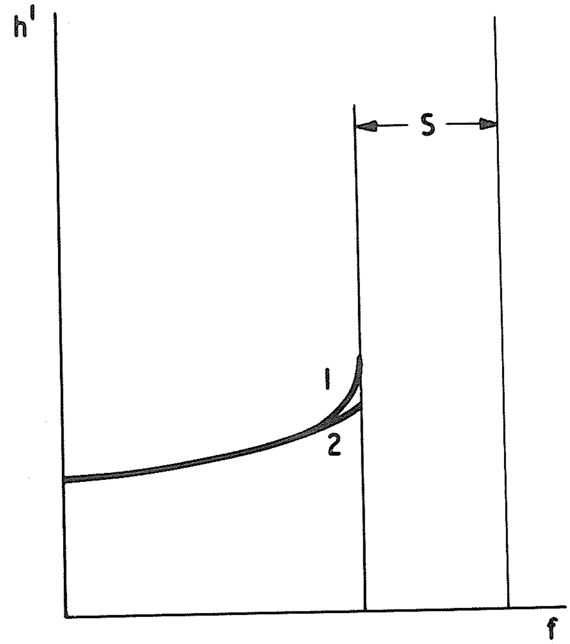


Fig. 3.41 Use of C and S with fxI

For foF2 more accurate than 10% and missing band less than 20% or 5Δ :
Use (foF2 + fB/2)DS.
For foF2 more accurate than 10% and missing band wider than 20% or 5Δ : Use S.
For foF2 more accurate than 20%, (foF2)DS entry; and missing band less than 20% or 5Δ : Use (top frequency of missing band)ES.
All other less accurate cases: Use S.
The rules for missing bands due to C are identical except that S is replaced by C.
Note: If the missing band is less than 10% or 3Δ wide, the characteristic is given by the middle value for the missing band with US (see accuracy rules).

3.32. Scaling rules:

(a) Measure the highest observed frequency of the traces directly reflected from the F layer, e.g., of spread F or polar spurs as shown on the medium gain ionogram. If closely spaced ionograms show the presence of a spread structure which is relatively gain stable, the top frequency of this structure is preferred. Use the ionogram which shows it most clearly.

(b) The normal descriptive letter symbols should be used to show the reasons for absent entries.

(c) Monthly tabulation sheets may be left blank for columns at hours for which spread F traces are seldom or never seen, as is the practice for E and F1 parameters. Most groups find it more efficient to ignore this point and tabulate fxI at all hours.

(d) When spread is absent, the numerical value of fxF2 (fxF2) is used with descriptive letter X: (fxF2)-X.

3.33. Use of descriptive letters: Apart from the modified accuracy rule given above, the use of the following descriptive letters is the same as for other parameters: C, D, E, G, S, Y.

For letters A and B the following special rules apply:

A - The value of fxI is replaced by letter A when the presence of lower thin layers, such as Es, prevent observation of all F-layer traces.

B - There are a number of cases where descriptive letter B is appropriate. The principal rules are given first and then the particular cases.

(a) If all traces disappear as a result of absorption use replacement letter B. If traces can be seen on the high gain ionogram only, use rules (b) or (c), as appropriate.

(b) If the spread traces disappear as a result of absorption but the normal traces can still be seen, use (fxF2)DB. The numerical value (fxF2) can be deduced from foF2, Fig. 3.40(b).

(c) If the x-mode scatter traces are missing because of absorption, use the top frequency of the o-mode scatter trace, foI, plus fB/2 together with qualifying letter O and descriptive letter B : (foI + fB/2)OB, (Fig. 3.40(c)).

(d) If fmin is high, showing large absorption, but the value of fminx cannot be determined, use qualifying letter M (interpretation doubtful: reading may be foI instead of fxI) and descriptive letter B.

Note: When the signal/noise ratio is low, fxI is power sensitive; when high, it is usually independent of power as far as is known at present.

(e) If fmin is normal and foI is near or below fB, fminx will be greater than fB and fxI is given by (foI + fB/2)OB, Fig. 3.40(d). The probable value of fminx for this case can be deduced from ionograms having the same value of fmin but larger values of foF2.

3.34. Use of z-mode trace: At night in sunspot minimum years foF2 can fall into the medium wave broadcasting band and be hidden by interference. In these cases a missing value of fxI can be deduced from the z-mode trace using the relation;

$$fxI = fzI + fB$$

The value of fxI is given by (fzI+fB)ZS.

If the z trace is not spread in these circumstances this is most likely to be due to absorption. Use (fzI+fB)DB.

This rule is only useful when an ionosonde operating to low frequencies is available (e.g., down to 0.2 MHz). In other cases this section should be ignored.

NOTES

4 Es CHARACTERISTICS

4.0 General Considerations

The scaling conventions for the Es parameters to be circulated on a world-wide basis are based on a compromise. It is clear that a wide variety of phenomena are included under the name sporadic E, and the study of these phenomena is not yet sufficiently developed to permit them to be considered separately on a world-wide basis [A401, Figs. 31, 33, 34; A88I, Figs, 64, 77-79; A96I, Figs. 87-91, 93-99; A112I, Figs. 130, 131, 141, 142]. Diagrams illustrating Es have been given in Figs. 1.2, 1.8, 1.9, 1.11, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6. The distinction between types of Es facilitates the study of this problem (section 4.8). An additional difficulty arises because a given type of trace may arise from different causes, particularly in widely spaced parts of the world. It is always tempting to regard the current local interpretation as general and to simplify the rules accordingly. This is advantageous for local studies but can cause serious discontinuities in the compatibility of data from different regions or epochs of time.

The basic rule is that all traces from E-region heights which cannot be interpreted as due to a thick nontransparent layer should be treated as sporadic-E traces.

The distinction between blanketing and non-blanketing traces is very important both scientifically and operationally, and tabulations of the blanketing frequency fbEs can be at least as useful as those for foEs. It should be noted that fbEs is determined at a well defined place - where the ray path of the first F echo goes through the Es layer. In contrast, foEs corresponds to the highest ordinary-wave frequency returned from Es in the sounding cone (which usually has an aperture of about ± 10°) by a reflection or scattering mechanism. In most cases at high latitudes the Es traces found during disturbed conditions are blanketing when overhead and non-blanketing when seen at oblique incidence. Both parameters are highly variable in time so that it is particularly important that the number of values which contribute to the medians should be kept as large as possible.

The Es characteristics to be scaled (Fig. 4.1) fall into two groups: (1) numerical measurements, e.g., foEs, fbEs, h'Es, which must be made sufficiently homogeneous to be useful for geophysical studies and the prediction of radio frequency propagation phenomena; and (2) type indices showing the incidence of different types of Es traces with time and position on the world.

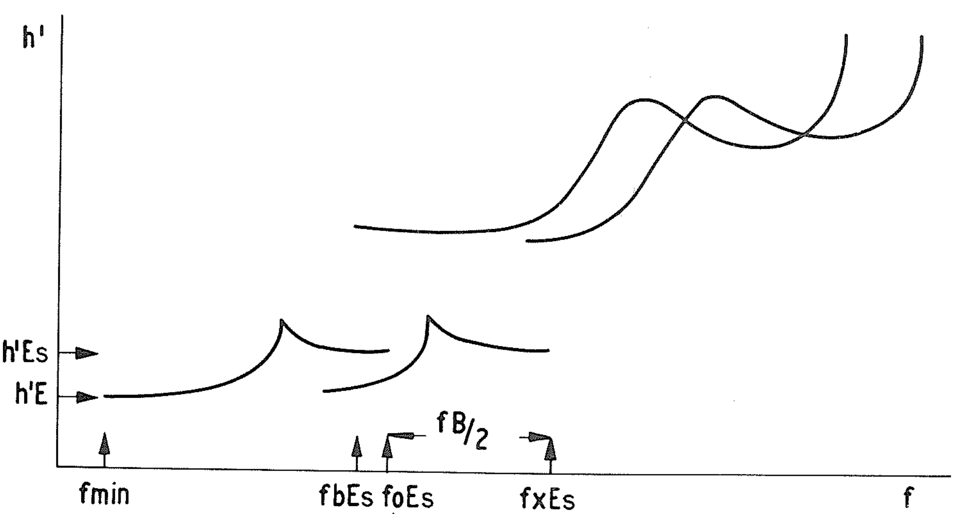


Fig. 4.1 Es nomenclature

In the use of data foEs has considerable advantages over fxEs and the provision of homogeneous tables of either parameter is more valuable than a table containing a mixture of both, even when individual values are clearly marked as due to o or x components. The international standard parameters are, therefore, based on the ordinary-wave component though departures from this convention are permitted where really necessary. The rules given for identifying the ordinary-wave component can, of course, be used to identify the extraordinary-wave component also. It is always implied that values tabulated as foEs have been obtained using the standard rules given below. Rules are also given to enable fxEs to be scaled if this is found to be desirable (see section 4.5).

At stations where the advantage of scaling fxEs rather than foEs is great, tables of fxEs may be substitued for those of foEs. For practical reasons the blanketing frequency fbEs and the virtual height h'Es must always refer to the ordinary-wave component. The following rules have been arranged using the assumption that the characteristics scaled are foEs, fbEs and h'Es. They apply with appropriate changes (indicated in section 4.5) if fxEs, fbEs and h'Es are the characteristics scaled. The selection rules for foEs and fxEs are summarized in a table in section 4.32.

Where the data from a station is processed mechanically it is not essential to make the original reductions homogeneous, provided the different components are clearly identified by one or other of the descriptive letters O and X, or, in really doubtful cases, M. The process of adding or subtracting 1/2 fB can be done mechanically so as to produce homogeneous tabulations for interchange. This relaxation of the rules is allowed only when the operator knows that the corrections will be made by computer and that he has taken precautions to use symbols O, X, M accurately.

A special difficulty arises at high latitude stations during periods of particle activity. It frequently happens that, during the course of a disturbance, storm types of Es (Es types a and r (section 4.8)) transform into a thick night E layer or vice versa. Thus, foEs, fbEs transform into foE values. Analysis of both Es characteristics and normal E at night are influenced by this transformation. The appropriate rules are given in section 4.2.

4.1 Es Characteristics to be Tabulated

4.11. <u>The following characteristics are normally tabulated for Es</u>:

- foEs: The ordinary-wave top frequency corresponding to the highest frequency at which a mainly continuous Es trace is observed.
- h'Es: The lowest virtual height of the trace used to give foEs.
- fbEs: The blanketing frequency of an Es layer, i.e., the lowest ordinary-wave frequency at which the Es layer begins to become transparent. This is usually determined from the minimum frequency at which ordinary-wave reflections of the first order are observed from a layer at greater heights. foEs, fbEs and h'Es must all be scaled using the same Es trace.

A numerical value for foEs, fbEs and h'Es (with qualifying and descriptive letters, where appropriate) or a descriptive letter replacing a value, is entered on the daily tabulation sheet for all of the 24 hours.

4.12. <u>Es types</u>: There are eleven specified categories into which Es traces are classified (section 4.8). The number seen at one station is usually smaller.

4.13. <u>Units for tabulation</u>:

foEs and fbEs: 0.1 MHz
h'Es:
(a) with expanded height scale ionograms, 1 km;
(b) when scaling accuracy is better than ±2 km tabulate to nearest odd km at least;
(c) when scaling accuracy is better than ±5 km tabulate to nearest 5 km.

4.2 Es Scaling Conventions

4.21. Since the values of foEs and fbEs observed can change with the sensitivity of the ionosonde, these parameters should be deduced using the ionogram obtained at normal (medium) gain.

4.22. h'Es should be scaled using the ionogram on which it can be measured most accurately.

4.23. Traces due to thick occulting layers, such as 'E2' or other 'intermediate layers' in the day should not be included in Es tabulations (this does not apply to night E), (see below).

4.24. <u>Rules when night E is present</u>: When foE at night is greater than the value appropriate for normal E (K condition, section 3.2), night E is present. This is normally preceded by Es type r or Es type a. The critical frequency of night E is usually much greater than for normal E at this time. Typical stages in the development from retardation Es (type r) to night E are shown in Fig. 4.2. Occasionally Es type a changes into night E, with similar changes in the F traces and the same conventions.

Case (i) No retardation at low frequency end of F traces, Fig. 4.2(a), Es type r; h'Es, foEs, fbEs as given by ionogram.

If foE below fmin, foE is (fmin)EB, h'E is B*

* Footnote: If h'E is not usually recorded at these hours the entry can be left blank but h'E, h'Es entries should always be made whenever a numerical value of foE is available. They may be numerical or G values.

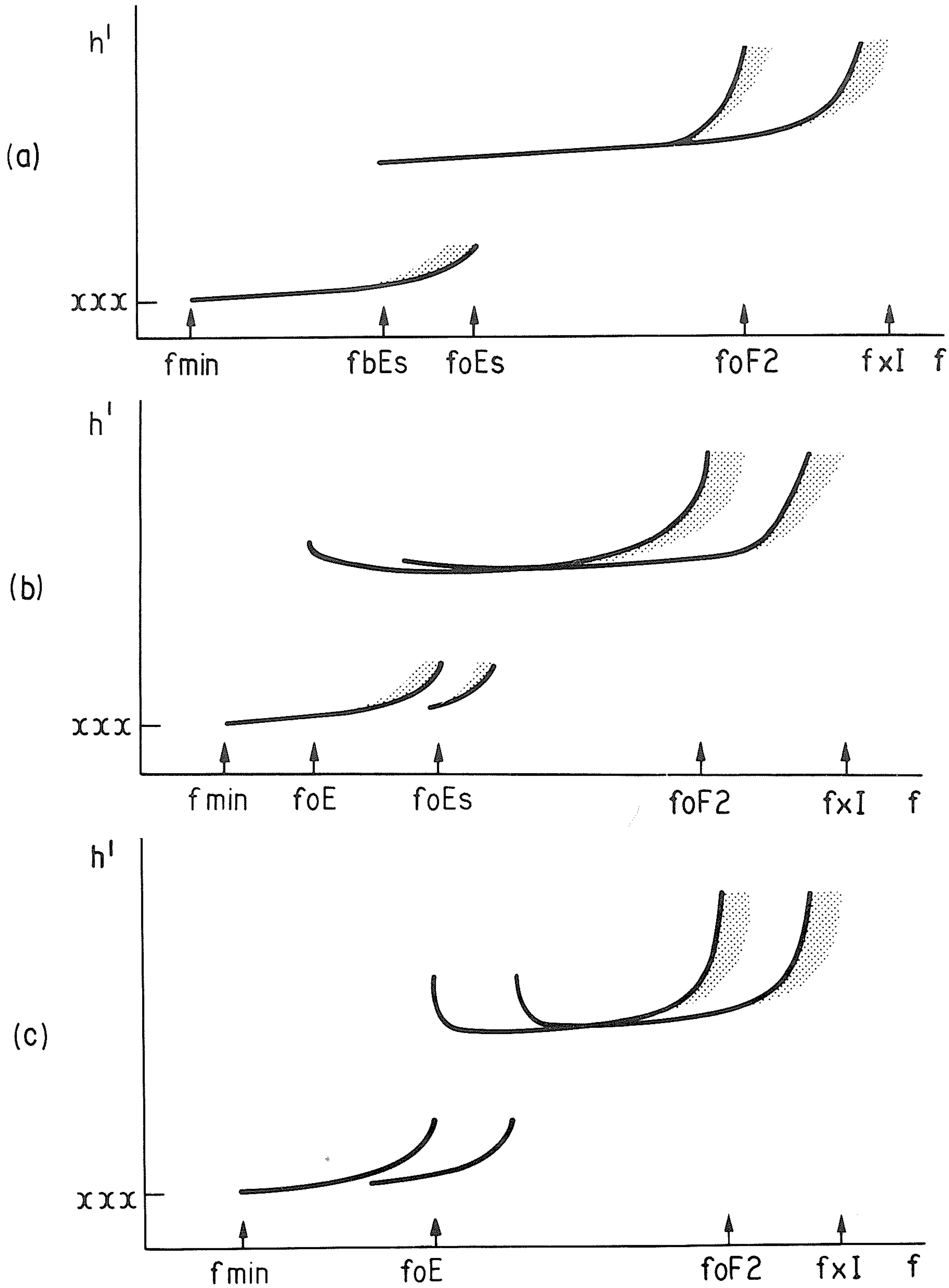


Fig. 4.2 Conventions for Es type r and night E

(a) (b) show Es type r (c) night E
In (b) foE for night can be seen by retardation of F trace; (foE)UK but h'E is A
In (c) foEs and fbEs = (foE)-K h'Es = (h'E)-K

If foE above fmin, foE is (fbEs)EA, h'E given by E trace (very uncommon except on low frequency ionograms).

Case (ii) Retardation at low frequency end of F traces, Fig. 4.2(b), Es type r, foEs is given on ionogram.

fbEs is (foE)UK h'Es is xxx-K
foE is (foE)UK h'E is A

(There is always some doubt when only half a cusp is visible; hence, U preferable).

Case (iii) Night E, Fig. 4.2(c).

Es type k (night E)
foEs is (foE)-K h'Es is (h'E)-K
fbEs is (foE)-K
foE is (foE)-K h'E is xxx-K

Note, unless fmin is high, both o and x traces will normally be seen when night E is present.

Whenever fbEs is given by a night E trace, fbEs = (foE)-K. The entry (foE)-K must be put in both the foE and the appropriate Es tables (foEs and fbEs).

4.25. When no Es echoes are observed the following conventions are adopted:

If a trace corresponding to a thick layer in the E region, e.g., normal E, or retardation is present at the low frequency end of the ordinary-wave F-region trace, the descriptive letter G must be used; appropriate rules are found in section 3.2 (G), (Fig. 4.3).

If fmin is greater than the lower limit of the ionosonde and absorption is clearly indicated, the numerical Es characteristics should be replaced by the descriptive letter B, except when letter G applies, (see Figs. 3.7, 3.8, 3.16, 3.17).

In all other cases the descriptive letter used for fmin should also be used to describe the absence of the Es trace (e.g., C, E, S).

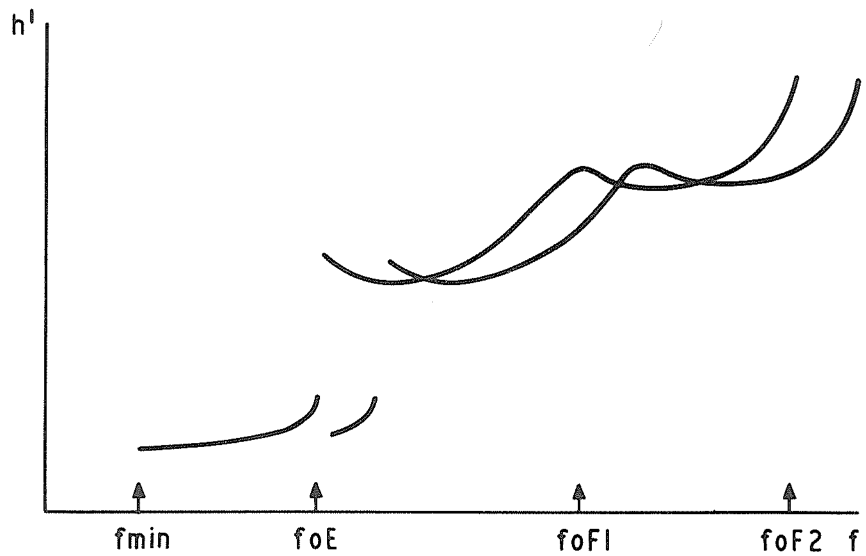


Fig. 4.3 No Es present. Use of G.

foEs is (foE)EG
fbEs is (foE)EG
h'Es is replaced by G

4.3 Techniques for Distinguishing between the Magneto-ionic Components in Es Traces

4.30. The evaluation of foEs depends on distinguishing whether the top frequency ftEs observed is due to an ordinary foEs or extraordinary fxEs wave reflection. There are a large number of possible cases which are discussed in detail in section 4.31, paragraphs (a) to (g) and summarized in section 4.32. These enable any difficult case to be evaluated. For most ionograms there is little difficulty since there are ample indications (e.g., 4.31(a), (b)) of whether ftEs is fxEs or foEs. In most practical cases it is fxEs. The simplest criterion is to see if F region x traces are present at or below ftEs; if so, it is fxEs, if not foEs. When absorption is not present, e.g., at night for most latitudes, ftEs equals fxEs if it is more than about 250 kHz above the gyrofrequency fB (numerically above about 1.4 MHz) and foEs if it is below this frequency. Near fB it is foEs. Borderline cases should show easily recognized, separate o and x traces. During daytime hours, observe the relation between the minimum frequency of the x traces, the number of multiple traces present and their minimum frequencies. Usually absorption conditions are similar from day to day and hour to hour so that if ftEs is seen at a frequency where x traces are usually seen it will be fxEs. Always try to use several tests in doubtful cases, and refer to the paragraphs below to make sure the correct interpretation has been made. As fmin increases due to absorption, the lower frequency part of the x trace disappears and it becomes more likely that ftEs equals foEs. Always check that no F-layer x trace is visible at or below ftEs.

If the ionosonde is faulty, a logical approach may not be successful. Direct comparison of the difficult case with ionograms with identifiable Es traces, or with no Es and similar absorption. will usually show clearly whether ftEs is fxEs or foEs.

4.31. Detailed rules for distinguishing foEs:

(a) For normal thick reflecting layers, differences in the virtual height of reflection of the two magneto-ionic components generally enable the two traces to be identified easily. The daytime 'c' and 'h' types of Es give traces which can often be identified by the changes in height of the trace due to retardation in the normal E layer (Fig. 4.1). However, for most types of Es trace the two components are superimposed at essentially the same height and other criteria are necessary.

(b) When absorption is present, a clear distinction is often possible because the absorption of the x component is normally greater than that of the o component at the same frequency. The x component is also greatly weakened at frequencies near the gyrofrequency, even when the normal absorption is very small.

(c) At night, when the absorption is usually negligible, comparison of the top frequency of the Es trace, ftEs, and the gyrofrequency, fB, gives the following rules:

If ftEs	< fB	ftEs = foEs	(Fig. 4.4)
If ftEs	≥ fB	ftEs = fxEs	(Figs. 4.5 and 4.6)

(d) Systematic inspection of the ionogram can very often determine which component is present at the high frequency end of the trace, even in cases where both traces are superposed and show no obvious distinguishing features. The first method depends, in essence, on comparing ftEs with the minimum frequency of the x-component trace for the ionogram as a whole, fminx. This is necessarily above the gyrofrequency. If Es traces occur at frequencies above fminx, the extraordinary component must be present. Hence the top frequency, ftEs, must correspond to the extraordinary component. If the Es trace stops at a frequency below fminx the extraordinary component cannot be present.

Thus if	ftEs ≥ fminx	ftEs = fxEs
and if	ftEs < fminx	ftEs = foEs

The rule can only break down if there is a sudden change in the variation of the sensitivity of the ionosonde with frequency. This should not occur with properly maintained modern equipment, but is readily recognized when present. Clearly it is not necessary to measure fminx, it is sufficient to know that fminx is greater or smaller than ftEs.

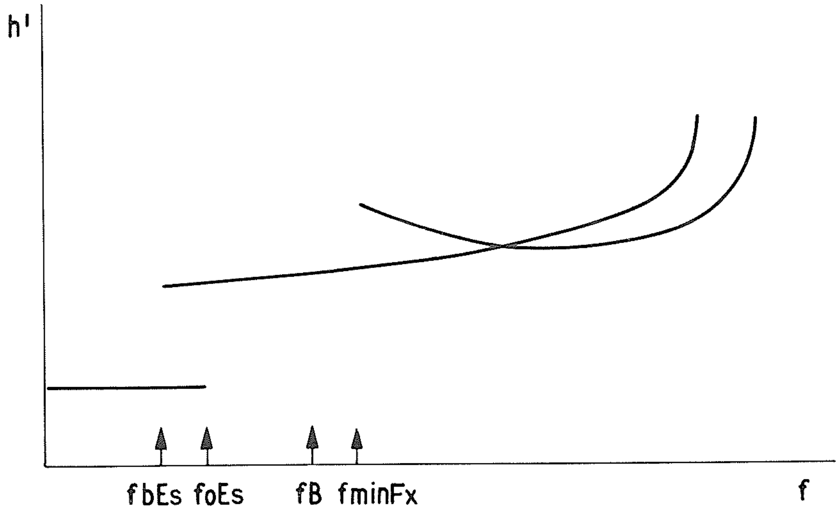


Fig. 4.4 ftEs below fB at night, ftEs is foEs.

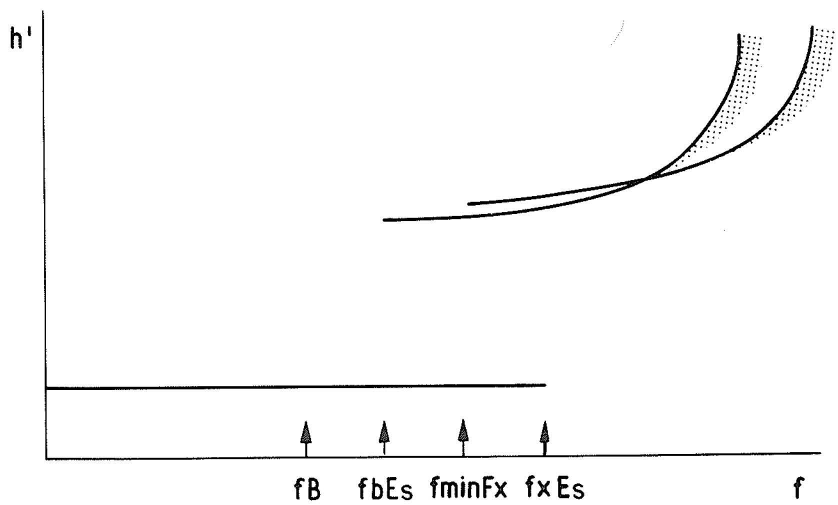


Fig. 4.5 ftEs above fB at night

ftEs above fminFx so ftEs is fxEs
Note fmin low so absorption small.

(e) The high frequency end of the record should be inspected first. In most cases there is no difficulty in recognizing the two components in the F traces and the low frequency end of the F-layer x trace is easily found. This is called fminFx and provides a useful practical criterion. Three cases can arise in practice:

(i) ftEs > fminFx (Fig. 4.7)
The Es trace must contain an x component and hence <u>ftEs</u> = <u>fxEs</u>.

(ii) ftEs = fminFx (Fig. 4.8)
When the difference δ between ftEs and fminFx is less than half the gyrofrequency, 1/2 fB, the top frequency cannot be foEs without an x trace appearing at higher frequencies. Therefore <u>ftEs</u> = <u>fxEs</u>. This is shown by an indirect argument: Suppose the Es trace visible up to fminFx-δ is an ordinary trace ($\delta \leq 1/2$ fB). Then the corresponding x trace should stop at (fminFx-δ+1/2 fB), and this is higher than fminFx. Thus this trace cannot be absorbed and should be visible on the ionogram. As this is not true in the case we consider, the hypothesis that we have an ordinary trace must be wrong, so that ftEs = fxEs.

(iii) ftEs < fminFx
Two subcases are possible:
(1) No E-region trace (neither E nor Es) appears within half the gyrofrequency below fminFx (Fig. 4.9). This shows that, taking the ionogram as a whole, the x trace stops at fminFx so that fminFx = fminx. Hence the observed Es trace cannot be an x trace and ftEs = foEs.

(2) An x trace from a thick layer in the E region is present (E or E_2). In this case the arguments used above are repeated for fminEx instead of fminFx giving the three cases illustrated in Figs. 4.10, 4.11, 4.12.

These rules can fail if the equipment limitation mentioned in (d) above is present.

(f) There remain the cases where fminFx cannot be determined. If this is due to total blanketing (Fig. 4.13), in conditions for which we would normally expect to see the F traces we should presume that the missing F-layer x trace is replaced by an Es-layer x trace and therefore <u>ftEs</u> = <u>fxEs</u>.

Sometimes, but rarely, ionograms are obtained which apparently differ from the cases discussed above. These differences are most commonly due to layer tilts causing oblique sounding reflections. For example see the discussion on fbEs (Fig. 4.22(a) (b)).
The remaining case where fminFx cannot be determined although an Fx trace is present is the only difficult one. This condition is found when both components are superposed (Fig. 4.14) or when scatter is present (Fig. 4.15). This is discussed in (g) below.

(g) It is only necessary to attempt to identify the Es traces directly when the frequency rules cannot be applied. When no absorption is present rule (c) always applies. When absorption is present we may use our experience of the usual behavior of the ionosphere, at most stations, to provide a basis for informed reasoning of the probable interpretation.

If ftEs is comparable with foE it is probable that the x component of the Es trace is absorbed and <u>ftEs</u> = <u>foEs</u> (Fig. 4.16). This class is extremely rare as almost all cases can be solved by normal rules.

If ftEs is considerably higher than foE, assume that the x trace is present and <u>ftEs</u> = <u>fxEs</u> (Fig. 4.17).

If absorption is present at night but no night E is visible the value of fmin may be used to estimate whether ftEs = foEs or ftEs = fxEs, high values of fmin suggesting the former. In particular if ftEs is near fmin, <u>ftEs</u> = <u>foEs</u> (Fig. 4.18).

Summarizing these considerations it can be stated that in almost every really doubtful case it may be assumed that <u>ftEs</u> = <u>fxEs</u>.

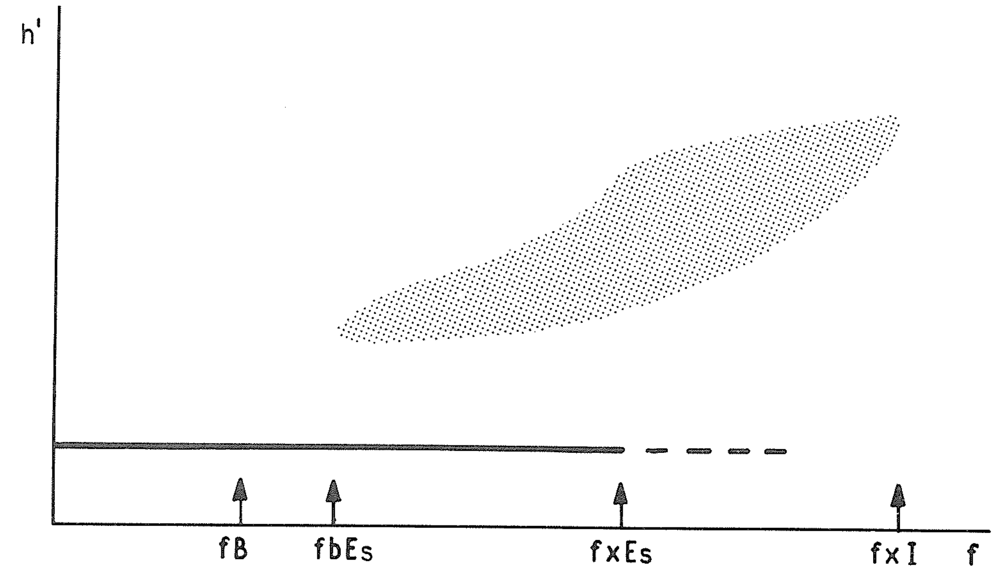


Fig. 4.6 foEs at night
Note fmin low so absorption small.

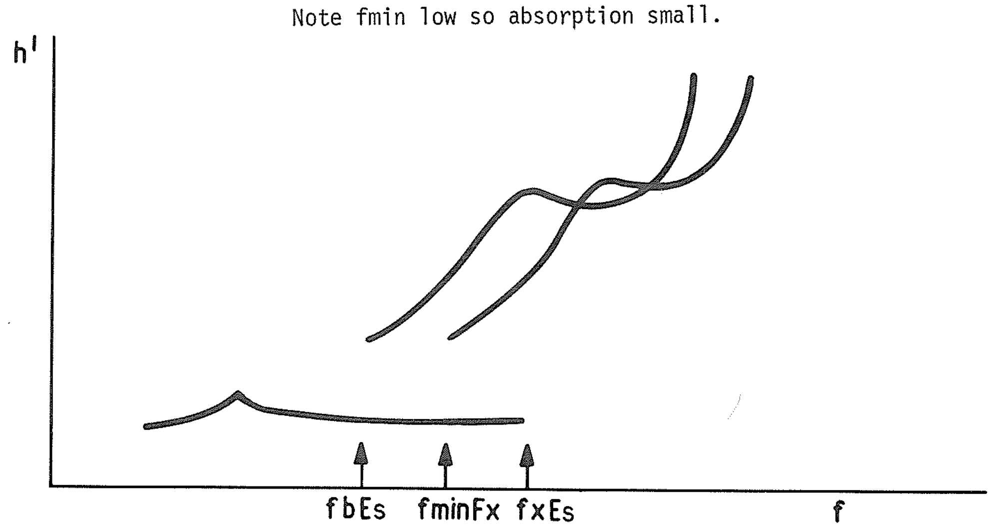


Fig. 4.7 ftEs>fminFx

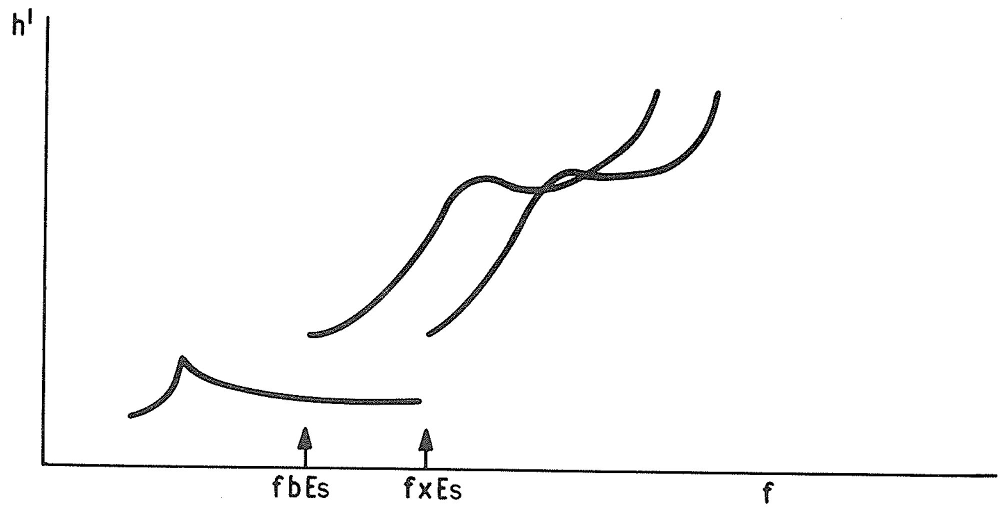


Fig. 4.8 ftEs = fminFx

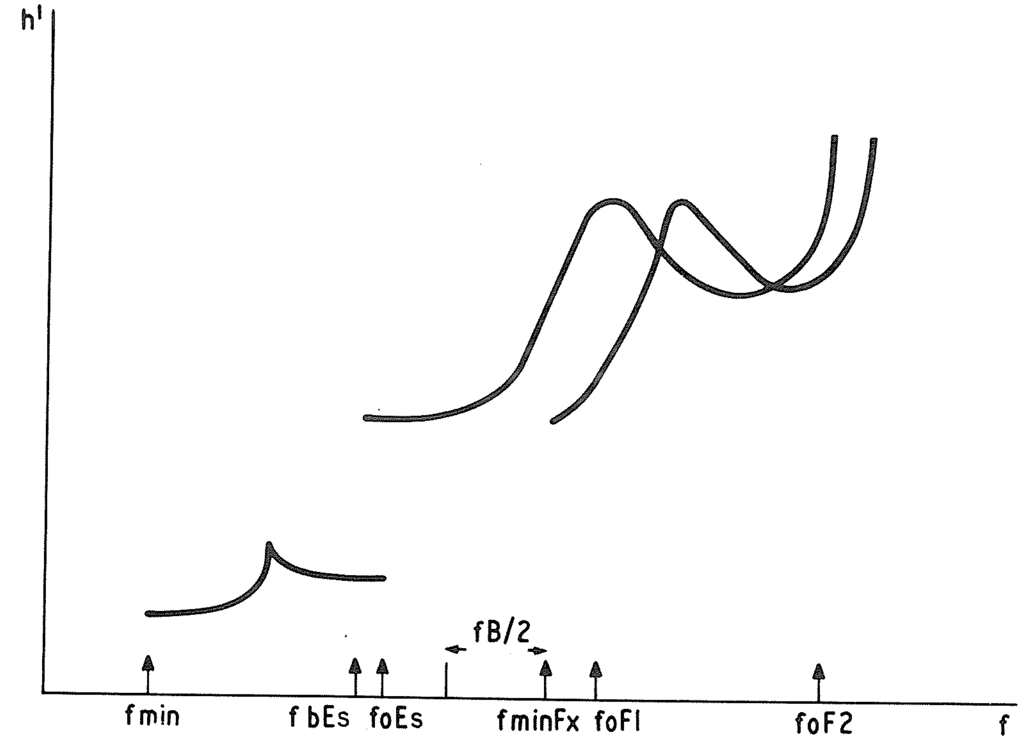


Fig. 4.9 fminx given by fminFx. Daytime.

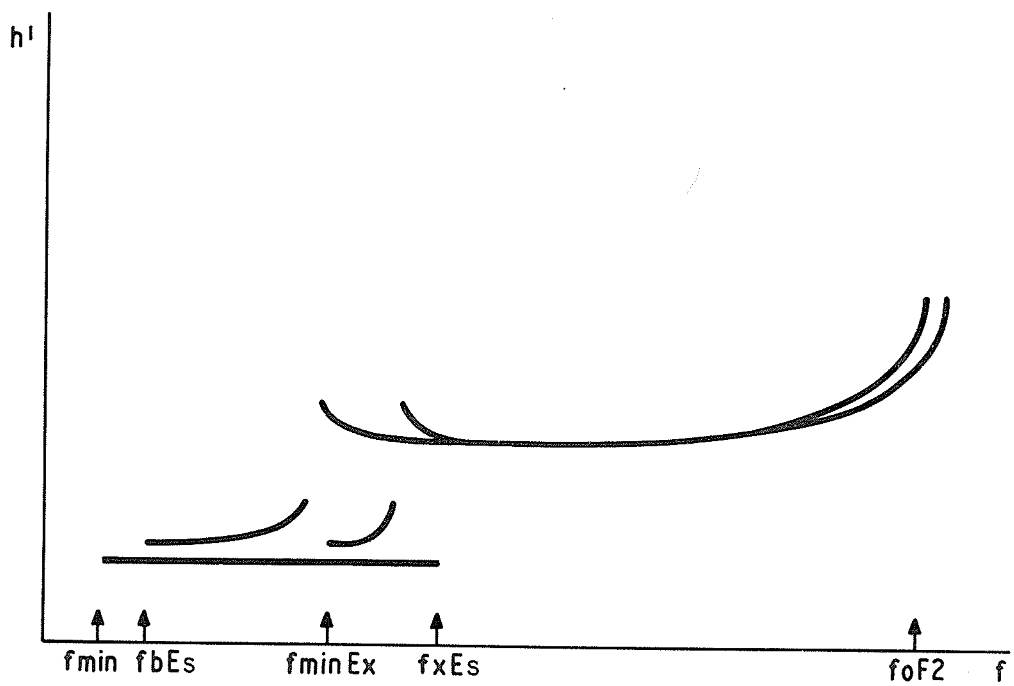


Fig. 4.10 fminx given by fminEx

foEs = (fxEs-fB/2)JA if foEs greater than foE
foEs = (fxEs-fB/2)-G if foEs less than foE
fbEs = (fbEs)-G
Es type low.
If E trace not horizontal h'E = (h'E)EA.

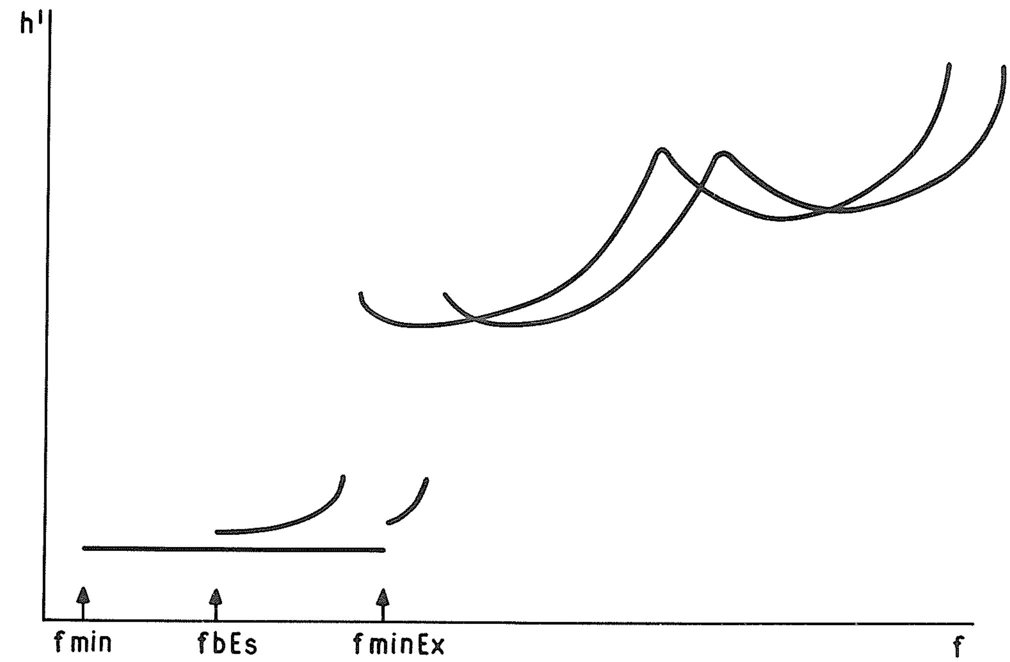


Fig. 4.11 ftEs determined by fminEx
ftEs is fxEs

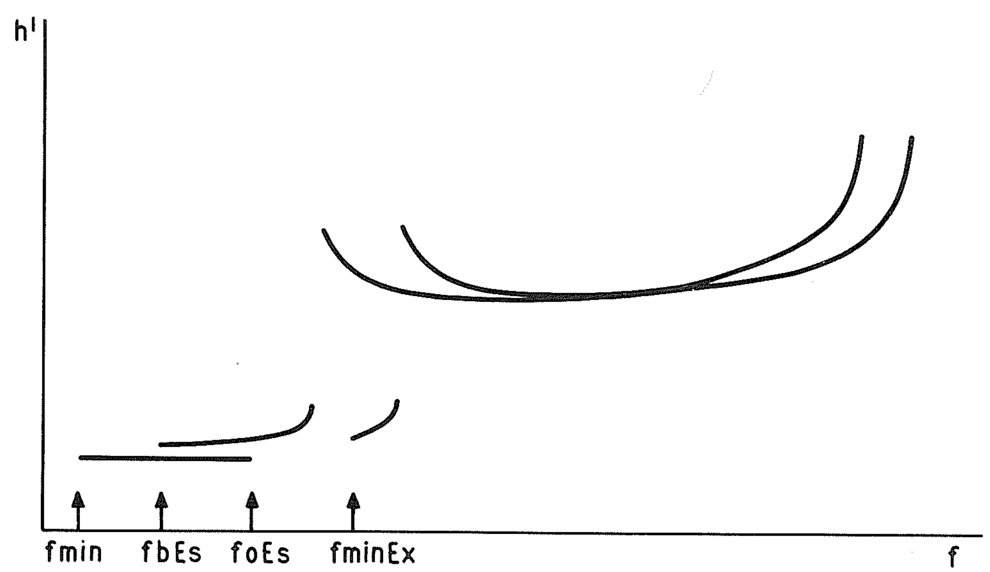


Fig. 4.12 ftEs determined by fminEx
ftEs is foEs

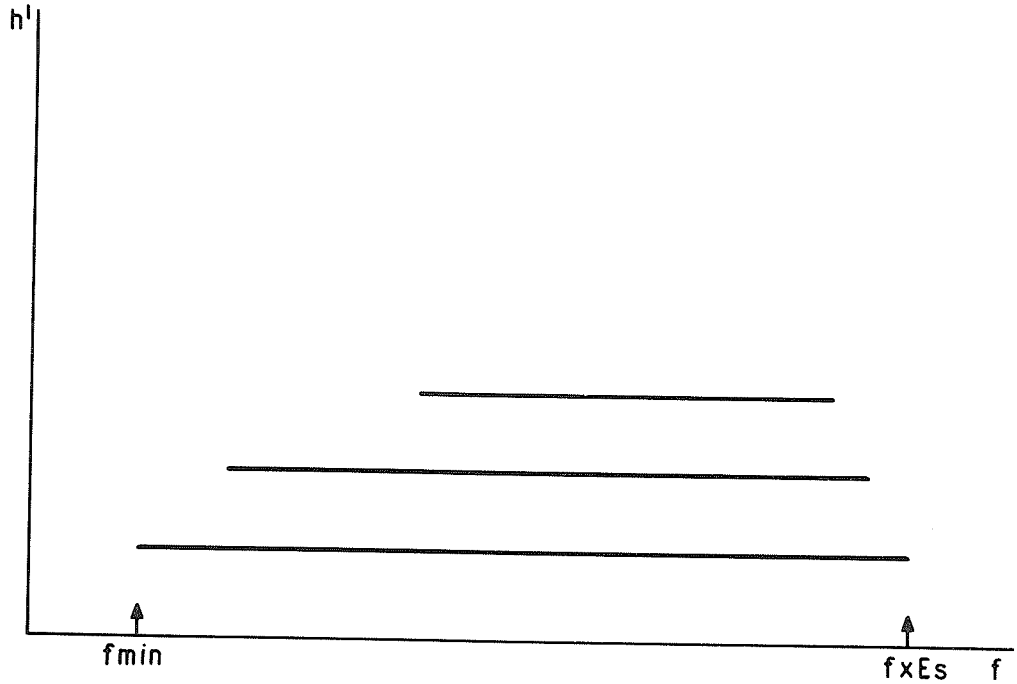


Fig. 4.13 Total blanketing. Normal absorption
ftEs is most likely to be fxEs

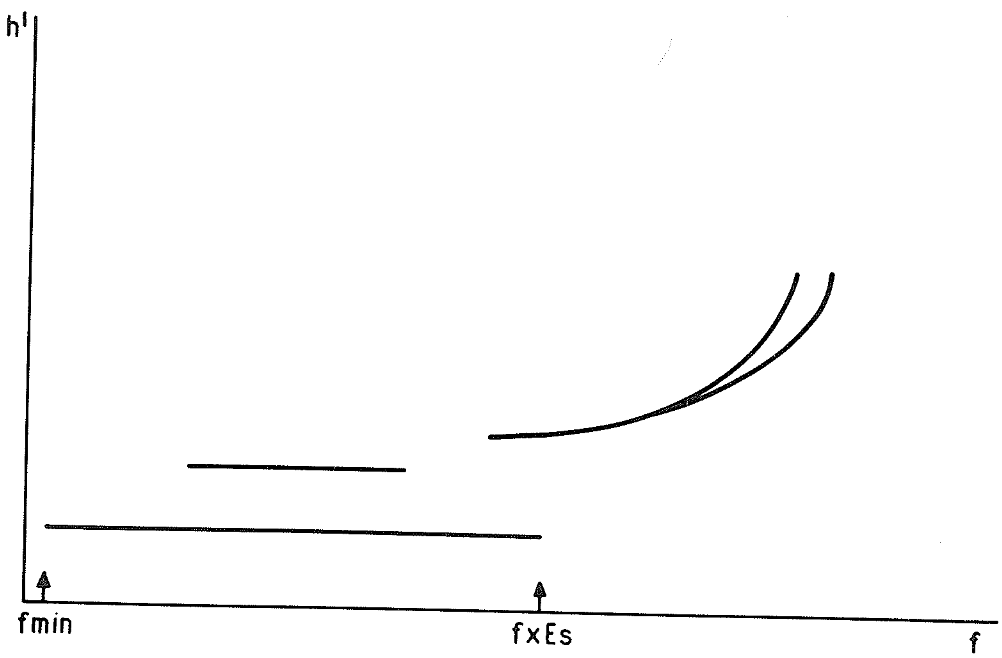


Fig. 4.14 Superposed components
ftEs is most likely to be fxEs in this case as absorption small.

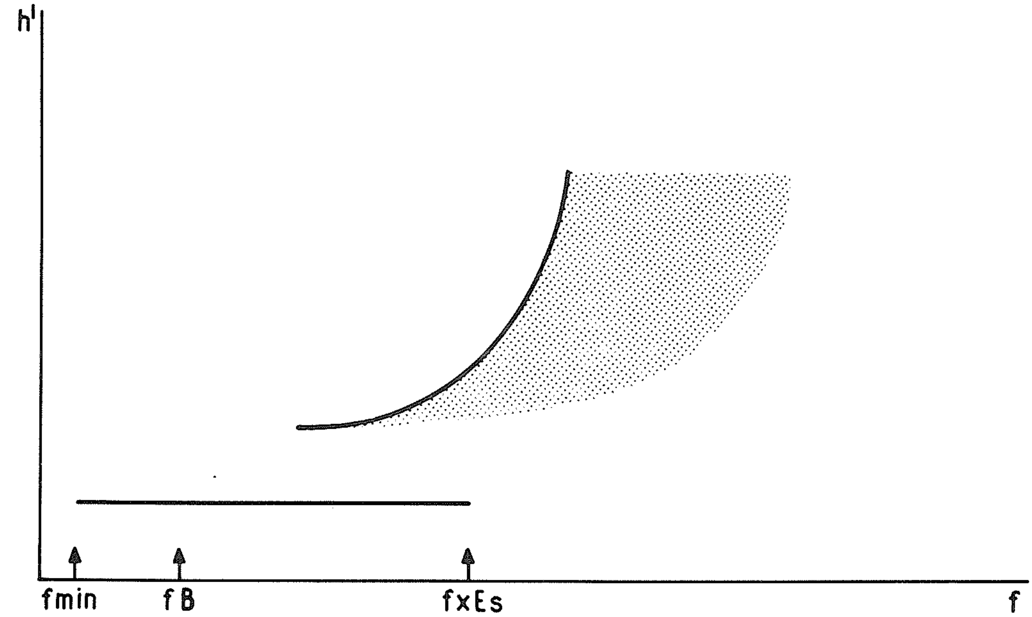


Fig. 4.15 Scatter present

If fmin normal ftEs is likely to be fxEs.

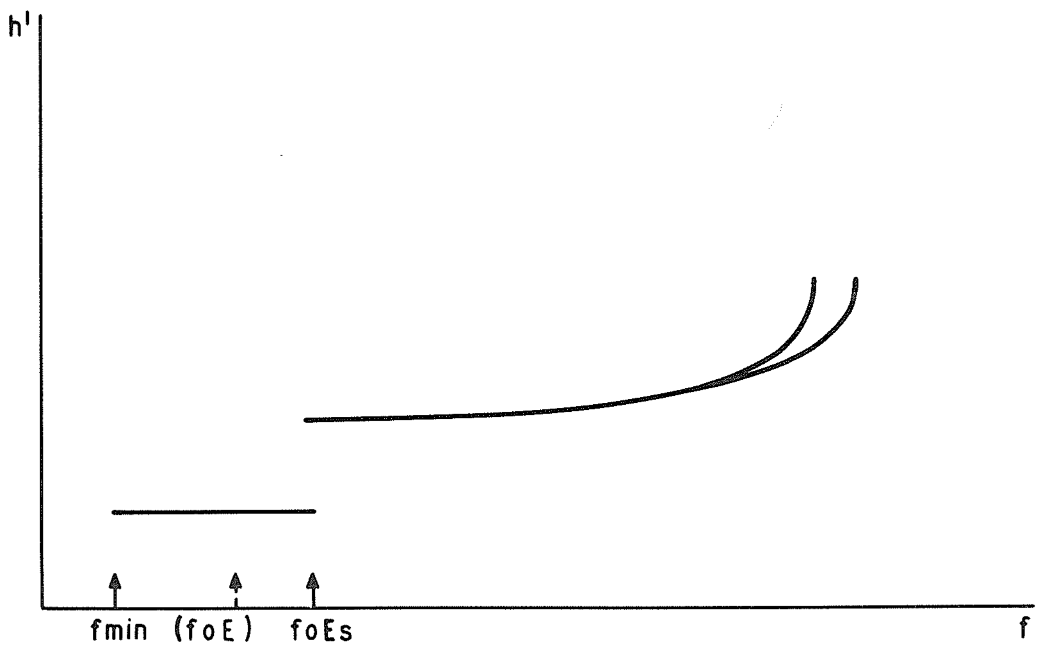


Fig. 4.16 foEs near foE

ftEs is most likely to be foEs (very rare case).

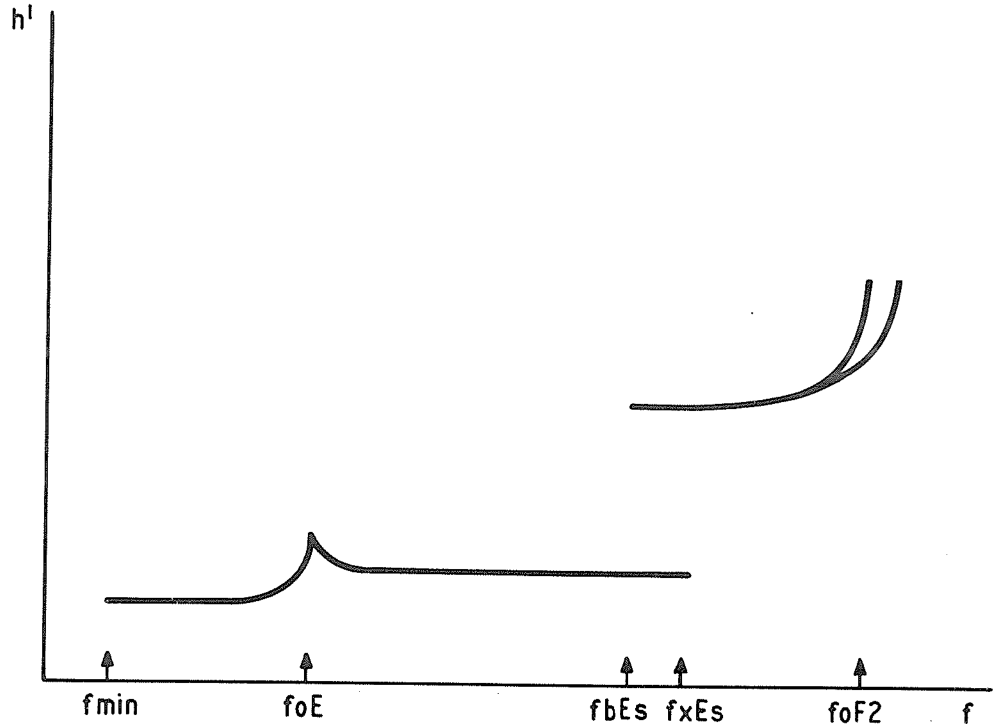


Fig. 4.17 fminFx not visible, absorption normal

fmin normal
ftEs occurs at frequency where x trace would be expected to occur
foEs = (fxEs - fB/2)JA

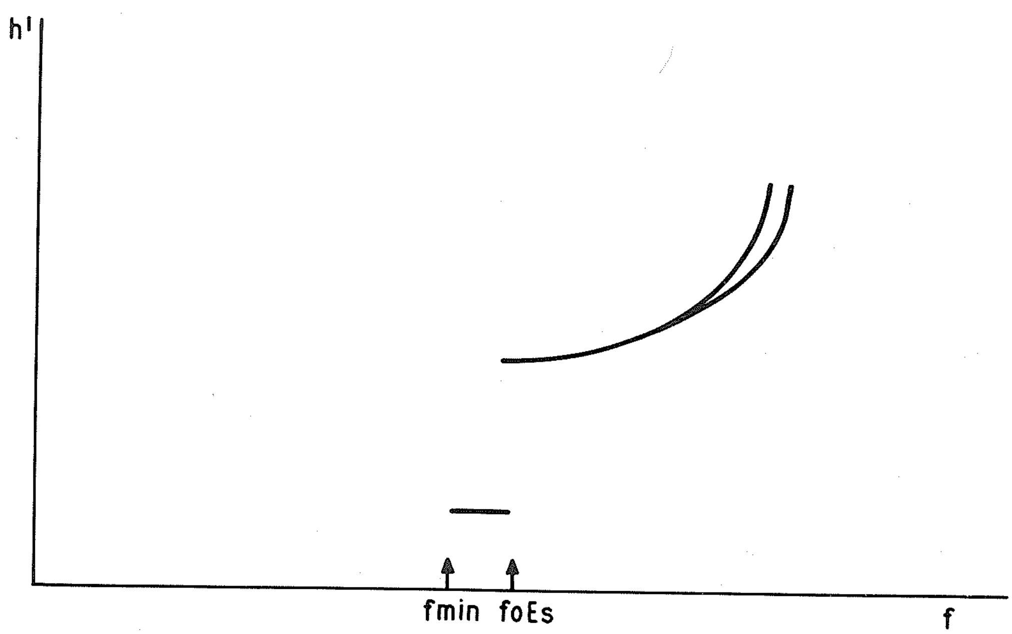


Fig. 4.18 fminFx not visible, absorption large

fmin larger than normal, multiple reflections missing.
ftEs probably foEs as x trace usually much more absorbed than o trace.

4.32 Instructions for distinguishing Es components

Table 4.1

	Para. No.	Conclusion that ftEs = fxEs	Conclusion that ftEs = foEs	Figure
General rules	a,b	Separation by absorption or by group retardation		4.1
	c	No absorption ftEs>fB		4.5,4.6
	c		No absorption ftEs<fB	4.4
	d	ftEs≥fminx	ftEs<fminx	
When fminFx known	e	ftEs>fminFx		4.7
	e	ftEs=fminFx		4.8
	e		ftEs<fminFx (no E trace present within 1/2 fB of fminFx)	4.9
	e	ftEs>fminEx		4.10
	e	ftEs=fminEx		4.11
	e		ftEs<fminEx	4.12
When fminFx not known	(i)	Estimate when absorption is absent		
	f	Total blanketing		4.13
	f	Superposed o and x traces		4.14
	f	F layer scattered		4.15
	(ii)	Estimate when absorption is present		
	g		ftEs∿foE	4.16
	g	ftEs≫foE		4.17
	g		ftEs∿fmin	4.18
	g	At night ftEs≫fmin≫fB		

4.4 Scaling of foEs

4.41. The selection rules for identifying the Es trace which should be scaled are as follows:

(a) Ignore all traces which indicate oblique reflections from evidence on the ionogram or the sequence of ionograms.

(b) Ignore all very weak intermittent reflections.

(c) Ignore all rapidly varying or transient phenomena. For fast recorders, meteor traces which would otherwise resemble an Es trace can often be identified by the occurrence of fairly regularly spaced fading. These traces should be ignored.

(d) Select from the remaining traces the one which is mainly continuous to the highest frequency. This trace should be used for scaling foEs and h'Es. The highest frequency to which the trace is mainly continuous is called its top frequency. The current meaning of 'mainly continuous' is that a break in the trace which can be ascribed to an occasional fade or change in the sensitivity of the ionosonde is ignored if the trace continues regularly beyond the break. Rules (a), (c) do not apply to Es type a.

4.42. The rules for measuring and tabulating foEs are:

(a) When the ordinary and extraordinary Es traces are separated in virtual height or frequency (see section 4.3) or the ordinary component alone is present and identifiable, the top frequency of the ordinary-wave trace is the required value of foEs.

(b) When the ordinary and extraordinary traces are not separated but evidence exists from the rules in section 4.31 (d to g; especially e, iii) that ftEs = foEs, this value is scaled as foEs.

(c) When the rules for distinguishing between the components show that ftEs = fxEs, the preferred method is to subtract 1/2 fB from the observed value of ftEs and tabulate the resultant value qualified by J and described by X.

(d) When the distinction between the components cannot be made but it is most likely that ftEs = fxEs, the preferred method is to subtract 1/2 fB from the observed value of ftEs and tabulate the resultant value qualified by J and described by M.

(e) When the distinction between the components cannot be made but it is most likely that ftEs = foEs (an extremely rare case in practice), scale ftEs described by M.

(f) When no Es trace is present on the ionogram the detailed rules given in section 3.2 for descriptive letters B, C, E, G and S are applied. The main points may be summarized as follows:

B - fmin is high; foEs equal to the numerical value of fmin qualified by E and described by B.

C - Instrumental fault; foEs replaced by descriptive letter C.

E - fmin equal to lower frequency limit of ionogram; foEs replaced by descriptive letter E. (In medians always use frequency EE).

G - Normal or night E echo traces present. foEs replaced by descriptive letter G.

S - Night conditions; fmin tabulated with qualifying letter E and descriptive letter S. foEs tabulated in same way as fmin.

(g) For stations with low frequency ionograms that have a wide interference band, see letter S in section 3.2 for use of letters DS with foEs.

4.43. At stations where most values of foEs must be deduced from fxEs, it is permissible to omit the use of JX in rule (c) above. Es is too variable for the probable additional error to be significant unless the majority of values are direct observations of foEs. Rules (d), (e) should be observed in this case.

4.44. The international rules allow two simplifications to be made to the scaling rules (c), (d), (e) (section 4.42) at stations where conditions do not justify the work involved in calculating foEs. When the rules for distinguishing between the components show that ftEs = fxEs, tabulate ftEs with the descriptive letter X. When the distinction between the components cannot be made tabulate ftEs with the descriptive letter M. The use of these simplifications must be clearly indicated on foEs tables for interchange.

4.5 Scaling of fxEs

Tables of values of fxEs circulated in place of tables of foEs must always be clearly titled as follows:

fxEs ($\sim$ foEs + appropriate mean value of the correction term 1/2 fB).

The selection rules and instructions for distinguishing between the two components are identical to those for foEs.

(a) When the ordinary and extraordinary Es traces are separated in virtual height or frequency (see section 4.42 (a), (b)) the top frequency of the extraordinary Es trace is the required value of fxEs.

(b) When the ordinary and extraordinary Es traces are not separated but the identification rules show that ftEs = fxEs, the top frequency of the extraordinary Es trace is the required value of fxEs.

(c) When the top frequency of the Es trace is known to be foEs add 1/2 fB and tabulate the resultant value qualified by O and described by the letter showing why fxEs was not present, usually B, R or S.

(d) When the distinction between the components cannot be made but it is most likely that ftEs = fxEs, tabulate the observed value of ftEs described by M.

(e) When the distinction between the components cannot be made but it is most likely that ftEs = foEs (an extremely rare case in practice), add 1/2 fB and tabulate the resultant value qualified by O and described by M.

(f) When no Es trace is present on the ionogram, the detailed rules given in section 3.2 for the descriptive letters B, C, E, G and S are applied (see also section 4.42).

(g) For stations with low frequency ionograms that have a wide interference band, see letter S in section 3.2 for use of letters DS with fbEs.

4.51. The use of J, O, M and X for foEs or fxEs is summarized in the following table:

Table 4.2

	foEs		fxEs
	preferable	simplified	
ordinary	... - -	... - -	xxx O B
extraordinary	ooo J X	(ftEs) - X	... - -
unknown, estimate o	... - M	(ftEs) - M	xxx O M
unknown, estimate x	ooo J M	(ftEs) - M	... - M
Numerical example (1/2 fB assumed to be 0.6).			
	foEs		fxEs
	preferable	simplified	
ordinary	039 - -	039 - -	045 O B
extraordinary	067 J X	073 - X	073 - -
unknown, estimate o	041 - M	041 - M	047 O M
unknown, estimate x	089 J M	095 - M	095 - M

Underlined values indicate that the numerical value has been directly obtained from the ionogram.

4.6 Scaling of fbEs

fbEs is always determined using the ordinary-wave trace for the layer first seen through the Es.

If several Es traces giving blanketing are present on the same ionogram, the value of fbEs to be tabulated is the value of blanketing frequency due to the trace which gave foEs (Fig. 4.19 (a) and (b)). All observed values of fbEs should be plotted on the f plot.

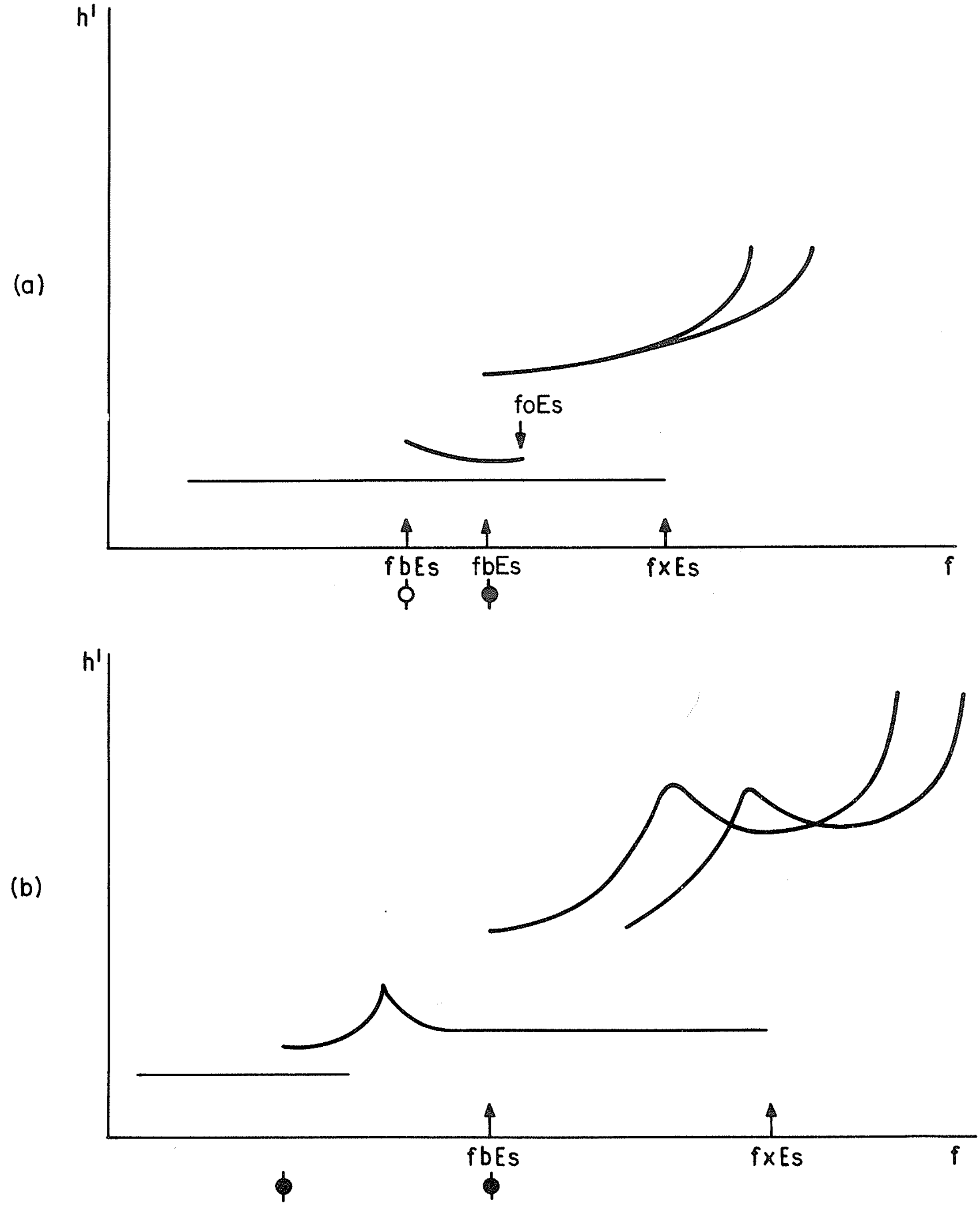


Fig. 4.19 Scaling of fbEs

The f plot symbols (Chapter 6) are also shown.

Note: (i) The tabulated value of fbEs is always given by trace with highest value at foEs.

(ii) All values of fbEs are shown on the f plot.

When the Es trace giving foEs is partially reflecting at all frequencies and a thick layer is present, fbEs is given by the critical frequency of the thick E layer trace associated with its lowest frequency qualified by E and described by G, Fig. 4.20.

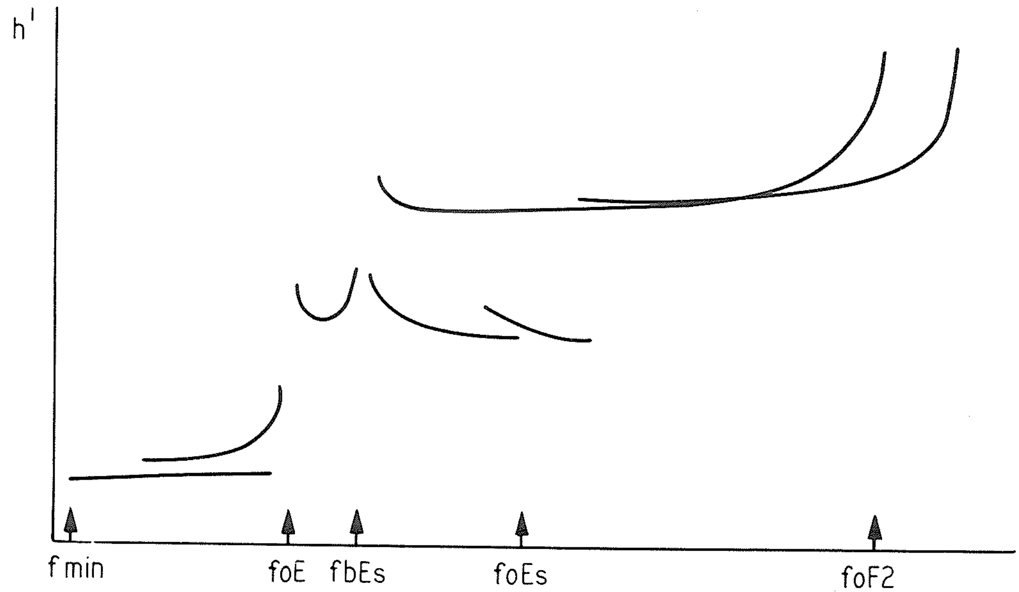


Fig. 4.20 Non-blanketing Es.

This figure shows both Es type h and Es type ℓ
foEs as shown
fbEs is tabulated as (fbEs)EG. fbEs is equal to foE2, the critical frequency of the intermediate layer.

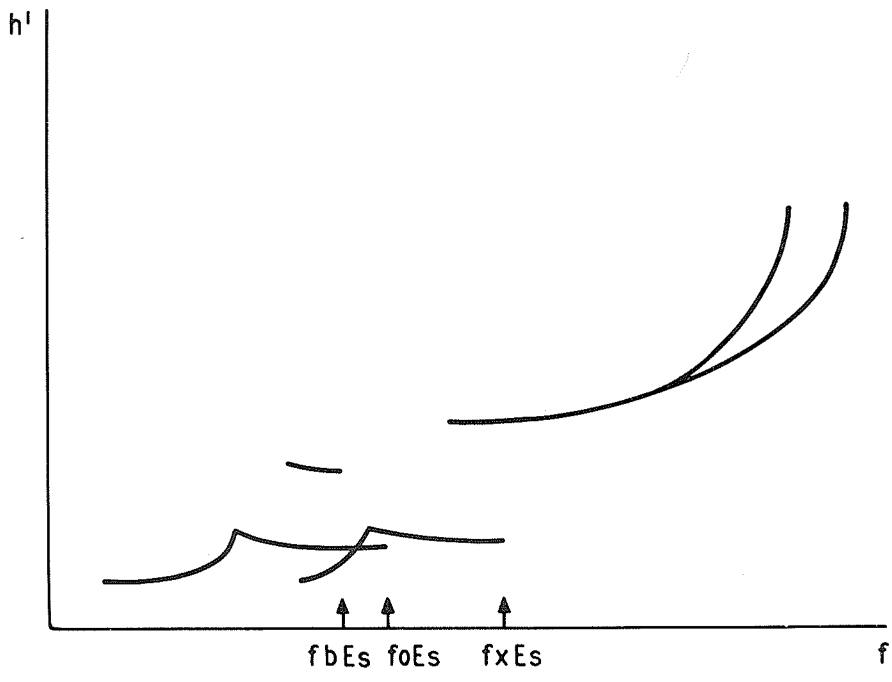


Fig. 4.21 Blanketing indicated by strong second order Es

fbEs given by second order (fbEs)UY, see Fig. 4.22.

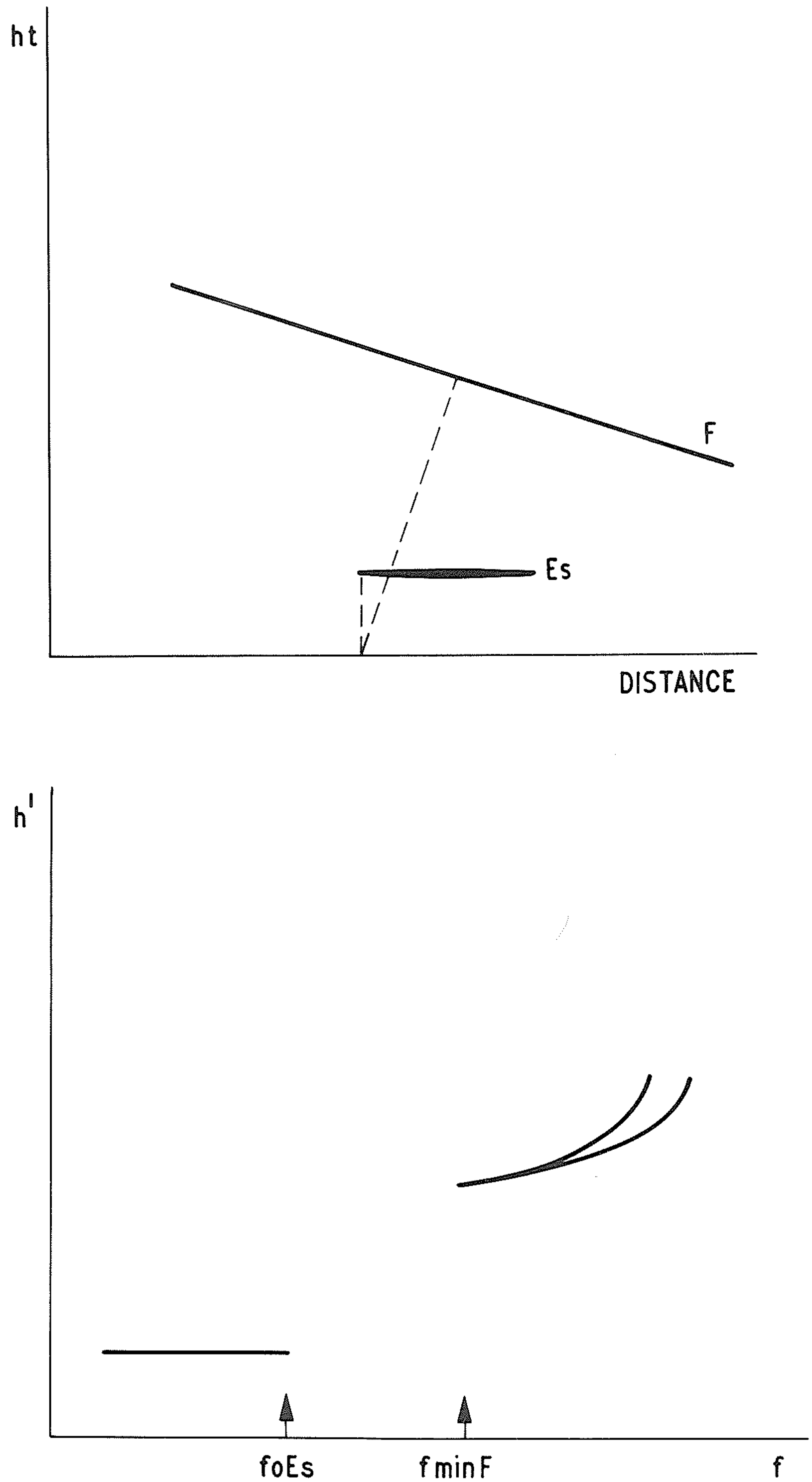


Fig. 4.22 Lacuna due to a tilted F layer
fbEs = (foEs)UY

Note: The presence of the tilt will usually be detected by height differences between the first and second order F traces, (see section 2.7).

The value of fbEs cannot exceed foEs within the usual accuracy rules. When the minimum frequency reflected from higher layers is greater than foEs, fbEs can only be scaled if the ionogram (Fig. 4.21) or sequence of ionograms indicates that blanketing is present. The usual accuracy rules apply. Retardation at fminF indicates the presence of retardation absorption. If the multiple F-trace heights are consistent use R in preference to Y. A gap in frequency between the Es and F trace is most often produced by a tilt of the F layer, which is then sounded in an oblique direction (Fig. 4.22 (a) and (b)). The observed lower frequency limit of the F trace does not correspond to overhead conditions. The numerical value of foEs, qualified by U and described by Y, is tabulated for fbEs. This case can often be identified by comparing the first and second order F-region traces. A descriptive letter alone (e.g., S, C, R, Y) is used in these cases where blanketing is not clearly indicated.

When Es is not observed the letter used to replace the numerical value of foEs is also used to replace that for fbEs (section 4.42).

When complete blanketing occurs (i.e., no reflections from higher layers appear at all), it is not possible to evaluate fbEs with certainty. However, the statistics of fbEs lose much value if these high values are not numerical. Therefore, a new convention has been adopted as stated in section 3.2, letter A using fbEs = (foEs)AA unless this is clearly misleading.

(a) If the trace is solid to foEs, tabulate (foEs)AA (Fig. 3.1).

(b) If the trace is not solid to foEs, or if two or more multiple traces are present with the value of the top frequency of the second order trace much smaller than foEs (Fig. 3.2) tabulate the value of foEs deduced from the top frequency of the second order trace with qualification AA respectively. (Note: If these values have to be deduced from the x-mode trace, AA should be used in preference to JA in cases (a) (b)). Values of fbEs deduced from the solid part of the trace and rule (a) should usually agree within the accuracy rules for limit values with the value deduced from (b).

(c) Rules (a) (b) cannot be used, fbEs should be estimated from the most probable value of foF2, fbEs = (foF2)DA. This should be found from the sequence of foF2 values near the time involved or from corresponding values on other days.

4.7 Scaling of h'Es

h'Es is the lowest virtual height of the trace used to give foEs. If the ionosonde is on gain runs, the height should be scaled from the ionogram on which it can be measured most accurately.

When the low frequency end of the Es trace is affected by group retardation due to the regular E layer and the Es trace does not become horizontal, tabulate the value of the lowest virtual height observed. The tabulated value is qualified by letter U or E as required by the accuracy rules, and described by the letter G.

When Es is not observed, the letter used to replace the numerical value of foEs is used to replace that for h'Es also.

4.8 Classification of "Types of Es"

4.81. <u>Classification procedures</u>: Whenever possible all Es traces appearing on the ionogram should be listed in the column on the tabulation sheet provided for Es types. The classification is independent of the scaling rules for the characteristics foEs, h'Es and fbEs. Thus types of Es corresponding to weak or oblique reflections can be recorded even though they are not scaled for numerical values. All observations available in the hourly sequence, including the high gain sounding, should be used in judging the types of Es present. [B section III pps. 1-10].

4.82. <u>Tabulation of Es types and multiple echoes</u>: When more than one type of Es trace is present on the ionogram, the type for the trace used to determine foEs must be written first. The other types of Es traces are arranged in sequence of descending number of multiples.

The first two types tabulated must each be followed by a number indicating the number of traces seen up to 9. If only the fundamental is present, however, number 1 must be tabulated. The number of reflections of a given type should be determined from the normal gain sounding.

4.83. Description of standard types: The nine standard types of Es are identified by lower case letters: f, ℓ, c, h, q, r, a, s, d. These letters suggest the corresponding names: flat, low, cusp, high, equatorial, retardation, auroral, slant and D region, respectively. It is strongly emphasized that these names are not restrictive. The letter 'n' is used to designate any Es trace that does not correspond to any of the nine types [A94D]. The presence of night E is designated by the letter k.

The standard types are:

f: An Es trace which shows no appreciable increase of height with frequency, Fig. 4.23. The trace is usually relatively solid at most latitudes [A96I, Figs. 93 (b)(c)(e)]. This classification may only be used at hours when a thick E layer is not usually observable (the hours for which a numerical value of foE cannot be obtained). At other hours apparently flat Es traces are classified according to their virtual height: h or ℓ. [B III, 3, 9; IIA 59 Dec., 62 Dec., 63 June, 65 June, 70 June, 71 Raratonga June and Dec., 74 Dec., 82 June, 83 Dec.]. Low frequency ionograms show that most cases of night time f type Es would have been classified as ℓ type though occasionally c or h type would be appropriate.

ℓ: A flat Es trace at or below the normal E layer minimum virtual height or below the night E layer minimum virtual height [A96I, Fig. 93(d)]. [B III, 3, 5, 9; IIB 36 Sept., 42 Dec.]. (Fig. 4.24 (a)(b)).

c: An Es trace showing a relatively symmetrical cusp at or below foE. This is usually continuous with the normal E trace, although when the deviative absorption is large, part or all of the cusp may be missing. (Usually a daytime type.) [A96I, Figs. 93 (d), 94, 95]. [B III, 4, 9. Many other cases]. (Fig. 4.25 (a)(b)).

h: An Es trace showing a discontinuity in height with the normal E layer trace at or above foE. The cusp is not symmetrical, the low frequency end of the Es trace lying clearly above the high frequency end of the normal E trace. (Usually a daytime type.) [A96I, Fig. 97]. [B III, 4, 5; IIB 42 (all), 46 Sept. Freiburg, 51 Sept., 52 Dec., 55 June, Sept., 57 Dec., 61 June, 62 June Tsumeb, 64 June, 83 Dec.]. (Fig. 4.26 (a)(b)).

q: An Es trace which is diffuse and non-blanketing over a wide frequency range. The spread is most pronounced at the upper edge of the trace. (This type is common in daytime in the vicinity of the magnetic equator.) [A96I, Figs. 93(a), 98]. [B III, 8, IIB 84 Ibadan, Kumasi June; 85 Dec.; 86 all; 87 all]. (Fig. 4.27).

r: An Es trace showing an increase in virtual height at the high frequency end, similar to group retardation. The trace is blanketing over part or nearly all of its frequency range. This is distinguished from the usual group retardation (as in the case of an occulting thick E layer) by the lack of group retardation in the F layer traces at corresponding frequencies and the lack of complete blanketing [A96I, Figs. 93 to 96, A104I, 120]. (see Figs. 4.2, 4.28).

a: All types of very diffuse (spread) traces are combined in auroral type Es. These can extend over several hundred kilometers of virtual height. Typical patterns show a flat or slowly rising bottom edge to the pattern, with stratified traces in it which vary rapidly in time. The width of the trace is usually greatest well below foEs or fxEs, often at frequency near fminF, Fig. 4.29. The pattern usually alters rapidly in time. Es type a traces are usually seen at oblique incidence and patterns at different virtual heights are usually independent (most often are from different directions). Es type a seldom, if ever, shows multiple reflections.

s: A diffuse Es trace which rises steadily with frequency and usually emerges from another type Es trace [A96I, 93h, 98]. The rising trace alone is classified as 's'; the horizontal trace is classified separately. Es type 's' can arise from foE, fxE; foEs, fxEs, or from an intermediate point in the Es trace. At high latitudes, the slant trace usually starts to rise from a horizontal Es trace, such as Es ℓ or Es f, at frequencies which greatly exceed the E-layer critical frequency, or from Es type r, or night E traces. At low latitudes, it usually arises from foE and is associated with Es q, Es h and Es c. It is occasionally seen arising from fxE. Es type s traces must not be used to determine foEs, fbEs or h'Es. [B III, 7, 8, 9] (Fig. 4.30 (a)(b)).

d: A weak trace at heights below 95 km associated with high absorption and large fmin. This is not strictly an Es trace though it appears similar to one, and should never be used to give values of fmin, foEs, h'Es. It is never blanketing but the associated absorption may prevent reflections from higher layers. In practice, most often seen at heights near 80 km, [B III 10] (Fig. 4.31).

n: The designation 'n' is used to denote an Es trace which cannot be classified into one of the standard types. When a trace appears to be intermediate between any two classes a choice should be made whenever possible even if it is uncertain. 'n' should be used sparingly.

Note: If a form of Es not included in the standard types given above occurs frequently at a station, it is permissible to devise a new type and designate it with an appropriate letter. It should be clearly distinguishable from the other types and completely described in the scaling notes. Type d originated in this way but is now recognized internationally. Such proposals should be submitted to INAG for comment.

k: The designation k is used to show the presence of night E [B III, 7]. When foEs >foE (night E) the Es type precedes k; e.g., r1, k, h. A typical pattern is shown in Fig. 4.2(c).

4.84. Missing data: By convention, Es types are only entered when seen and the appropriate spaces are left blank whenever no Es trace is present. No attempt is made to show the reason, i.e., do not use letter symbols B, C, G, S, etc., in this table.

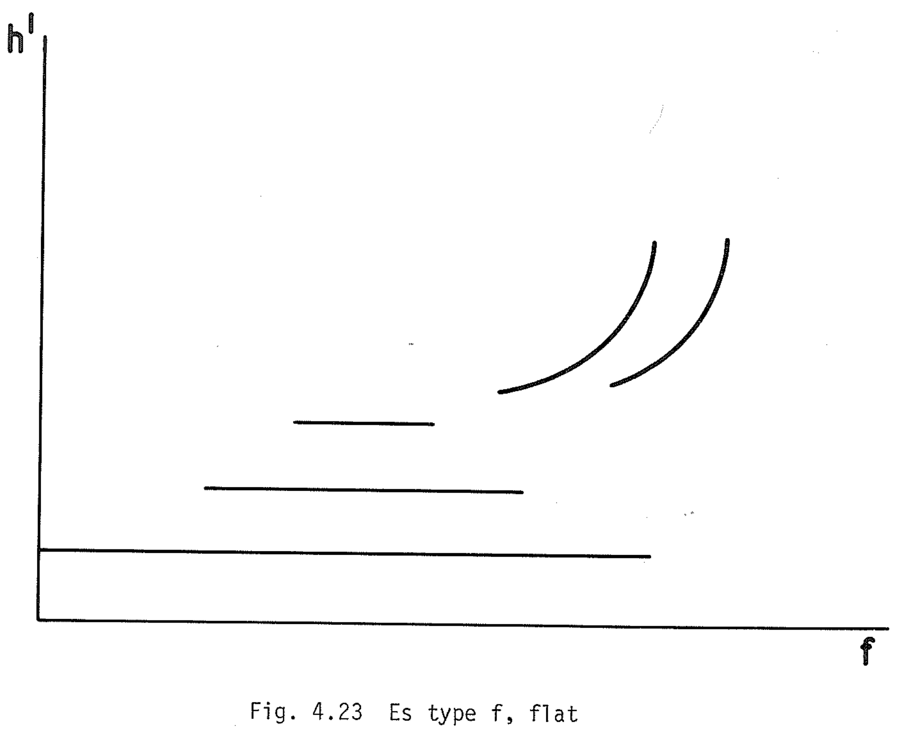
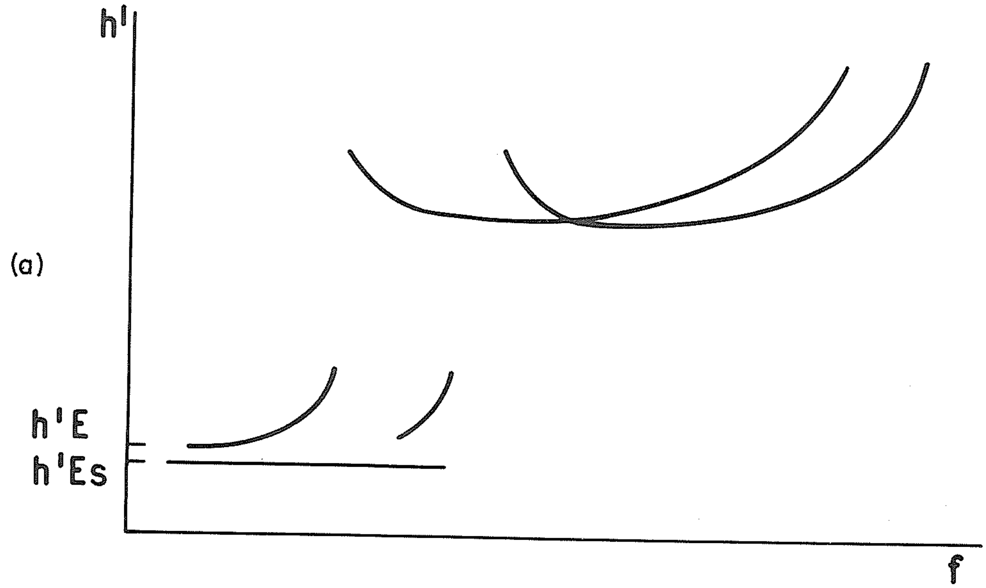


Fig. 4.23 Es type f, flat

Use only when a thick E layer is not usually observable at the time of the ionogram. Otherwise use ℓ.



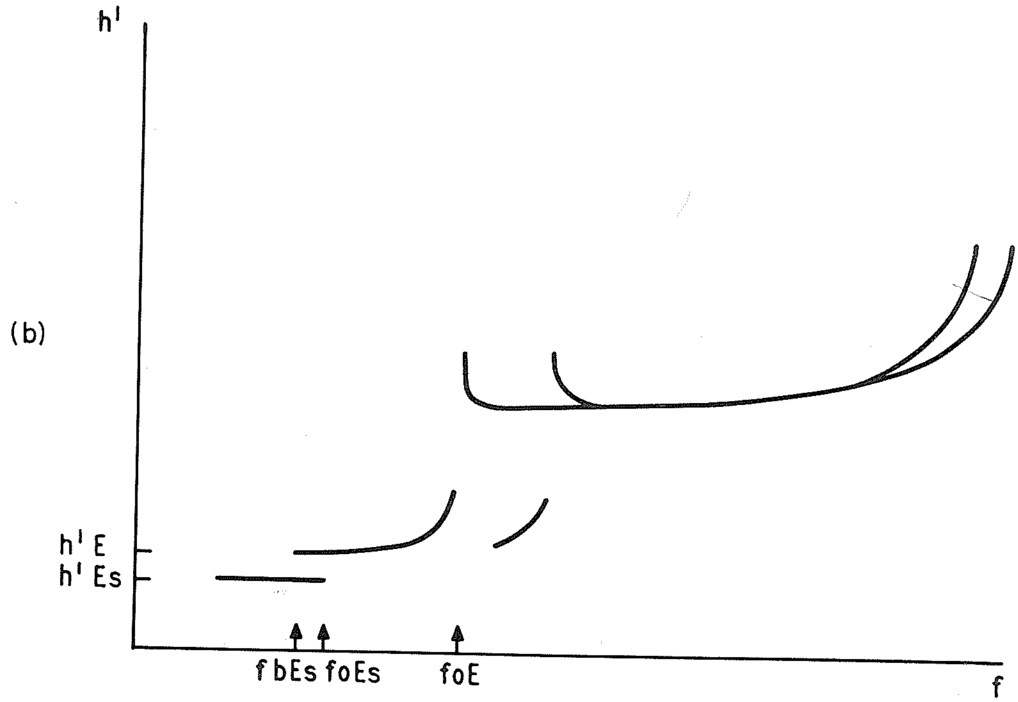


Fig. 4.24 (a)(b) Es type ℓ, low

Note a pattern similar to Fig. 4.23 with h'Es less than the normal value of h'E for the hour should also be classified as type ℓ.

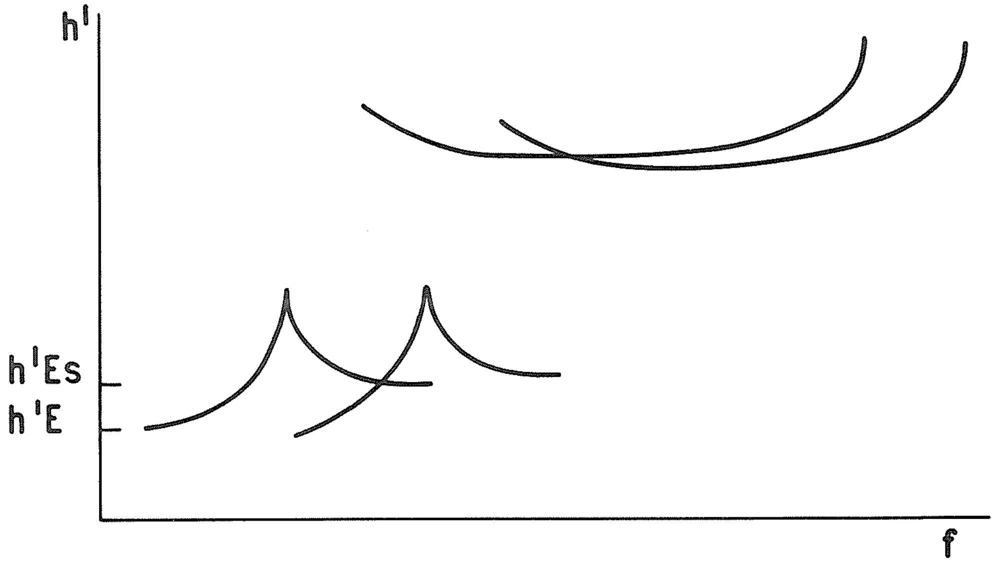


Fig. 4.25 (a) Es type c, cusp

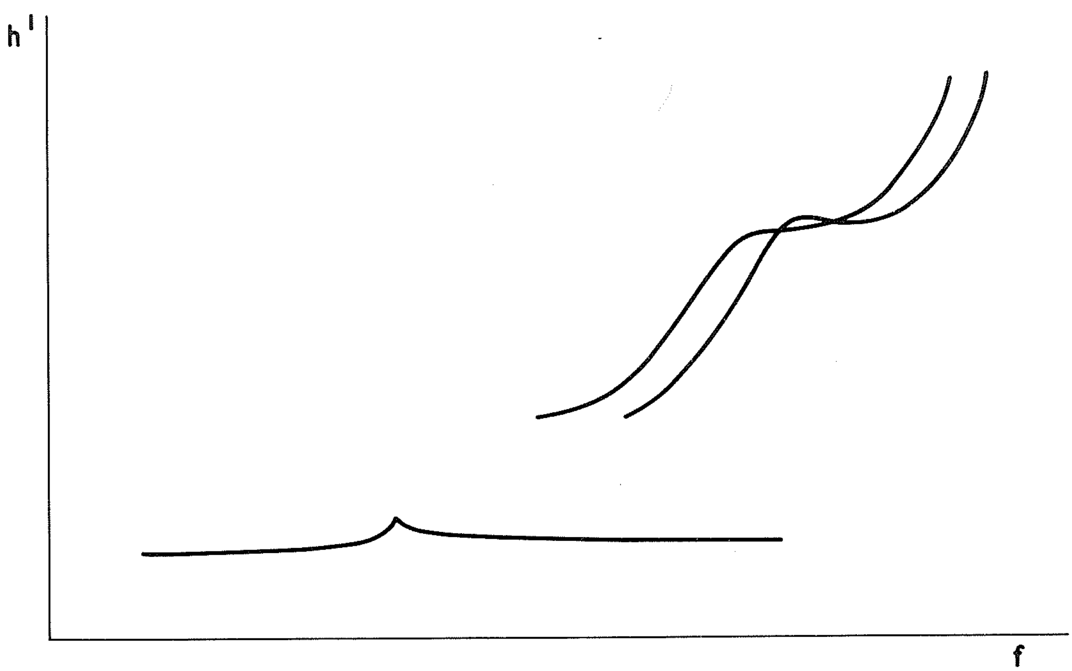


Fig. 4.25 (b) Es type c, cusp
foE blanketed by c type Es.

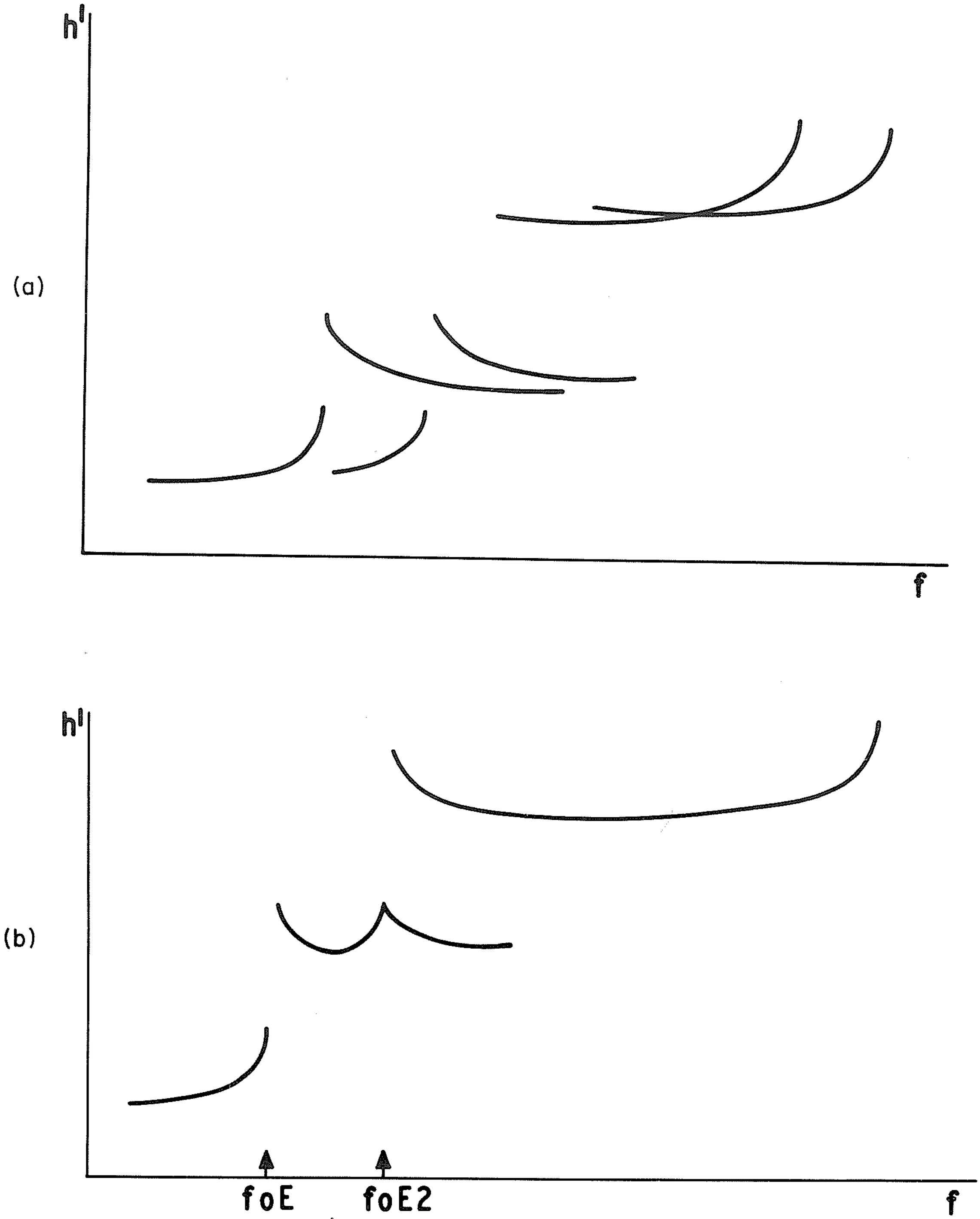


Fig. 4.26 Es type h, high

(a) The Es trace lies slightly above the E trace. When partial, the traces would not extrapolate to a common point except at a great height.

(b) A cusp like pattern from an intermediate stratification is also high - it is clearly above hmE.

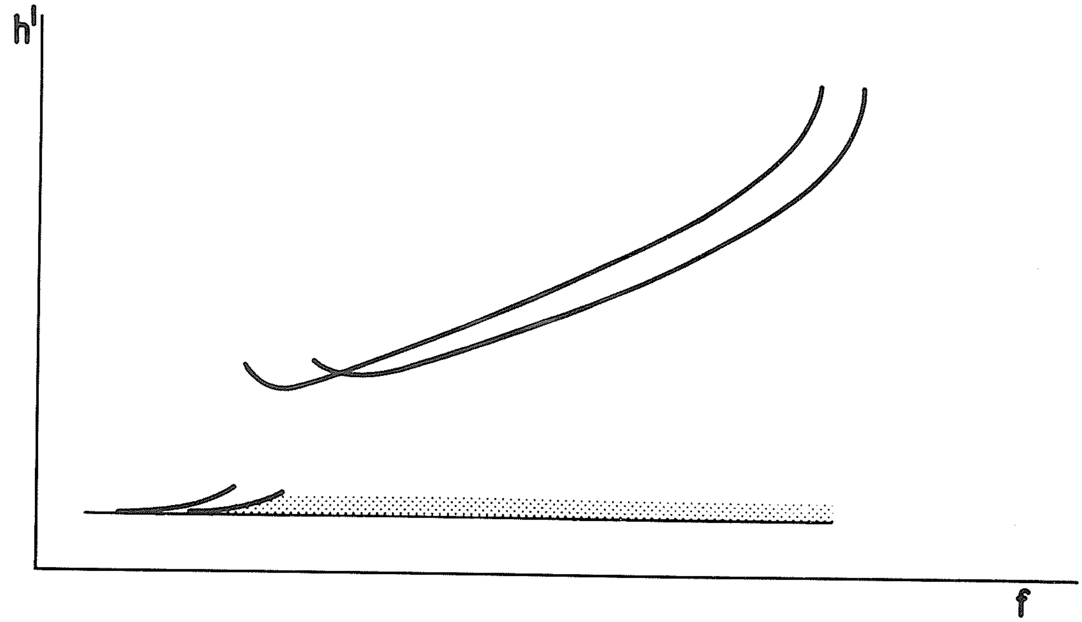


Fig. 4.27 Es type q, equatorial

A weak scattered trace extends to very high frequencies and does not blanket. Note Es type ℓ can be superposed in the low frequency end of this trace and is then blanketing. ftEs is assumed to be fxEs so foEs = fxEs - fB/2 for this trace. When ℓ and q types are superposed fbEs is deduced from the ℓ trace.

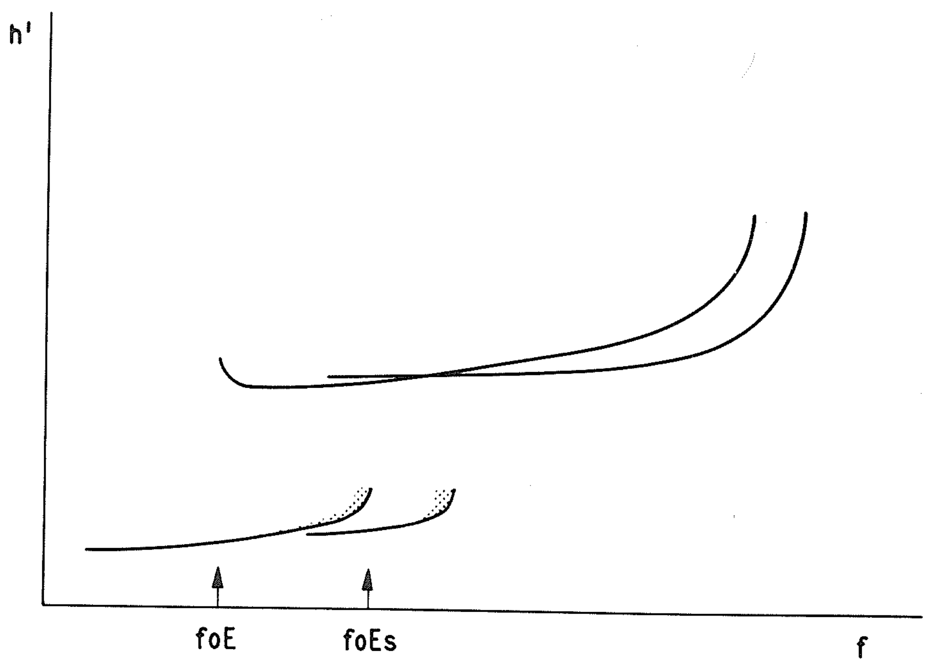


Fig. 4.28 Es type r, retardation

The trace is normally blanketing over part of its length. In this figure fbEs = foE, but the F trace can also show no retardation at fminF, see Fig. 4.2(a),(b).

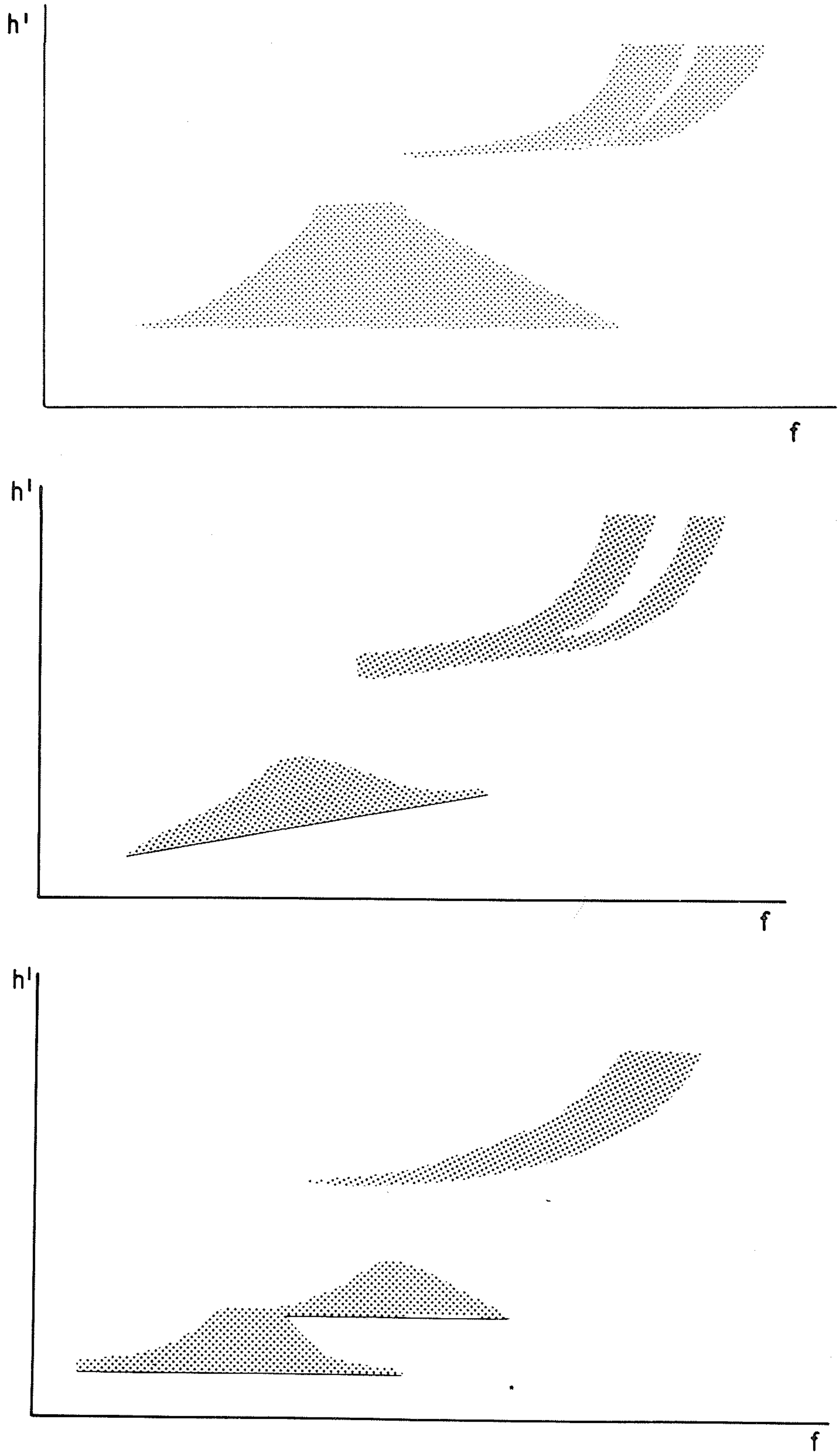
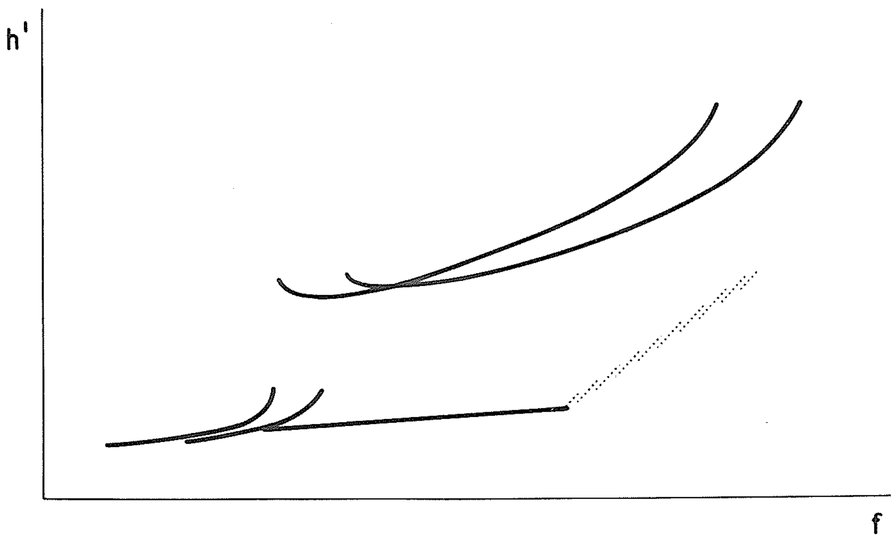


Fig. 4.29 Es type a, auroral

A wide range of diffuse spread traces are classified as Es type a. Some common patterns are shown above. The F traces are usually, but not always, also spread.



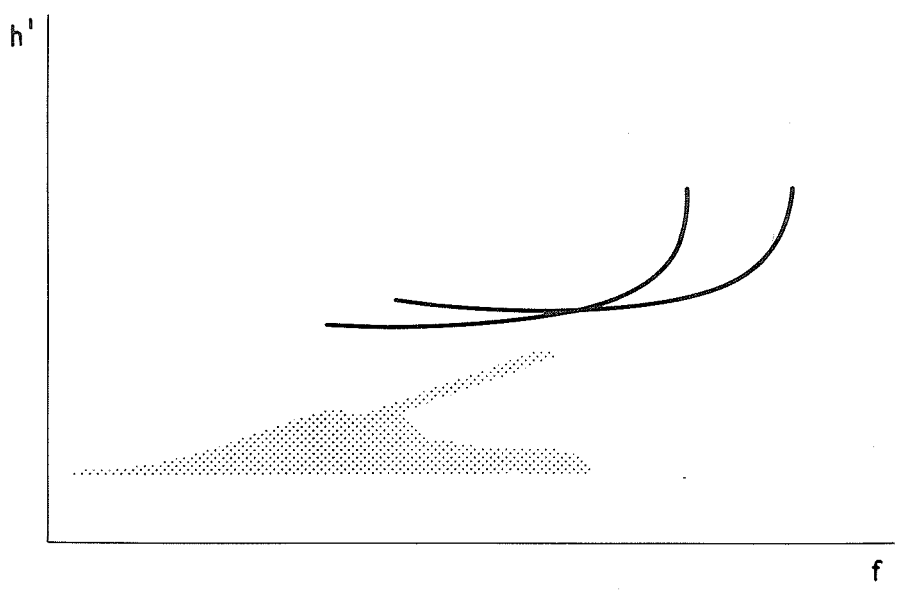


Fig. 4.30 Es type s, slant

Es type s can arise from any type of Es trace or from foE or fxE. It is most commonly seen with types f, ℓ, a, and occasionally q, r. Incidence varies with station location.

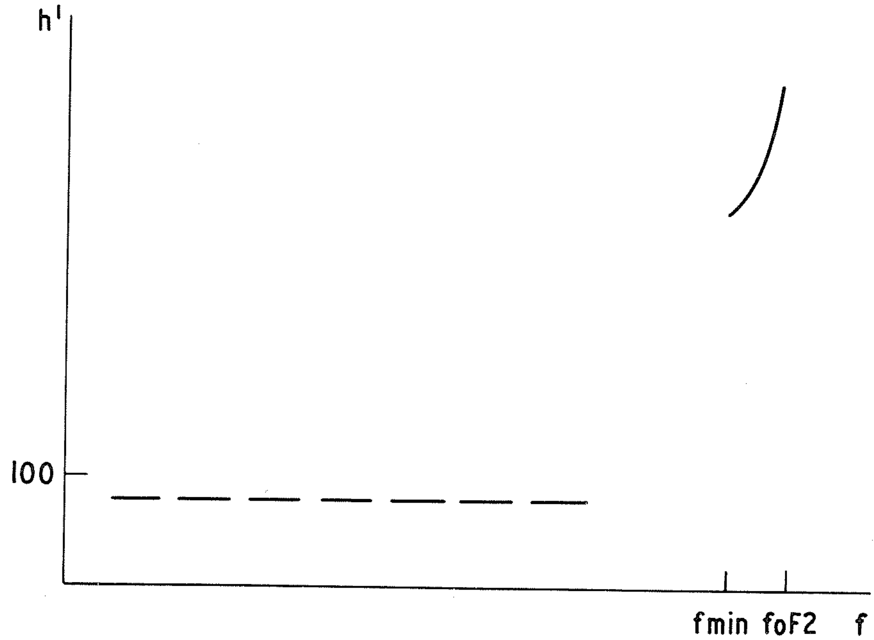


Fig. 4.31 Es type d. Partial reflection from absorbing layer.

A weak trace normally seen below 90 km and extending between 1 and 3 MHz, sometimes higher in frequency. All other traces show high absorption or are missing because of it (B condition).

4.85. Notes on distinguishing between Es types: The following notes are intended to help distinguish the correct type where pairs of types (e.g., f, a) may be confused. When in doubt the final decision is always to be based on the International Rules, section 4.83. Common but not essential features are stressed where these aid the identification.

f,a: Except when high absorption is present or foEs is below fB flat Es, type f, usually shows multiple traces and is blanketing over at least part of the frequency range. In contrast Es type a seldom shows multiple traces. A little spread may be seen above Es flat on the first order when absorption is low whereas Es a (auroral) will show great spread for the same conditions.

When high absorption is present it can be difficult to distinguish between types a and f. A high gain ionogram can be used to help in this case. For type a there will be a significant increase in spread with gain, for type f little or no change. If spread is seen under high absorption conditions (fmin high), this by itself indicates type a rather than f since the weak scatter often seen with type f under low absorption conditions is quickly removed by a small increase in absorption.

r,a: r traces usually show blanketing over part of the range and show a curved upper limit closely similar in shape to the retarded part of the normal E curve, with greatest heights near foEs. In contrast, a traces usually cover a greater range of heights and often show maximum spread at a frequency well below foEs. Quite often the F trace shows retardation at a frequency appreciably lower than foEs suggesting the presence of night E, and the r trace is blanketing to near this frequency.

ℓ,d: A weak ℓ trace can look like a rather high d trace but is then only seen when absorption is small, low fmin, and multiple echoes present. The d type would be associated with high absorption. Frequently a weak ℓ trace is seen only very near to foE, whereas the d trace usually extends to the lowest recorded frequencies. Very dense type ℓ Es can occur at low heights, but then usually shows multiple traces. Type d never shows multiple traces.

q,ℓ: When both are weak traces, q extends over a wide frequency range, ℓ over a narrow, e.g., q might extend over 1-20 MHz, ℓ over 1 to 3 MHz. When ℓ extends over a wider frequency range it is blanketing over at least part of the range.

Where q is very common, combined q,ℓ traces (ℓ slightly higher than q, can be seen occasionally and distinguished by the blanketing effect of ℓ at low frequencies, and the normal value of foEs is associated with the q. Classify as q,ℓ. q is extremely rare except within about ± 15° from the magnetic equator.

h,c: When absorption is high near foE, letter symbol R, compare relative heights of h'E, h'Es with similar values for clear cases of h,c. h'Es for h usually lies at least 10 km above h'E.

ℓ,z: At high latitudes, the z-mode reflection from E is often lower than the o mode and can look similar to a low Es trace. Similar features separated by about 1/2 fB suggest z rather than ℓ. The z-mode trace usually blankets the lower part of the E trace, The blanketing frequency varying very slowly with time. Low type Es traces do not always blanket when foEs is less than foE, and their blanketing frequency usually varies rapidly with time.

4.9 Provisional f plot Indication of fxEs

A number of stations are experimenting with the addition of the top frequency of Es (ftEs) to the f plot. To encourage conformity the following conventions are recommended:

(a) The standard f plot rule that the f plot shows what was actually observed should be strictly obeyed.

(b) An open triangle △ is recommended when ftEs is equal to fxEs.

(c) A closed triangle ▲ is recommended

(i) if the value is doubtful
(ii) if the interpretation, fxEs, is doubtful
(iii) if the observed value of ftEs is foEs.

(d) Limit values are indicated by adding the appropriate descriptive letter above the solid triangle if the true value is greater than that given, below if less.

The additional information appears valuable provided it is restricted to the Es trace used to give foEs.

Note: For G conditions the symbol for foE takes precedence over the symbol for Es, i.e., use an open or closed circle, not a triangle, in these cases. The plotting of ftEs or fxEs on f plots is purely voluntary and is not at present recommended internationally.

NOTES

NOTES

5 TOPSIDE SOUNDER IONOGRAMS

5.0 Introduction

The topside of the ionosphere can be investigated by means of an ionosonde operating from a space platform, such as a rocket or a satellite. Topside soundings from such an ionosonde can measure the virtual depth to a particular density or feature of the ionosphere, from the ionosonde down to the peak of the F layer. Since echo returns are also frequently observed from directions other than vertical, the terms virtual range or apparent range rather than virtual depth or height, are normally used as a coordinate for topside ionograms.

5.01. A topside sounder can be built to give ionograms at locations that are rather closely spaced along the path of the sounder; if a satellite borne sounder is in a near Earth polar orbit, above the peak of the F layer, it is possible to cover almost all geographical areas at least twice in a given 24 hour period. However, the selection of a particular orbit restricts the measurements that can be made from a single satellite. For example, an equatorial orbit (inclination 0°) samples all local times but only one latitude, whereas a polar orbit (inclination 90°) samples all latitudes but only two local times for a given 24 hour period.

5.02. Since the horizontal velocity of a satellite in near Earth orbit is approximately constant at 5 to 10 km/sec, a topside sounder with a pulse recurrence frequency (prf) of 30 Hz travels from 167 to 133 m between pulses. Thus spatial resolution (i.e., the distance travelled during one ionogram) and frequency resolution (i.e., the frequency difference between successive pulses) are competing requirements in the design of topside sounders, just as temporal resolution (i.e., the number of ionograms per unit time) and frequency resolution are in competition in ground based sounder design. The prf of a pulse sounder is determined by the range over which sounding is required. In the satellite case, the required sounding range depends not only upon the apparent range from the satellite to the peak of the F layer (i.e., upon the altitude of the satellite) but also upon the scale height of the ionosphere near the satellite, and upon the extent to which oblique or field-aligned propagation is present. If the satellite is in high orbit, and sounding to the peak of the F layer is desired, the prf must be low. For altitudes up to 1500 km a prf of 60 Hz is generally adequate, whereas for an altitude of 3000 km a prf of 30 Hz is appropriate.

5.03. Two of the topside sounder satellites that have been launched illustrate the compromises that have had to be made to meet the above restrictions. The Fixed Frequency sounder of Explorer XX obtained an "ionogram" each 0.1 sec, i.e., about 0.75 km of horizontal travel, but the ionogram consisted of only 6 frequency samples, between 1.5 and 7.22 MHz. The swept frequency sounder of Alouette II, on the other hand, is designed to provide high frequency resolution; the sounder takes about 14 sec to sweep from 0.2 to 20.0 MHz, providing about 400 frequency samples, but during this time the satellite travels about 100 km. Other factors, of course, also restrict the coverage actually obtained from a given satellite; for example, the number and location of telemetry stations, the capacity of on-board data storage, the efficiency of the sounder system, and the amount of energy that the spacecraft can provide to power the sounder may be critical factors in determining the coverage obtained. Also topside sounder ionograms usually give only limited information on the shape of the layer below the peak of the F layer. Thus the data obtained from topside sounders complement but do not replace those obtained from the network of bottomside sounders.

5.04. Since topside ionograms are normally analyzed at a few centers only, detailed instructions on interpretation and data reduction will not be given here. These, as well as many other related subjects are covered in considerable detail in the June 1969 Proc. of the IEEE, a special issue on topside sounding. References to this issue made in this Chapter will be denoted [I] with the page number. A complete list of the contents is given in section 5.76. This chapter is restricted to a simplified and general description with appropriate references. It also contains a summary of preferred nomenclature and listings of various types of topside sounding data that are available.

5.1 Reflection Traces

5.11. Figures 5.1, 5.2, and 5.3 show topside sounder ionograms with the main reflection traces identified. These traces result from radio waves that propagate in the corresponding z, o, and x modes, approximately vertically downward from the satellite, become reflected, return to the satellite, and are detected by the sounder receiver [I p 949, p 960]. The low-frequency cutoffs (that is, the minimum frequency for which a particular mode can propagate in the plasma near the satellite) for these modes are called fzS, foS and fxS respectively, where S shows that the measurement was made at the satellite height. The cutoff for the o mode corresponds to the local plasma frequency, fN. The three mode cutoffs for any satellite height S in the ionosphere are related to the plasma frequency fN, by

o mode $$fN = foS \qquad (5.1)$$

z mode $$fN = \sqrt{fzS\ (fzS + fB)} \qquad (5.2)$$

$$\text{x mode} \qquad fN = \sqrt{fxS\ (fxS - fB)} \qquad (5.3)$$

where fN and fB are measured at the satellite height.

Note: Equation (5.3) is used, in the Canadian data booklets, to deduce the plasma frequency at the satellite which is then denoted JFOS. In these booklets FH is used to denote the gyrofrequency at the satellite. In NASA data booklets this quantity is denoted by FHS.

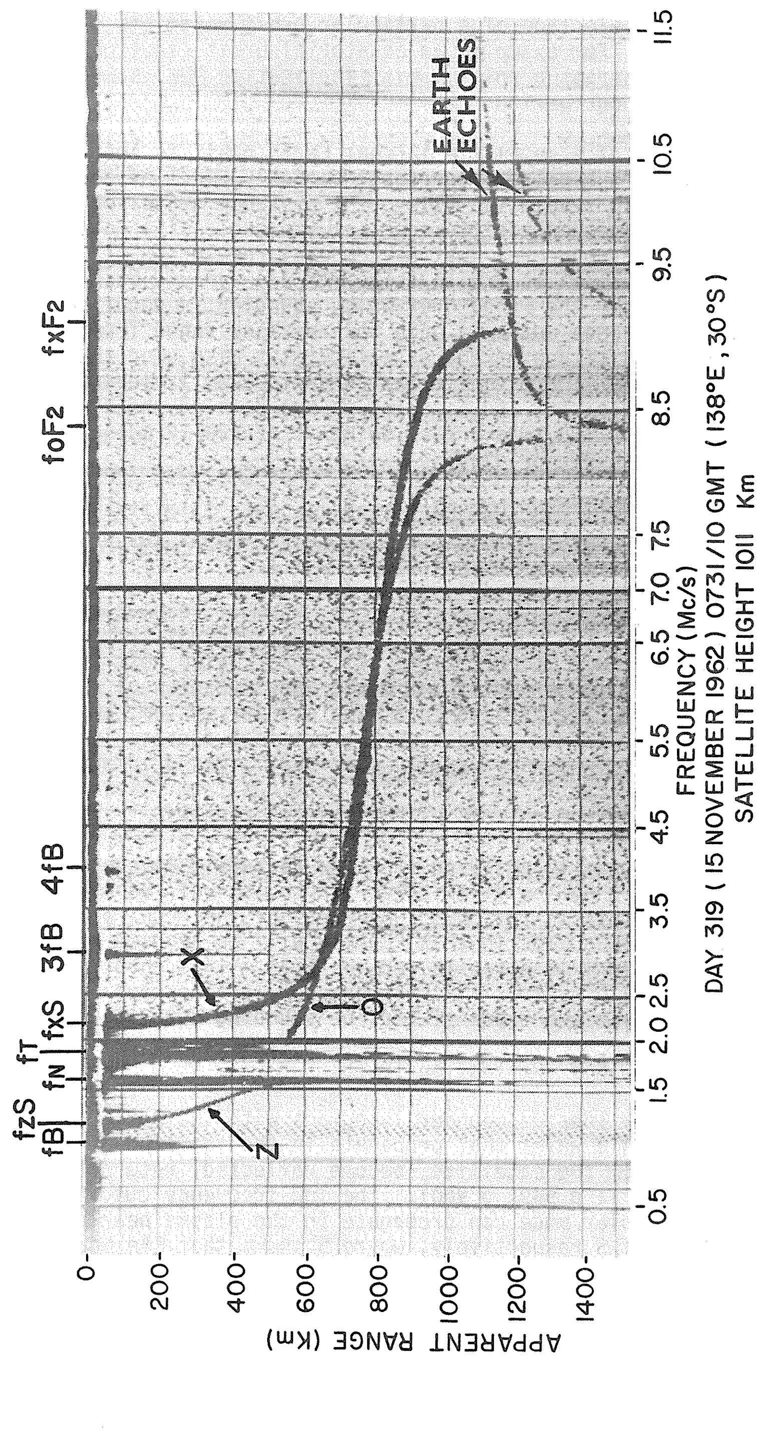


Fig. 5.1 An Alouette I ionogram illustrating z-, o- and x-wave traces, cutoffs, resonance spikes and earth echoes.

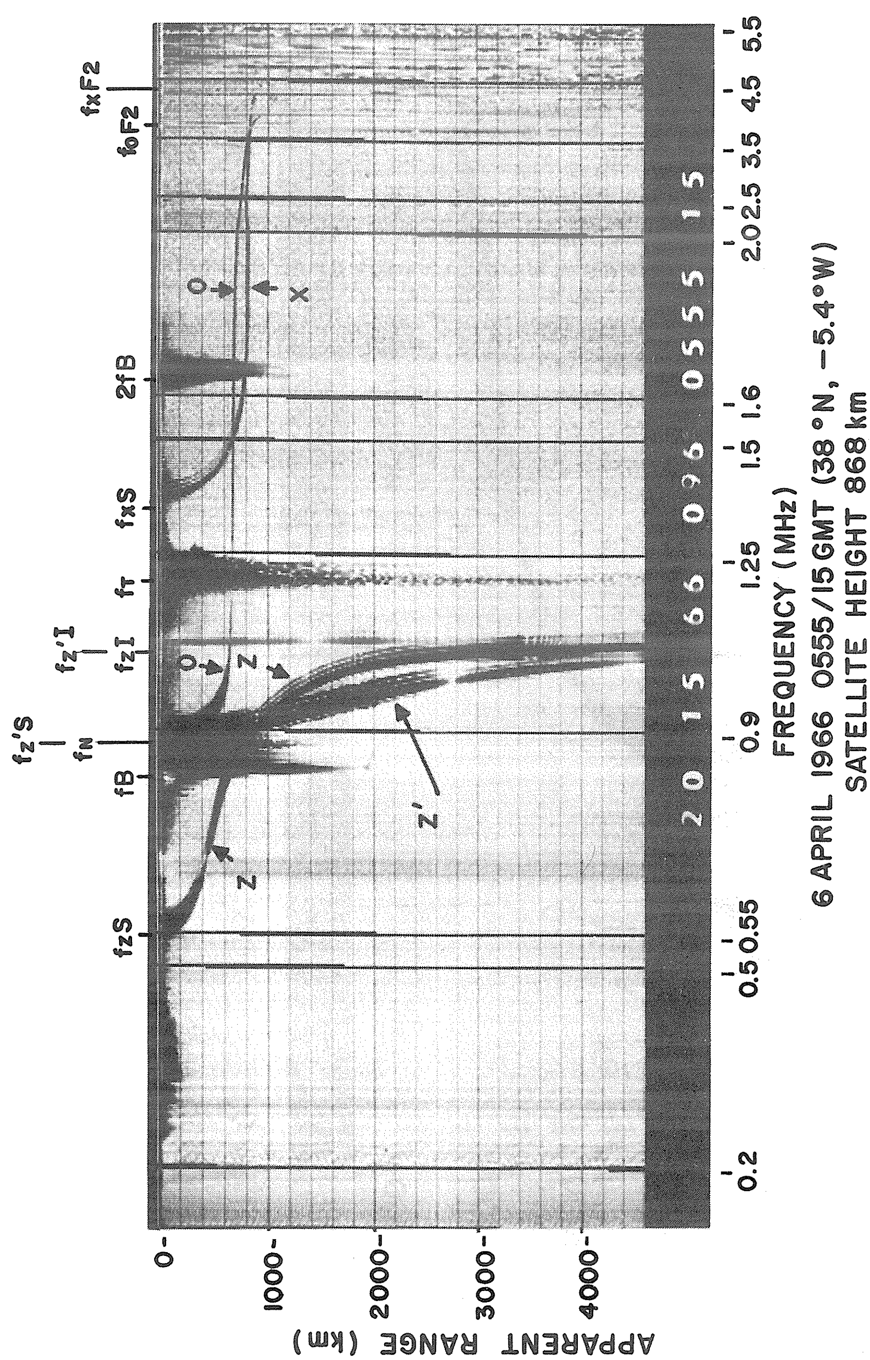


Fig. 5.2 An Alouette II ionogram illustrating z-, o-, x- and z'-wave traces, cutoffs and resonance spikes.

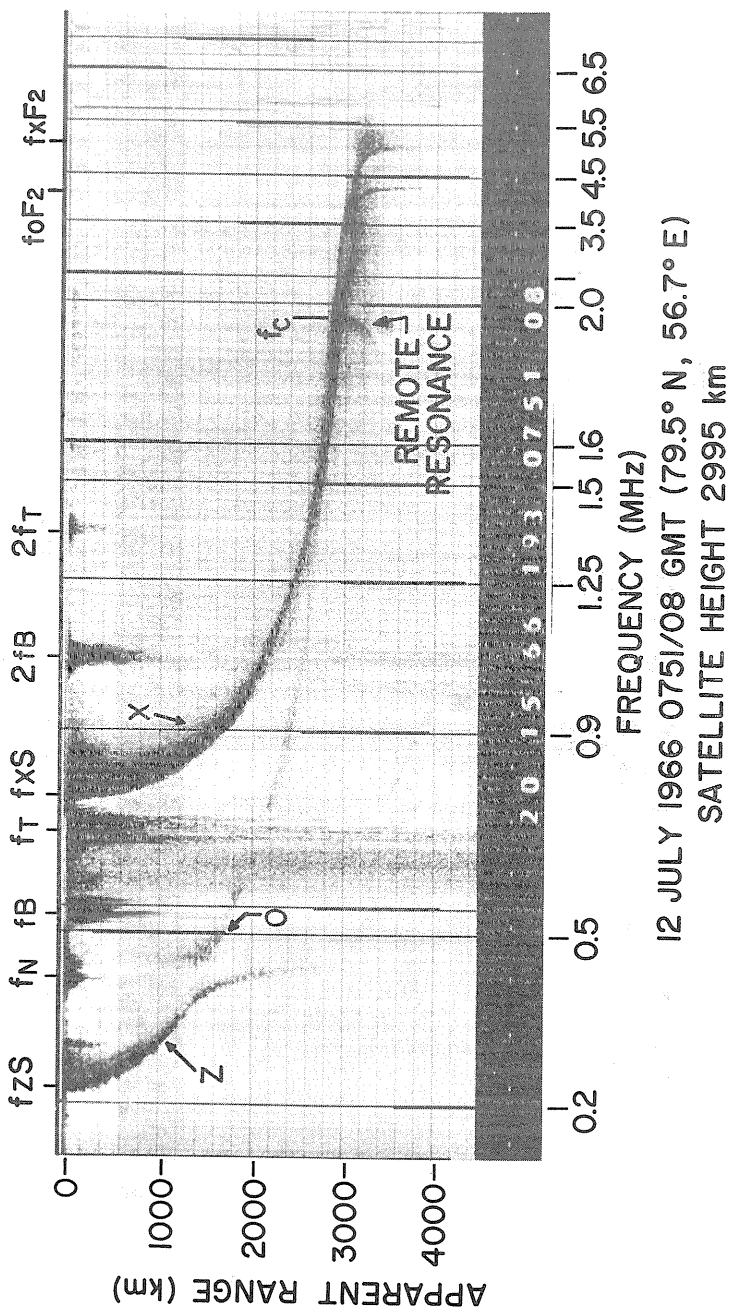


Fig. 5.3 An Alouette II ionogram illustrating z-, o- and x-wave traces, cutoffs, resonance spikes and the remote resonance.

5.12. As the sounder frequency increases above the mode cutoffs, the waves penetrate progressively to greater depths below the satellite before being reflected [I p 949]. The maximum frequencies at which the o and x waves can be reflected from the F layer are the critical frequencies foF2 and fxF2. At frequencies above foF2 and fxF2 the waves may propagate to the Earth's surface and be reflected back to the satellite; such waves are observed on the ionograms as "Earth echo" traces. In Fig. 5.1, note retardation near foF2 and fxF2 in Earth echo traces, that decreases with increasing frequency. Sporadic E echo traces may also be seen when foEs exceeds foF2 [I p 1019]. The extraordinary-wave trace is frequently more complete than the ordinary so that the extraordinary-wave parameters are easier to deduce than the ordinary. For the same reason electron density profiles are calculated using the extraordinary trace, and the ordinary is used to confirm that they are correct [I p 960].

5.13. The z-wave mode also penetrates progressively to greater depths below the satellite as the sounder frequency increases above the z-wave cutoff, but as it approaches a certain frequency, defined as fzI, it encounters very great retardation (Figs. 5.2, 5.3) [I p 949, 960, 1143]. Practically all of this retardation occurs near the satellite. At fzI the retardation is so great that the wave can no longer propagate in the vertical direction. The z wave may still propagate obliquely at frequencies above fzI but cannot return to the satellite. The frequency at which the fzI is observed is an upper limit condition for z-wave vertical incidence propagation. This frequency is given by

$$fzI = \sqrt{\frac{fT^2 + \sqrt{fT^4 - 4fN^2\, fB^2 \cos^2\theta}}{2}} \qquad (5.4)$$

where fT is the upper frequency limit for z-wave propagation perpendicular (transverse) to the magnetic field-direction. fT is called the upper hybrid frequency and is related to fN and fB by

$$fT = \sqrt{fN^2 + fB^2} \qquad (5.5)$$

Thus fzI is found in the relatively narrow frequency range between fT and the larger of fN and fB. The plasma frequency fN can be estimated from fzI using Eq. (5.4) in the form

$$fN = \frac{fzI}{fB\cos\theta}\sqrt{fT^2 - (fzI)^2} \qquad (5.6)$$

5.14. If the plus sign in Eq. (5.4) is replaced by a minus sign, this equation will yield the frequency for infinite retardation of the whistler mode at vertical incidence [I p 949].

5.15. An additional z-wave reflection trace, called z', is sometimes seen between fN and fzI. This trace is due to obliquely reflected z-wave echoes, [see I p 1089, 1097]. The z' wave begins to propagate at fN, thus

$$fz'S = foS = fN\ . \qquad (5.7)$$

The z'-wave retardation becomes infinite at the regular z-wave infinity, thus

$$fz'I = fzI \qquad (5.8)$$

At frequencies just below fzI, the z echoes correspond to reflections of the z wave at heights which are usually several hundred kilometers below the satellite, but generally well above the layer peak. Only on rare occasions does the z wave penetrate to the F2-layer peak, (Fig. 5.2).

5.16. Reflection traces resulting from non-vertical propagation are common on topside ionograms [I p 1019, 1097]. The most common types are the result of propagation along field-aligned ionization structures. Propagation along such structures is sometimes observed to occur from one hemisphere of the Earth to the other (i.e., conjugate ducted propagation) when the satellite is located at low or relatively low latitudes. Radio waves that propagate obliquely from the satellite may also be scattered or reflected by field-aligned structures located at some distance from the satellite before returning. In addition, large scale horizontal gradients may also cause the radio waves to be reflected from points not vertically below the satellite. Many of the reflection traces resulting from non-vertical propagation can be recognized from the characteristic patterns they produce on the ionograms together with a knowledge of ionospheric radio wave propagation.

The vertical traces can be identified when a computer is available by calculating the apparent electron density distribution from each of the x-mode traces and finding the corresponding o-mode trace patterns. These are consistent with the observed pattern when the propagation is vertical [I p 986].

5.2 Resonance Spikes

5.21. Resonances are observed at certain frequencies as persistent signals excited in the close vicinity of the satellite by the transmitted pulse of the on-board sounder. Their duration is variable but the frequencies are characteristic of the local plasma medium. Some of these frequencies are determined by the classical parameters of a cold electron plasma, fN and fB, others occur at complex functions of these parameters. Also spikes occur at harmonic frequencies of the basic resonances (see the ionograms in Figs. 5.1, 5.2 and 5.3). It appears that a suitable explanation of the spikes cannot be obtained with "cold electron plasma" theory but involves at least the compressibility of the electron gas, i.e., "hot plasma" theory. The sounder generates slowly propagating waves in the electron gas. These waves are similar to a sound wave in the electron gas, with longitudinal propagation of compression and expansion, and involve space charges, i.e., have longitudinal electrostatic fields. The waves have several names, e.g., electronsound wave or electrostatic wave.

These electrostatic waves are launched obliquely by the sounder at frequencies within several kilohertz of the characteristic frequency, travel short distances (several kilometers) from the satellite, are reflected, and return to it, producing an echo. The apparent range of these echoes is so extremely sensitive to frequency that echoes with apparent ranges covering the entire sounder range can be produced by frequencies from a small part of the transmitted frequency range. Thus, a long continuous signal is received which appears like a spike on the ionograms, as shown in Figs. 5.1, 5.2 and 5.3. Some of the other resonance may be produced simply by electrostatic waves which travel along with the satellite.

5.22. The principal resonance spikes occur on the ionograms at (to better than 20 kHz) the following frequencies, characteristic of the local plasma medium:

plasma frequency	fN
gyrofrequency	fB
upper hybrid frequency	fT
second harmonic of the gyrofrequency	2fB
second harmonic of the upper hybrid frequency	2fT

The fN spike appears strong when fN > fB and weak when fN < fB. The fT spike appears strong when fT < 2fB and weak when fT > 2fB. The 2fT spike is not observed when fT > 2fB but it is usually observed when fT < 2fB.

5.23. Some of the principal resonance spikes are useful for obtaining the local plasma frequency when the reflection trace cutoffs are not observed. These spikes are related to fN and fB as follows:

the fN spike occurs at fN;

for the fT spike, $fN = \sqrt{fT^2 - fB^2}$; (5.9)

for the 2fT spike, $fN = \sqrt{(\frac{2fT}{2})^2 - fB^2}$ (5.10)

Sometimes the sidebands of the transmitted power spectrum are visible in the fN spike. Then the local plasma frequency can be measured to a few kHz [I p 1135].

5.24. In addition to these principal spikes, the 3fB, 4fB, etc., spikes are also frequently observed. Other types of electrostatic wave or resonance phenomena that can have a spike-like appearance are the fQ type resonances, the diffuse spike fD and the "floating spike" [I p 949, 1089, 1097, 1128].

Due to non-linear phenomena in the plasma near the satellite, spikes relating to the difference or the sum frequency of two principal resonance spikes are at times also observable [I p 1108].

5.25. A remote resonance is frequently observed on high-latitude ionograms recorded in the presence of field-aligned irregularities (Fig. 5.3) [I p 949, 1089, 1097, 1128]. It appears as a spike-like trace jutting downward from the x-wave trace at a frequency above that of the local 2fB spike. The remote resonance echoes are generated by the downgoing x-wave pulse at heights where 2fB equals the sounding frequency. The high-frequency cutoff of the remote resonance, fC, is observed on the ionograms where the remote resonance trace joins the x-wave trace. This frequency corresponds to the value of 2fB at the real height of reflection of the x-wave trace. The variation of total magnetic field intensity (and hence 2fB) with height is known accurately from field models and therefore a real height can be determined from fC. It can be shown that at this real height:

$$fN = \frac{1}{\sqrt{2}} fC = \sqrt{2}\, fB \qquad (5.11)$$

Note: fC is not a critical frequency and the symbol should not be confused with the conventional fc.

The remote resonance phenomenon thus provides a useful method of determining accurately and simply the electron number density at a certain height below the satellite. It provides a check for electron-density profile analysis as obtained from the x-wave echo trace because it is based on a completely independent measurement. However, the energy responsible for the remote resonance propagates along field-aligned ducts [I p 1128]. Hence the value of fN calculated from Eq. (5.11) is not the value at a real height vertically below the satellite (except over the magnetic poles) but at a real height on the field-line intersecting the satellite. The energy responsible for the x-wave trace can propagate either along field-aligned ducts or vertically. When the remote resonance is observed, most of the x-wave energy propagates along the field-aligned ducts. At high latitudes, where the field-lines are very nearly vertical it is not possible to differentiate between field-aligned and vertical incidence propagation from the reflection traces on the ionograms. Thus, for high latitudes, the propagation is very nearly vertical and when the remote resonance is observed Eq. (5.10) can then be used with negligible error.

5.3 Resonance Beats

5.31. When the satellite is in a region of very low electron density, that is, between about 10^7 - 10^8 m^{-3} (10 - 100 electrons cm^{-3}) fT and fB become very nearly equal, being separated only by about 1 to 4 kHz. Because it has a finite spectral bandwidth, the sounder pulse can therefore simultaneously excite the fT and fB resonances and the beat frequency, Δf = (fT - fB), may be observed on the overlapping resonance spikes on the ionograms [I p 949 and 1184]. Assuming that these resonances occur exactly at the upper hybrid frequency and the electron gyrofrequency, it can be shown that:

$$fN = \sqrt{(2fB + \Delta f) \quad \Delta f} \qquad (5.12)$$

The electron density N can readily be determined from Δf using the equation:

$$\frac{N}{m^{-3}} = 18.6 \cdot 10^6 \; M \; \frac{fB}{MHz} \qquad (5.13)$$

where M is the number of beats per 200 km apparent range which is easily determined from the ionogram. The upper hybrid resonance, however, does not occur exactly at the upper hybrid frequency, but in fact its frequency varies with apparent range in a very complicated way even when it is not close to fB or its harmonics. Thus, it is not feasible at the present time to calculate Ne exactly from the beat pattern.

5.32. For real height analysis of ionograms in which the electron density at the satellite is very low, the Δf beat has been used to obtain a "first guess" value of the starting frequency or fxS, for the x-wave reflection trace. The final fxS is then obtained by an iterative process and is usually found to be a factor of two to three higher than that obtained by the Δf beat, [see G.E.K. Lockwood, Radio Science, 5, 575, 1970].

5.4 Electron Density Versus Real Height Profiles

5.41. Electron density variations with real height are usually called N(h) profiles.

A comparison of an N(h) profile calculated from a topside ionogram with an N(h) profile calculated from incoherent backscatter measurements obtained while the sounder passed nearly overhead, is shown in Fig. 5.5.

5.42. The accuracy of the profiles computed from topside ionograms is affected by errors due to the following technical reasons:

- (i) The variable width of the echo traces on the ionogram.
- (ii) Departure from a linear sweep-rate.
- (iii) Range marker inaccuracies;

and, mainly, to two physical reasons:

(iv) The fact that propagation below the satellite may not be vertical.
(v) Limitations in the development and application of the theory for obtaining N(h) from the ionogram traces.

In addition:

(vi) Electron gas (cold plasma) theory may be an over-simplification to the real plasma in the topside ionosphere. For example, the properties of the resonance spikes can only be explained using "warm plasma" theory. This does not appear to be important for N(h) analysis.

If the ionograms can be easily interpreted and are scaled carefully, the computed profiles should be accurate to between ±5 km and ±10 km. Occasionally sideband traces due to the sidebands of the transmitted power spectrum are resolved near the cutoff frequency. These traces can be scaled exceptionally accurately and also provide redundancy so that profiles within about 100 km below the satellite can be more accurately determined [I p 1135]. Frequently, however, the ionograms are not easy to interpret and more sophisticated scaling procedures are necessary [I p 986]. In many research projects for which large numbers of ionograms have to be scaled on a routine basis, a more realistic figure for the accuracy of the computed profiles may be ±20 km, and sometimes ±50 km.

A main source of error is the assumption that the radio waves propagate vertically below the satellite. In many cases, field-aligned propagation can be identified on the ionograms, but there are times when the propagation is not obviously field-aligned and yet the height of the F-layer peak from profiles reduced from such ionograms will appear too low. Such profiles tend to overlap simultaneous bottomside profiles (see section 5.5). In addition, one percent of data recorded at telemetry stations have timing errors greater than 400 seconds; one-fifth percent have timing errors greater than 10,000 seconds. Such timing errors will probably be systematic over about 30 consecutive ionograms.

5.43. In contrast to bottomside N(h) analysis, the x-wave trace is normally used in topside N(h) analysis [I p 960]. Hence the calculated plasma frequency for the heights between the satellite and the F-layer peak depends on the variation in gyrofrequency over this height range. Gyrofrequencies calculated from magnetic field models are adequate in most cases.

5.44. When the plasma frequency at the satellite is very low, that is less than about 0.1 MHz, the x-wave cutoff, fxS, becomes obscured by the overlapping fB and fT spikes. An approximate value of fxS can be obtained from the (fT - fB) = Δf beat (section 5.32), or merely by inserting a very low "dummy" value of fN (say 0.03 MHz). The final value of fxS (and fN or N) is then obtained by an iterative process [G.E.K. Lockwood, Radio Science, 5, 575, 1970].

5.45. Satellites which are in elliptical orbits experience a height change during the time taken to record an ionogram; this height change for Alouette II or ISIS-1 can be up to 10 km so that if this effect is ignored, systematic errors will arise in the computed electron distributions. Computer programs are now available which take this change in height into account.

5.5 The Overlap Problem

5.51. When the height of the peak of the F layer is deduced for the same time and place by both bottom and topside sounding, the value from the bottom is sometimes higher than that found from the top. This overlap phenomenon, see Fig. 5.4, is clearly due to limitations in the interpretation and analysis of either or both sets of data. Overlaps of up to 50 km have been obtained by several workers; it was shown [I p 976] that the higher the satellite, the greater was the overlap. However, recent studies on the overlap problem indicate that profiles obtained from high quality topside ionograms agreed with incoherent scatter profiles, at least in Western Europe, (Fig. 5.5), [L. Fleury and C. Taieb, J. Atmosph. Terr. Phys. 1971, 33, 909-918].

5.6 Preferred Nomenclature for Topside Soundings

5.61. Since topside and bottomside soundings are often used together, it is desirable that the nomenclature and use of symbols for both should be as consistent as possible. However, in the early days of topside soundings, some differences became established that appear in published data and cannot easily be changed. Alternative forms which are often used are indicated in parentheses in section 5.64 below. In general subscript forms are used in text or where the theoretical value of a quantity is intended, and on-line forms for data. Thus, f_N is the theoretical value of the plasma frequency, and fN the measured value.

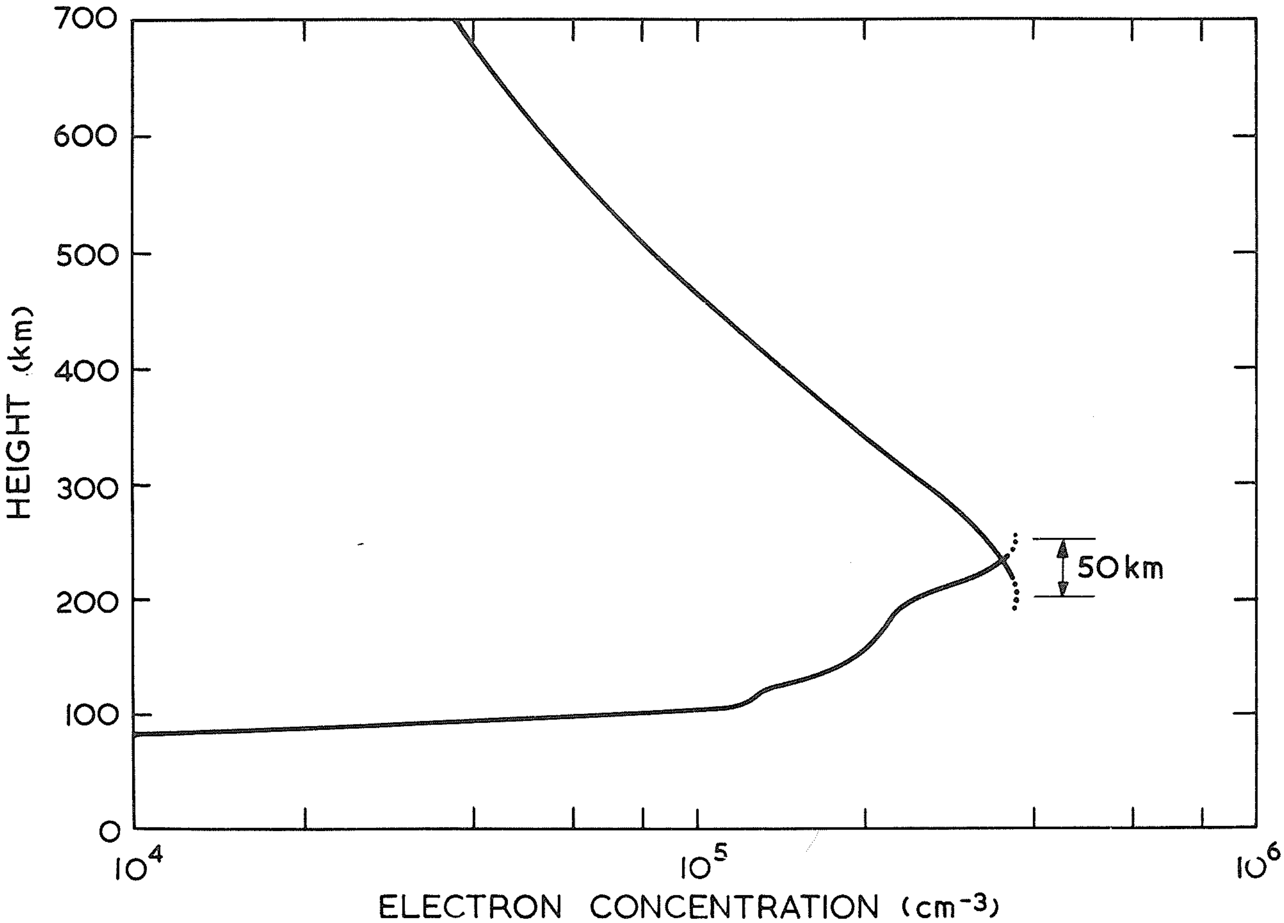


Fig. 5.4 Comparison of topside and bottomside electron concentration distributions deduced from ionograms recorded on July 4, 1966. The bottomside ionogram was recorded at Fort Belvoir at 1315 UT, and the topside distribution is the average of two distributions obtained from Alouette II ionograms recorded at about 1314 UT when the satellite was 2200 km above points situated respectively, 0.8°N, 0.1°W and 0.6°S, 0.3°W of Fort Belvoir.

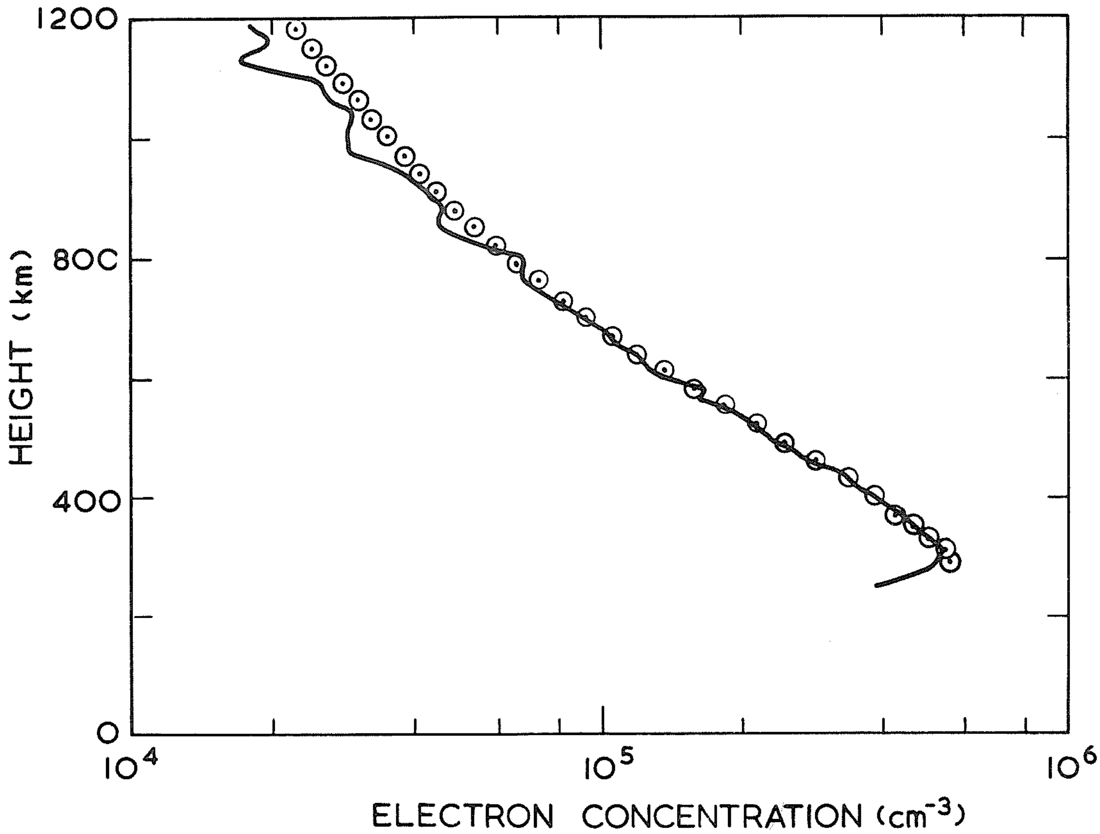


Fig. 5.5 Comparison between N(h) profiles obtained at 1824 UT on June 30, 1968, by means of Alouette II (circles) and the incoherent scatter radar (continuous curve) at Malvern, England. The satellite was 1190 km above a point 50 km south-west of Malvern, and the ionogram was recorded during the time taken to obtain backscatter data.

5.62. The characteristics foF2, fxF2, foF1, fxF1, foEs and fxEs have the same definitions on both top and bottomside sounding. The characteristics foF1 and fxF1 can only be observed on topside ionograms during G conditions, that is, when foF1 and fxF1 are greater than foF2 and fxF2.

5.63. The characteristics fN, fB, fT, foS, fxS, fzS, fzI, nfB and 2fT, as defined in 5.64, are now commonly used for topside ionograms to describe observed, calculated or theoretical values of frequencies characteristic of the ionospheric plasma at satellite height (zero virtual range). The theoretical relations among the electromagnetic characteristic frequencies , f1S, fxS, f2S and fzI have been deduced from the Appleton-Lasser equation with collisions neglected. The frequencies fN and fT can also be deduced from cold plasma theory; however, the frequencies nfB require the application of warm plasma theory. Scaled values for frequencies for resonance spikes and electromagnetic cutoffs, or values calculated from one or more of these characteristics and magnetic field models are consistent with each other to much better than 20 kHz, the frequency width of the transmitted pulse [I p1135]. Comparisons among the scaled values are limited by:

(i) Precision of the scaling
(ii) Accuracy of interpolating between frequency markers, and of the field models
(iii) Presence of irregularities in the ionospheric plasma
(iv) Application of the theory.

Reports of frequency shifts of many kHz [I p1139] between nfB resonance spikes scaled from Alouette I and II ionograms and field models are still controversial, and may be due to one or more of reasons listed above.

5.64. Nomenclature: Using the well known conventions for the reduced parameters

$$X = fN^2/f^2 \;;\; Y = fB/f$$

we have the following definitions and relations:

Frequency characteristics		Magneto-electronic condition for cold plasma
fN(f_N)	- the plasma frequency spike at the satellite	($X = 1$)
fB(f_H)	- the gyrofrequency spike at the satellite	($Y = 1$)
fT(f_T)	- the upper hybrid frequency spike at the satellite	($X = 1 - Y^2$)
foS	- the o-wave low frequency cutoff at the satellite	($X = 1$)
fxS	- the x-wave low frequency cutoff at the satellite	($X = 1 - Y$)
fzS	- the z-wave low frequency cutoff at the satellite	($X = 1 + Y$)
fzI	- the z-wave high frequency cutoff at the satellite where the retardation becomes infinite for vertical incidence propagation	($X = \frac{1 - Y^2}{1 - Y^2 \cos^2 \theta}$)
nfB(nf_H)	- the nth harmonic gyrofrequency spike at the satellite for n greater than one	($Y = \frac{1}{2}, \frac{1}{3}$, etc.)
2fT($2f_T$)	- the second harmonic upper hybrid frequency spike at the satellite	($X = \frac{1}{4} - Y^2$)

Notes on frequency characteristics:

(i) fN and foS are numerically identical under ideal conditions but are derived from different phenomena.
(ii) fN is the ambient plasma frequency measured at the satellite.
(iii) The characteristics fN, fB, fT, fzI, nfB and 2fT can also be used to describe frequencies characteristic of the ionospheric plasma at any level in the ionosphere. Unless specifically stated otherwise, they refer to values at satellite height.
(iv) In text the subscript forms f_N, f_B, f_T, etc. are allowable but for tabular data subscripts are never used.

Height characteristics

hS - height of the satellite above mean sea level. There is no agreed symbol for virtual depth or apparent range, though r' is often used.

5.65. Qualifying letters: Qualifying letters, following a numerical value, can be used in tabulation of the satellite height values, of plasma frequency fN or of number density N to indicate how the parameter was obtained:

O	- parameter obtained from foS	(o-wave cutoff)
X	- parameter obtained from fxS	(x-wave cutoff)
Z	- parameter obtained from fzS	(z-wave cutoff)
N	- parameter obtained from the fN spike	(plasma resonance)
H, (T)	- parameter obtained from the fT spike	(upper hybrid resonance)
R	- parameter obtained from the 2fT spike	
B	- parameter obtained from the (fT - fB) or Δf beat	
P	- parameter obtained from N(h) reduction using an iterative process.	

Qualifying letter following a numerical value can also be used to indicate that the parameter is less than or greater than the numerical value:

E - parameter less than the tabulated value
D - parameter greater than the tabulated value.

As on the bottomside, foF2 is often deduced from fxF2 and this can be indicated by the standard qualifying letter following the numerical value of foF2:

J - parameter deduced from fxF2
U - uncertain value, see section 5.66.

Notes: (a) H - is used only in tables of fN.
(b) Qualifying letters B and P are used only when the electron density at the satellite height is very low.

5.66. Use of qualifying letter symbols:

(a) When a qualifying letter is used it should be followed by a descriptive letter which shows why the qualification was necessary.

(b) When a deduced value is used although the direct value was measurable with adequate accuracy, the qualifying letter should be repeated as a descriptive letter.

5.67. Use of accuracy rules: It is possible that the accuracy rules given below, which were in use at the main analysis centers in 1970, will be changed in the future, (sections 5.8, 5.9).

For those analyzing topside ionograms for local purposes, the accuracy rules given in Chapter 2 may be used, noting that the reading accuracy in height varies with the height range in use. For ranges up to about 1000 km, Δ = 5 km, for greater ranges Δ = 10 km. Unless the recording equipment is very good, it may not be possible to maintain the frequency accuracy 1 in code A, section 5.84 below. In this case the frequency unit Δ should be selected from code A2 instead of code A1. Physically there are great advantages in adopting the bottomside practice of allowing the accuracy limits to vary with frequency so as to give fixed percentage limits.

The topside practice of allowing unlimited inaccuracy with symbols 4, 5 (bottomside E, D) can be seriously misleading. Workers are advised to use bottomside practice, with stated limits.

5.68. Descriptive letters: The standard bottomside list of descriptive letters (see Chapter 3) should be used for topside parameters whenever it is appropriate. The following particular points should not be overlooked.

Use of J: If Q is the appropriate descriptive symbol, foSJQ means that foS has been deduced from the observed value of fxS, the value of foS not being measured because of Q. foSJJ means that foS has been deduced from fxS, although foS could be measured with adequate accuracy.

Use of H: When fN is deduced from fT and fB because the value of fN was too low to be observed directly, use fNHE. In other cases use the appropriate descriptive letter showing why fN could not be observed directly, or HH as appropriate.

5.69. Anomalies: Topside ionograms show frequency spread when foF2 is spread and range spread when tilts are also present. Field aligned irregularities or steep horizontal gradients can give strong reflections for a sequence of ionograms, the range decreasing as the satellite approaches the field lines containing the anomalies [Clark et al., IEEE, 57, 493, 1969]. It is also possible to receive traces from echoes guided by the tube of force through the satellite position and reflected at the ionosphere at either end of this tube of force [I p 1019, 1097]. The delays on these echoes can be several times the period between successive pulses and they are seen only:

(a) when the frequency sweep is sufficiently slow for them to be in the receiver bandpass and
(b) there is sufficient gradient between tubes of force to provide good trapping.

5.7 References

5.71. A considerable literature on topside soundings now exists. Attention is drawn to the "Special Issue on Topside Sounding and the Ionosphere", published by the IEEE, June 1969, 57, No. 6, 859-1172. This contains many ionograms illustrating different phenomena observed on topside ionograms, and most available references previous to 1969 (see section 5.76).

Useful surveys are also available in Annals of the IQSY, 1969, 6, 167-185, by J. W. King, and in the Handbuch der Physik, XLIX/2, 503-520. The former summarizes the main characteristics of sounders flown and gives details of where the data are available.

5.72. Data deduced from many topside soundings have been published. The conventions adopted are summarized in sections 5.8 and 5.9. The data can be divided into two main groups:

(a) Synoptic tabulations of standard topside parameters.
(b) Selected blocks of electron density profiles.

5.73. Alosyn data: Synoptic topside sounding parameters are regularly analyzed and published in booklets called "Alosyn Data" obtainable from

Communications Research Centre
1241 Clyde Avenue
Ottawa, Ontario K2C 1Y3, Canada

These data are available also on digital magnetic tape from the Communications Research Centre, above, or

World Data Center A for Rockets and Satellites
Goddard Space Flight Center
Code 601
Greenbelt, Maryland, 20771, USA

5.74. Electron density data:

Electron Densities and Scale Heights in the Topside Ionosphere - Alouette I	Ames Research Center NASA San Francisco, California, USA
Data on Topside Ionosphere (Electron densities and Scale heights from Alouette II Observations over Japan)	The Radio Research Laboratories Ministry of Posts and Telecommunications Tokyo, Japan

In particular there are some NASA reports:

THOMAS, J. O., M. J. RYCROFT and L. COLIN — 1966 — Electron Densities and Scale Heights in the Topside Ionosphere: Alouette I Observations in Midlatitudes. NASA SP-3026.

CHAN, K. L., L. COLIN and J. O. THOMAS — 1966 — Electron Densities and Scale Heights in the Topside Ionosphere: Alouette I Observations Over the American Continents - Volume I: November, December 1962 and January 1963. NASA SP-3027.

CHAN, K. L., L. COLIN and J. O. THOMAS — 1966 — Electron Densities and Scale Heights in the Topside Ionosphere: Alouette I Observations Over the American Continents - Volume II: May and March 1963. NASA SP-3032.

CHAN K. L., L. COLIN and J. O. THOMAS 1966 Electron Densities and Scale Heights in the Topside Ionosphere: Alouette I Observations Over the American Continents - Volume III: June, July, September and October, 1963. NASA SP-3033.

5.75. Useful computation routines:

N(h) reduction	NASA Space Science Data Center Goddard Space Flight Center Greenbelt, Maryland, USA
FIELDG Magnetic Field Model	"
McIlwains L-value-Invariant	"

5.76. Papers concerning topside soundings in the "Special Issue on Topside Sounding and the Ionosphere", Proc IEEE, June 1969, 57, No. 6, 859-1187:

5.8 Conventions and Symbols used in Canadian Topside Data Evaluation

5.81. Synoptic topside data are usually tabulated by computer means so that the symbols used have to be available on computer printouts. For this reason the normal conventions, f for frequency, o x z for wave components, etc., are replaced by capital equivalents. For manual tabulation the standard form is preferred.

5.82. The symbols used in synoptic tabulations of Alouette and Isis data are:

YR Year
MO Month
DY Day of the month
GMT Universal Time at which the record was taken, in hours, minutes, and seconds, with

the minutes and seconds separated by a full stop (period). The time given is for 3.0 ± 1 seconds before the occurrence of the 0.5 MHz frequency marker.

LMT	Local Mean Time in hours and minutes
LONG	Longitude
LAT	Latitude
HGT	Height of satellite
CHI	Solar zenith angle, χ
DIP	Angle of dip of Earth's magnetic field at the satellite
FH	Gyrofrequency at the satellite, in MHz. The dip and gyrofrequency are usually calculated by using the set of 48 spherical harmonic coefficients for the magnetic field, B, of the Earth as determined by Jensen and Cain (epoch 1960).
JFOS	Ordinary-wave frequency at the satellite, calculated from the observed extraordinary-wave plasma frequency, FXS
FXS	Observed extraordinary-wave frequency at the satellite
FOF2	Observed ordinary-wave penetration frequency of the F2 layer
JFOF2	Ordinary-wave penetration frequency of the F2 layer, calculated from observed extraordinary-wave penetration frequency FXF2. The gyrofrequency appropriate to a height of 300 km is used for this calculation.
FXF2	Observed extraordinary-wave penetration frequency of the F2 layer
FES	Maximum frequency of observation of sporadic E
G	Strength of signal returned from the Earth, according to the following code:

1. Strong well defined echoes
2. Weak and intermittent echoes
3. Echoes not observed

KP 3 hourly Planetary Magnetic Kp index. The symbols -, o, ϵ replace the usual o and + in the second column for the Kp index

The symbol "-0" occurring in a column of the tabulations indicates that the parameter was not observed on the ionogram.

5.83. The accuracy and quality of the observations are coded according to the following tables and tabulated in columns marked FOF2A, FOF2Q; FXF2A, FXF2Q, FXFSA, FXSQ, FESQ. Accuracy is given by estimated error with number symbols 4 and 5 meaning magnitude is less than or greater than the value tabulated. 4 and 5 are directly comparable with E, D except that no accuracy limit is imposed in their use. In practice such values are often very misleading.

5.84. Accuracy limits: Two codes are used to describe the accuracy (as in 1971 and previously), Code A for estimated error and Code Q for quality of trace.

Code A		FXS	FOF2 and FXF2
1	Estimated error less than	0.025 MHz	0.05 MHz
2		0.05 MHz	0.10 MHz
3		0.10 MHz	0.20 MHz
4	less than tabulated value		
5	greater than tabulated value		

5.85. Quality of the reflection trace:

Code Q	No Spread	Slightly Spread	Moderately Spread	Extremely Spread
Unambiguous	A	D	G	J
Oblique traces	B	E	H	K
Cusps and/or forking of the records	C	F	I	L

The classifications of Spread F in this quality table refer to the degree of Spread F at the particular apparent height and frequency at which the parameter was obtained. It is not a classification of Spread F for the ionogram as a whole.

5.86. It is possible that the accuracy limits may be changed in the future.

5.9 Conventions and Symbols Used in AMES and NASA Synoptic Data Evaluation

5.91. Symbols, abbreviations and units (for Alouette and Isis Satellites):

N	electron density in units of 10^{11} m^{-3} ($10^5 cm^3$)
H	plasma scale height, km
h	real height above the ground, km
Pass	pass number of Alouette I
SPOINT	tracking station at South Point, Hawaii
UT	universal time given as $\underset{\text{hour},}{XX}$ $\underset{\text{minute},}{XX}$ $\underset{\text{second}}{XX}$; all zero digits on extreme left are suppressed
LT	local time given as $\underset{\text{hour},}{XX}$ $\underset{\text{minute},}{XX}$ $\underset{\text{second}}{XX}$; all zero digits on extreme left are suppressed
SAT	electron density at the altitude of the satellite
NT	electron content (integrated electron density) in units of 10^9 m^{-2} ($10^{13}cm^{-2}$)
Date	given as $\underset{\text{year},}{XX}$ $\underset{\text{month},}{XX}$ $\underset{\text{day}}{XX}$; all zeros are suppressed
HS	satellite altitude, km
LONG	geographic longitude, deg; positive sign indicates longitude east of Greenwich; negative sign, west of Greenwich
LAT	geographic latitude, deg; positive sign indicates northern latitude; negative sign, southern latitude
DIPL	magnetic dip latitude, deg; positive sign indicates northern magnetic latitude; negative sign, southern magnetic latitude
INVL	magnetic invariant latitude, deg
L	magnetic L-shell number
DIP	magnetic dip angle, deg; positive sign indicates northern magnetic latitude; negative sign, southern magnetic latitude
FHS	electron gyro-frequency at the satellite, MHz/sec
KP	planetary magnetic activity index, 0o, 0+, 1-, 1o, 1+, ...
QUAL	quality factor for the ionogram
SNL	sunlight indicator; 1 (satellite solar illuminated), 0 (satellite not solar illuminated)

5.92. Quality factor: The quality factor for each ionogram is coded as a two digit number (11, 21, 31, 12, 22, 32, 13, 23, 33) and defined as follows:

First digit:

1. Excellent quality ionogram. Extraordinary trace is narrow, of high contrast, easily identifiable, possesses only small gaps and cannot be confused with ordinary trace, no spreading or resonances anywhere along its extent. No spurious responses.

2. Good quality ionogram. Extraordinary trace is not too spread, of good contrast, fairly easily identifiable along most of its extent, any large gaps are easily interpolated and no major confusion exists with the ordinary trace, spreading or resonances, or spurious responses.

3. Poor quality ionogram, but readable. Considerable spreading, lack of contrast, overlapping traces and resonances, spurious traces, etc. Cause somewhat questionable scaling accuracies.

Second digit:

1. fxF2 clearly visible and read.

2. fxF2 not quite visible but highest visible frequency close to fxF2 or presence of ground reflections would allow an estimate of fxF2.

3. fxF2 not visible.

5.93. Further details are given in NASA SP-3039.

NOTES

6.0 General

The f plot is a daily graph of the frequency characteristics of the traces of the ionograms as a function of time, using internationally agreed conventions so that detailed observations from different stations may be compared efficiently [A135F, 153, 154].

It was originally developed to enable the complicated and rapidly changing ionograms from high-latitude stations to be reduced without numerous arbitrary and difficult decisions on the interpretation of the individual ionograms. However, it rapidly became clear that the f plot provided a very efficient method of recording and studying data which were too complicated or too numerous for conventional tabulation, and it has become a primary tool for analyzing the hour-to-hour or day-to-day changes in the ionosphere. Neither use should be overlooked.

In principle, any frequency characteristic can be indicated on an f plot. In practice, certain characteristics have been found to be both valuable and easy to plot and these have been chosen for world-wide reduction. Others may be added, where desirable for local or regional ionospheric reasons, provided that they do not cause confusion with the standard parameters, e.g., entries for foF1.5 at equatorial stations.

The single most difficult problem in reducing ionograms is to obtain representative hourly values when conditions are changing rapidly or when oblique reflections or spread echoes are present. Thus in certain zones it is often impossible to deduce particular parameters from the ionogram taken at the hour though these parameters can be identified on some or all of the ionograms taken earlier and later. The sequence then indicates if the parameter was likely to be varying smoothly through the missing observation, so that interpolation would be allowable, and suggests the best method of interpolation to use. The replacement of an accurate but non-representative value by a smoothed value is, in general, discouraged as it complicates the analysis of important but infrequent perturbations. It is allowed, in principle (see qualifying and descriptive letter T), to meet the requirement of obtaining sufficient representative values to be useful for prediction and geophysical studies but it should only be used where scientific studies of the ionograms have shown that it gives a real gain in the value of the data produced.

The f plot enables transient phenomena to be recognized readily and thus aids in the identification of the more stable phenomena. This is difficult to accomplish by eye while scaling ionograms, and such interpretations are usually not subject to check by other observers with more or different experience. When spread echoes occur, the range of possible values of the critical frequency is plotted. The graph is prepared without prejudging which is the o, x or z trace on a complex ionogram or which is an overhead echo and which an oblique. Thus the f plot provides a summary of the original observations with the minimum of interpretation and enables difficult decisions needed for hourly tabulations to be made with due consideration of all the available data. This application is particularly important at high latitude stations where blackout, spread echoes or rapidly changing oblique reflections frequently prevent the normal characteristics from being observed on individual hourly records. The practical value of an hourly tabulation greatly decreases when the number of non-numerical entries become large, and the f plot should be used to minimize these entries.

Normally all the standard frequency data except foEs are plotted on the f plot. Hourly values of foEs and of the non-frequency characteristics such as MUF factors and minimum virtual heights must, however, be tabulated separately. The f plot and daily work sheet may be prepared concurrently or separately, provided that when completed they are carefully examined and compared to insure that interpolations are made from the f plot, to complete the hourly tabulations wherever possible, and that hourly values on the f plot are consistent with the general trend. Where appropriate, doubtful, inconsistent values in the tabulation are replaced by interpolated values from the f plot.

With the development of sounders operating to low frequencies it proved necessary to replace the standard f plot by a new version with some additional rules and symbols. (See section 6.1). A very rapid technique for making f plots is described in section 6.14.

6.1 The Format for f Plots

6.11. <u>IGY standards</u>: The standard f plot form used during the IGY provides a frequency and time grid suitable for plotting quarter-hourly, or in a few cases, 10-minute interval observations. The frequency scale is linear from 0 to 10 MHz and logarithmic from 10 to 25 MHz. Some stations, where the top frequencies never reach these high values, use scales which stop at 15 or 20 MHz.

The standard form uses a linear scale of 15 mm per MHz from 0 to 10 MHz. The scale is compressed at higher frequencies, the ordinate y (in mm) is related to the frequency f(in MHz) by the equation:

$$\frac{y}{\text{mm}} = 345.4 \log \frac{f}{10\ \text{MHz}} - 195.4.$$

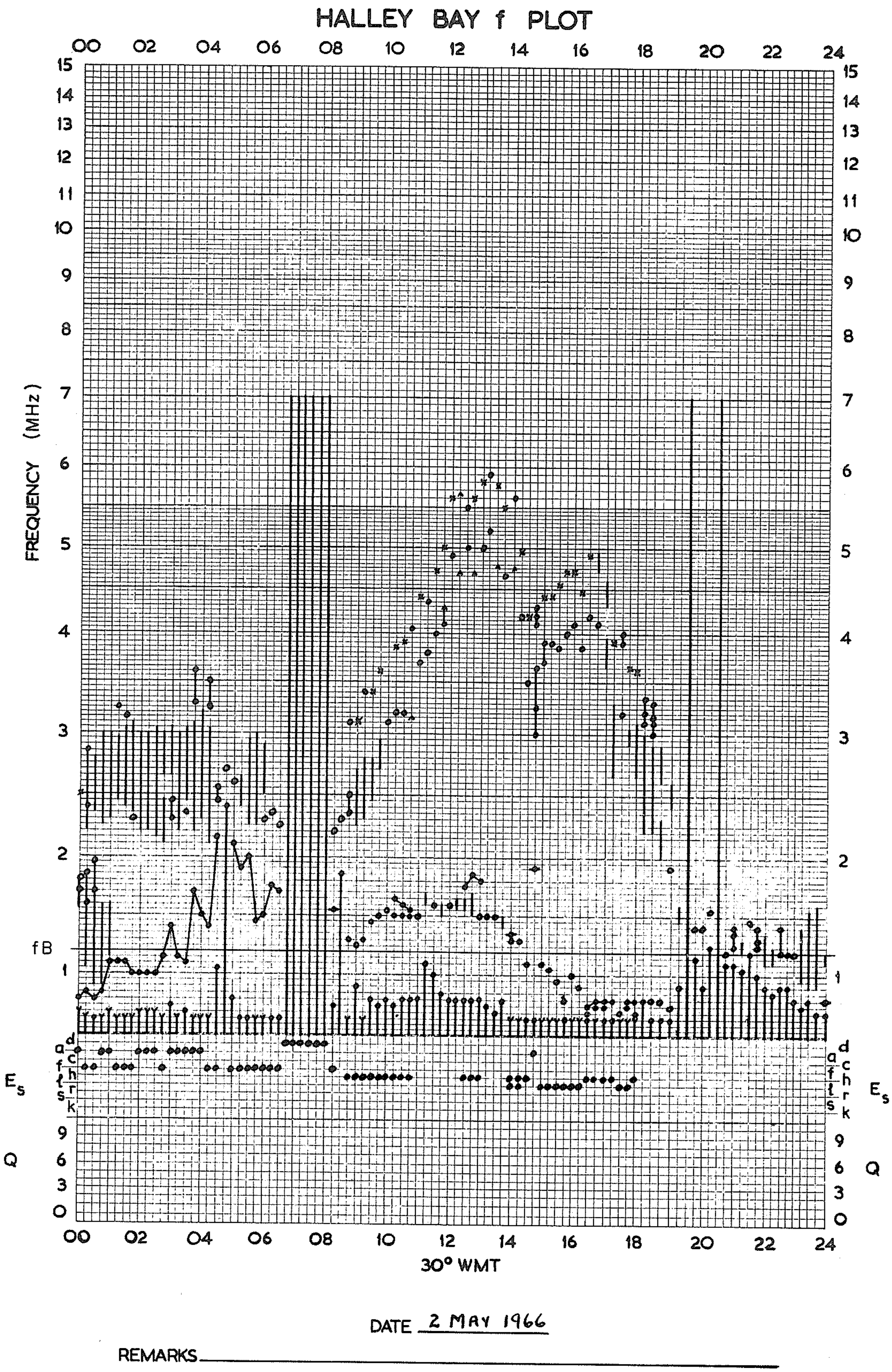


Fig. 6.1 Note fB calculated at 110 km.

This gives a continuous scale at 10 MHz. The standard time scales used are between 8 and 9 mm per hour for quarter-hourly recording or about 10 mm per hour for 10-minute recordings. Smaller spacing gives plots which cannot be effectively reproduced.

The frequency scale has heavy rulings at 1 MHz intervals and is subdivided into 0.1 MHz steps below 15 MHz and 0.2 MHz steps above this frequency. The time scale has heavy rulings every hour and is subdivided to give one line per observation, i.e., to give 4 lines per hour for quarter-hourly observations.

A small subsidiary scale is added on or at the top or bottom of the f plot to show the incidence of Es types. This graph normally contains 5 to 8 horizontal lines spaced about 3 mm apart.

Experience shows that this format is very satisfactory provided care is taken to make any entries, particularly line entries, sufficiently thick to be distinguished from the grid when reproduced. This requirement, which has not been adequately observed at some stations, should be stressed, as a considerable fraction of the f plots produced are unreadable in the published form and are therefore useless.

6.12. LF f plot format for stations with extended low frequency bands: It is desirable that these f plot sheets should be, if possible, the same size as the existing standard but that the scale below 1 MHz should be more open. Since data are not likely to be obtained, on the average, for more than half the time on frequencies below 1 MHz, a compromise between convenience of plotting and space is required. The spacing in that part of the f plot which is used the most (i.e., 2 to 8 MHz) should not be appreciably smaller than that used in the IGY form (section 6.11).

A suitable scale is one in which the spacing between the 0.1 MHz lines decreases geometrically from 3 mm at 0 MHz to 1.5 mm at 1.5 MHz. Let x(f) be the spacing between f and f + 0.1 MHz, then the standard format is given by :

$$\mathrm{Log}_{10} \frac{x(f)}{\mathrm{mm}} = 0.477 - 0.22 \frac{f}{\mathrm{MHz}} \cdot$$

The remainder of the f plot is identical with the standard IGY form except that the highest frequency is restricted to 23 MHz.

A heavy line should be marked on the f plot at the mean gyrofrequency, fB, calculated to the nearest 0.1 MHz for a standard E or F height, e.g., 110 km or 200 km from the equation:

$$\frac{fB}{\mathrm{MHz}} = 2{\cdot}8 \left(\frac{R_E}{R_E+h}\right)^3 \frac{B_o}{\mathrm{Gs}}$$

where Bo is the total field at ground level in Gauss (Gs), and R_E is the radius of the Earth. Bo has been mapped by geophysicists and ranges between about 0.3 Gs and 0.6 Gs.

A simpler alternative, which has the disadvantage that the frequency scale is not continuous, is to use 3 mm per 0.1 MHz from 0 to 1 MHz and then the standard scale. If this scale is used, a heavy line should be drawn across the chart at 1 MHz. This alternative should only be used if it is not possible to obtain the standard form.

6.13. Recommendations on the use of normal or LF f plot format: The IGY standard format should be used at stations with ionosondes starting at a frequency of 0.7 MHz or above. For stations with extended low frequency ranges, say down to 200 kHz, the new standard format (given in section 6.12) should be adopted provided that the quality of the low frequency ionograms and the amount of additional data justify a change.

6.14. Format adapted to the ionogram scales for projection analysis: Much time and effort can be saved by printing f plot forms with scales arranged to match the ionograms as projected for normal analysis. The appropriate entries can then be recorded exactly where observed, care being taken that the frequency marks on the ionogram and f plot coincide at least near the frequency being plotted. A convenient procedure for some projection systems is as follows:

> The f plot form is taped in place and the frequency markers of the projected ionogram are aligned with those on the f plot.
>
> An ordinary plastic triangle or similar straight edge is used as a guide in transferring data from the projected ionogram to f plot form. The straight edge is aligned with each frequency characteristic in turn. The proper symbol is then recorded at the point where the straight edge and the appropriate time of day marker intersect on the f plot

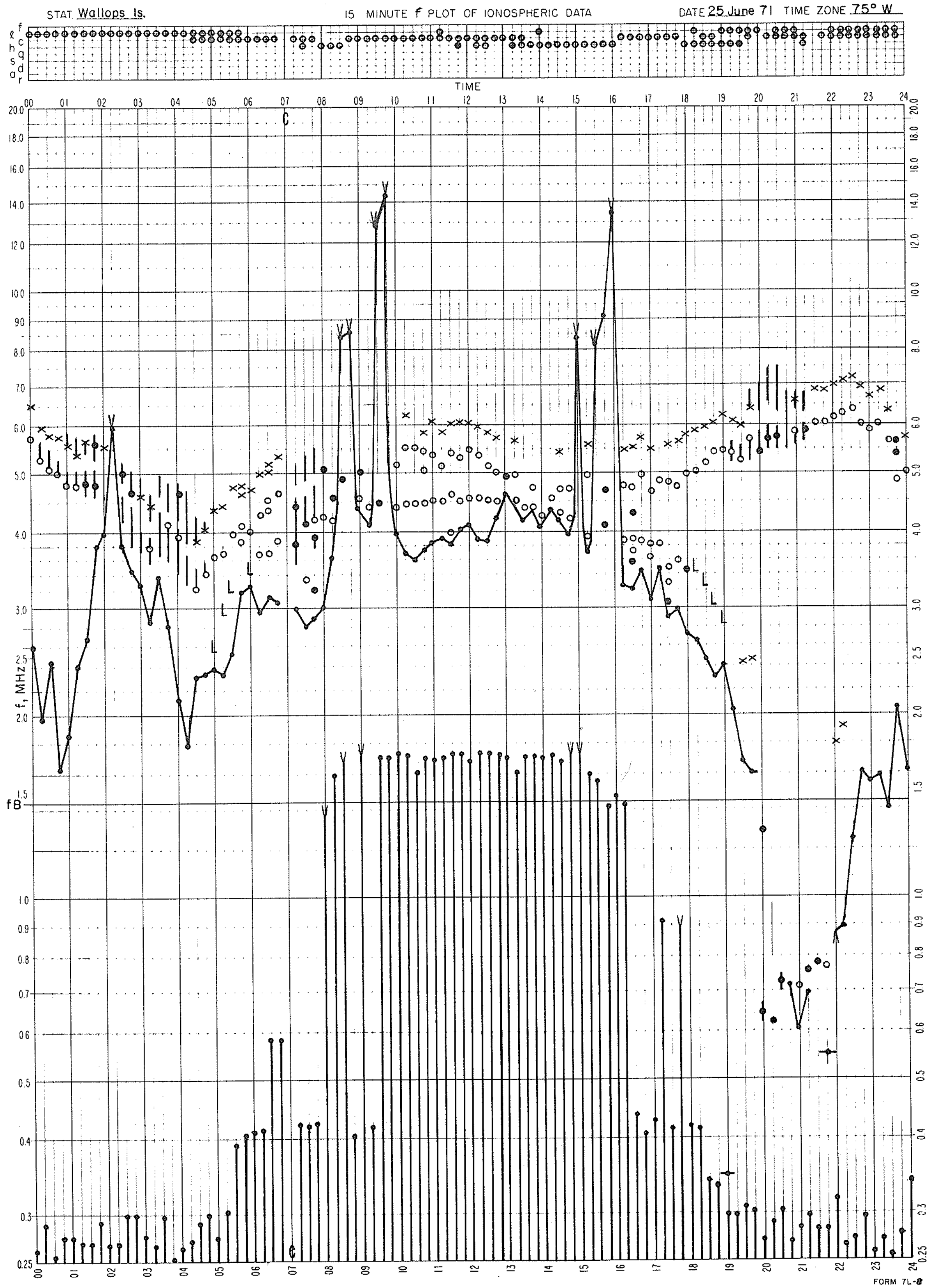


Fig. 6.2 Low frequency f plot

Note fB calculated at 200 Km.

form. The straight edge also facilitates connecting the points indicating fbEs and drawing the spread F line from fmI to fxI.

Types of Es are recorded following visual inspection of the Es.

For economic reasons this technique is preferable to the more laborious standard method, but makes intercomparison of sheets from different stations more difficult. In practice, f plots are usually reproduced on a reduced scale which varies from station to station so that this disadvantage is common to both methods.

6.2 Characteristics to be Plotted

The ordinary-wave critical frequencies of all layers normally observed are entered on the f plot. In addition, fmin, all values of fbEs and, for the F2 layer the x and z components are also plotted. The standard characteristics interchanged in this form are thus:

foF2, fxF2, fzF2, foF1, foE, fbEs, fmin.

The highest value plotted (as a line when spread is present) gives fxI.

It is useful to record fzE when seen.

The standard f plot forms also provide a special section for the Es types present to be recorded. These may be put at the top or bottom of the form as convenient. It is desirable, particularly at high latitude stations, to include an extra line, k, for night E since time sequences of Es a, night E, or Es r can be quite common and are interesting for research purposes.

6.3 f Plot Symbols

The following general symbols have been standardized internationally:

(a) Ordinary-wave critical frequencies which are unqualified as defined by the accuracy rules, are plotted as open circles (Fig. 6.3).

Note that the o-mode critical frequency for night E should always be shown as an open circle. (It is very variable in time and is otherwise not recognizable). When foE for night E is also fbEs use open circle with fbEs line (section 6.6).

(b) Extraordinary- and z-mode critical frequencies, for the F2 layer unqualified in the same sense, are plotted as x's or z's, respectively. If doubtful, they are shown as solid dots or lines (see (c) below).

The corresponding E and F1 layer x and z critical frequencies are omitted as they would increase the work and confuse the f plot without adding much additional information. They may be plotted when the ordinary is not observed or where needed to aid the interpretation of a sequence of observations.

(c) If the identity of a critical frequency is doubtful or the numerical value is uncertain, as defined by the accuracy rules, the most probable value is indicated by a filled circle (Fig. 6.4). This applies to all the components; o, x, or z. When the values for a particular ionogram plotted on the f plot are all doubtful for the same reason, the descriptive letter may be noted at the top margin.

(d) Where the near vertical mode has been established on a complex ionogram using the procedures described in section 2.7 and the critical frequency can be defined within the accuracy rules, an open circle should be used even if the trace is weak and high compared with other traces present.

(e) When spread echoes are present over a wide range of heights the spread of the echoes about the critical frequency is indicated by a straight vertical line extending over the frequency range covered by the spread (Figs. 6.5, 6.6). If a critical frequency is seen through the spread, its value is plotted at the appropriate frequency using the standard procedures given above (a, b and c) (Figs. 6.7, 6.8, 6.9). Care should be taken to make the line sufficiently solid to be clear when reproduced. Cross lines marking the ends of the spread or a slight displacement from the grid lines on the f plot greatly increases the clarity of reproduction.

(f) When spread is present from fmin upwards in frequency a small gap is made between the dot at fmin and the spread. This gap should not exceed one division on the frequency scale of the f plot.

(g) There are some cases where the F trace is replaced by a range spread pattern which does not show frequency spread. This can be represented by a line extending over the range of frequencies showing spread provided that letter q is used at both ends of the line. Occasionally frequency spread can be detected at the upper frequency end of the range spread pattern. In this case the line is broken between the range spread section and the frequency spread section with q in the break. q is not used where a main trace is visible or when it may confuse the interpretation of frequency spread, Fig. 6.10 (a)(b).

(h) 'V' represents 'less than' (qualifying letter E). (See section 6.7).

(i) 'Λ' represents 'greater than' (qualifying letter D). (See section 6.7).

Note: Do not use the 'greater than' symbol when the trace has been extrapolated to give the critical frequency. The extrapolated value should be plotted as a filled (doubtful) value. The 'greater than' and 'less than' symbols apply when there is no indication from the ionogram of the amount of extrapolation needed.

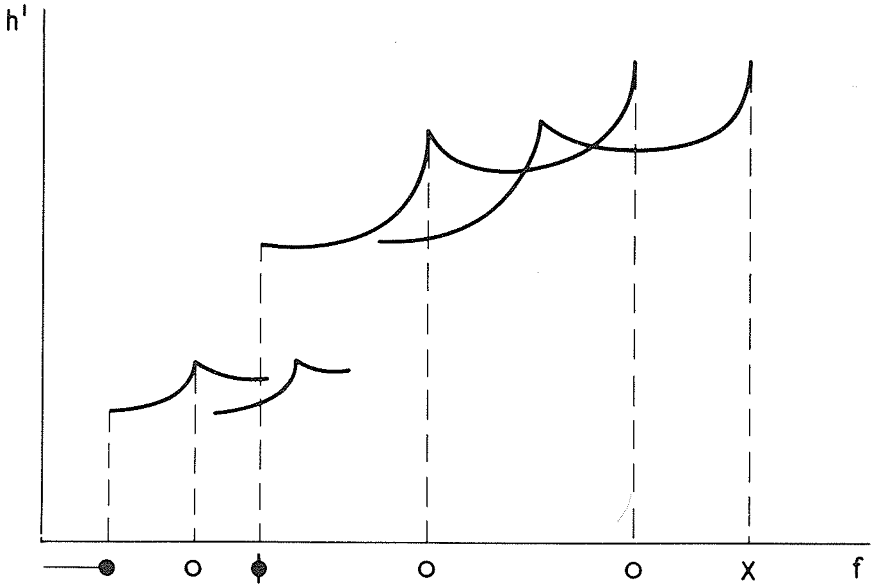


Fig. 6.3 f plot conventions for a typical normal ionogram. The symbols are placed at the appropriate frequencies on the f plot sheet.

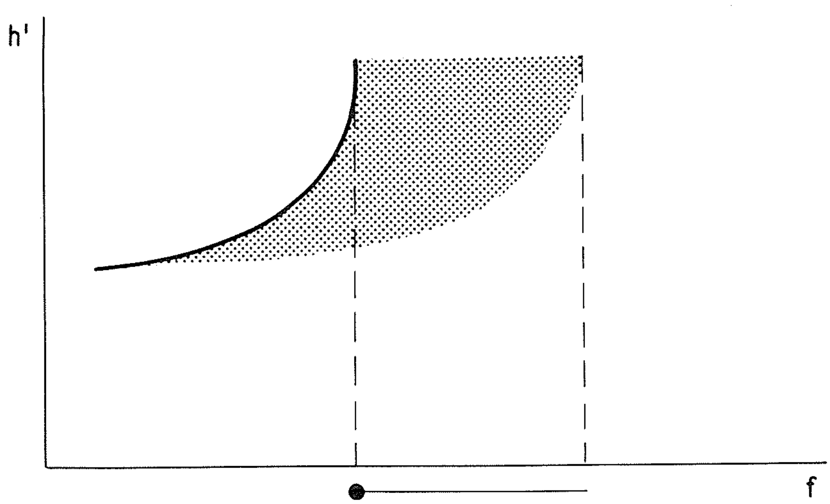


Fig. 6.4 f plot convention where critical frequency is doubtful

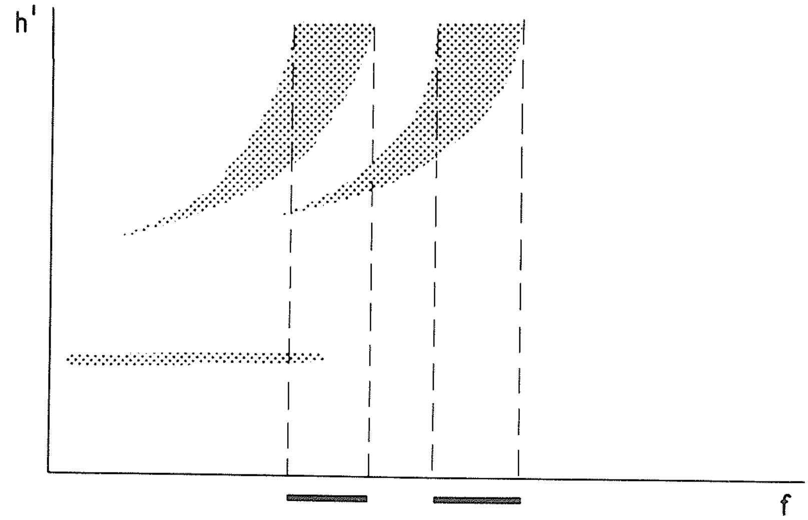


Fig. 6.5 f plot convention where spread is present

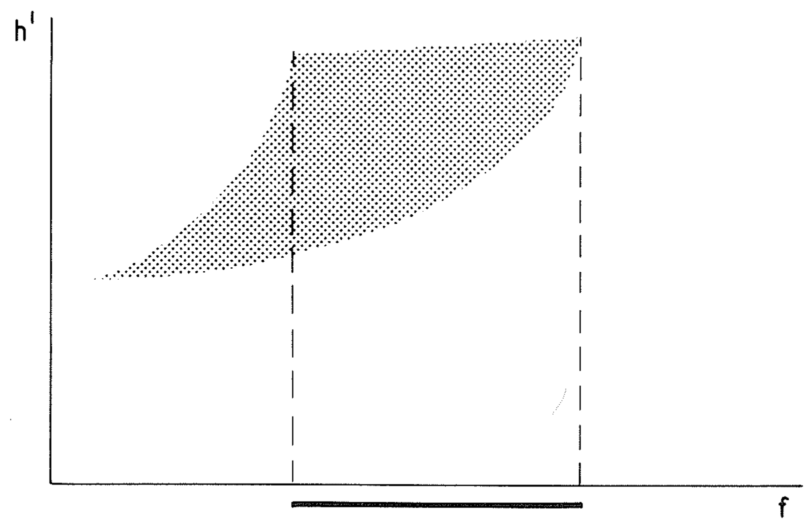


Fig. 6.6 f plot convention where spread is present

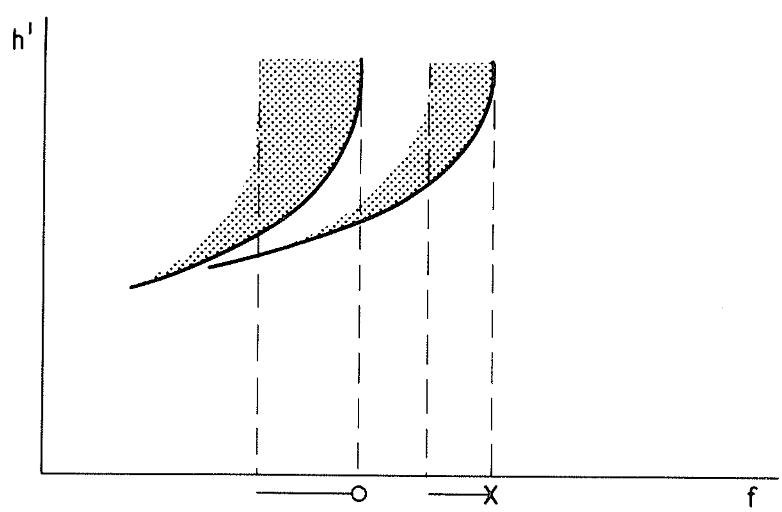


Fig. 6.7 f plot convention for critical frequencies where spread is present

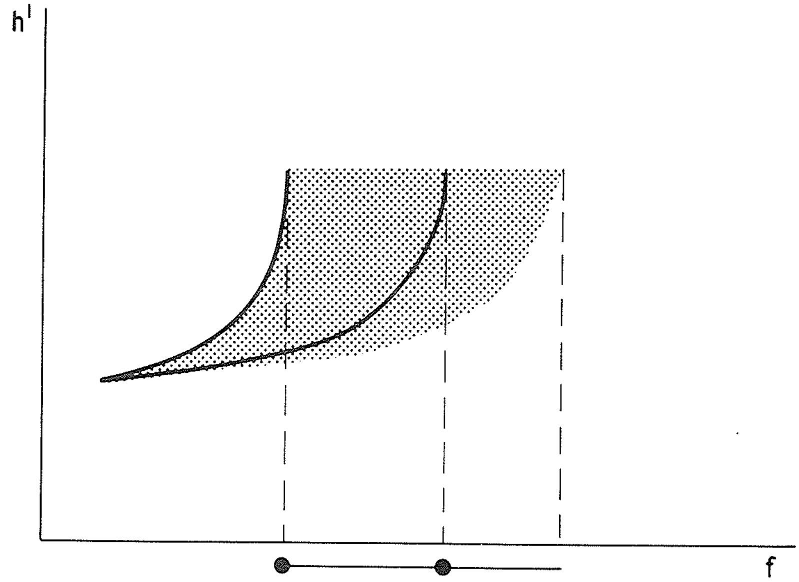


Fig. 6.8 f plot convention for critical frequencies where spread is present

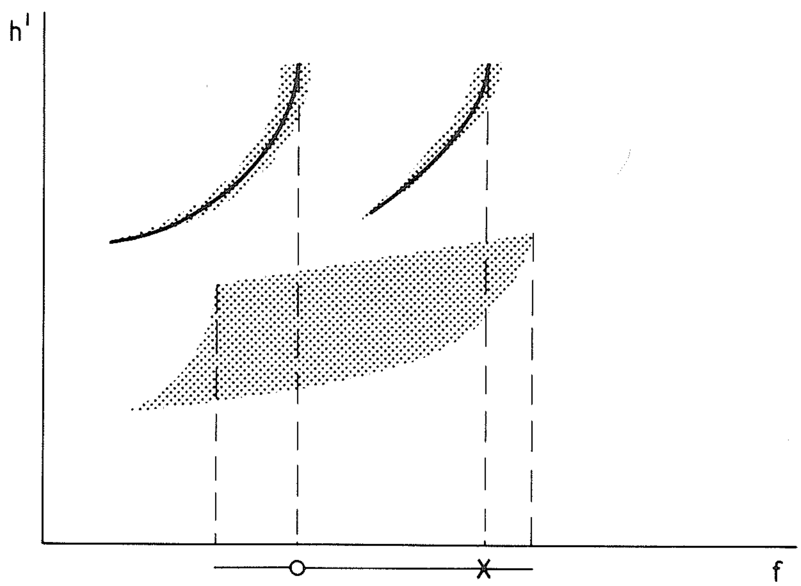


Fig. 6.9 f plot convention where critical frequencies are deduced from multiple order traces

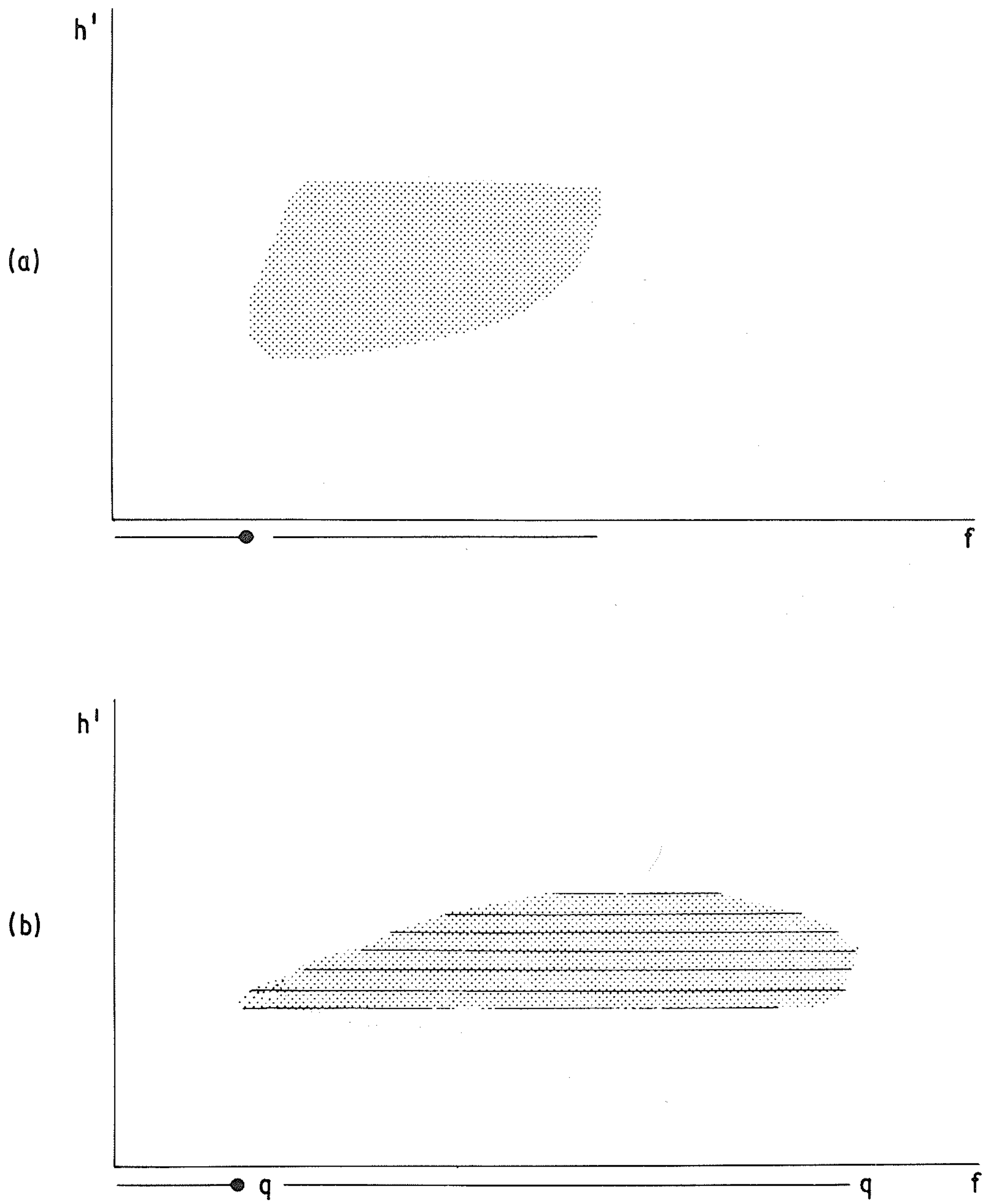


Fig. 6.10 f plot convention when spread is present

(a) Frequency spread. Small gap at fmin
(b) Range spread. Use of q.

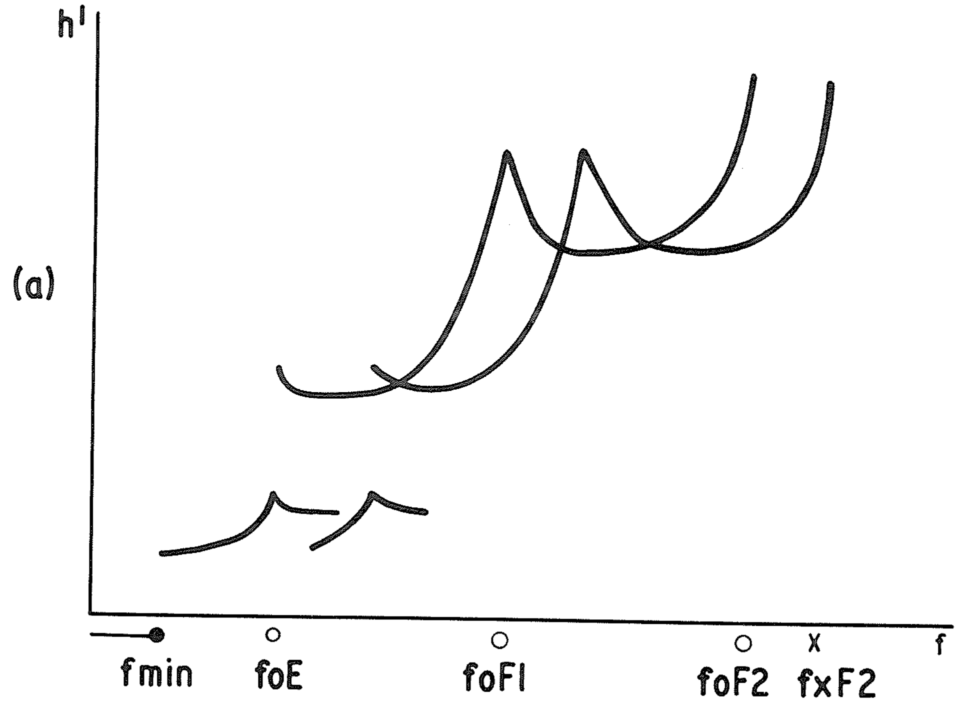


Fig. 6.11(a) Convention for plotting foF1

foF1 value not qualified. (foF1)--.

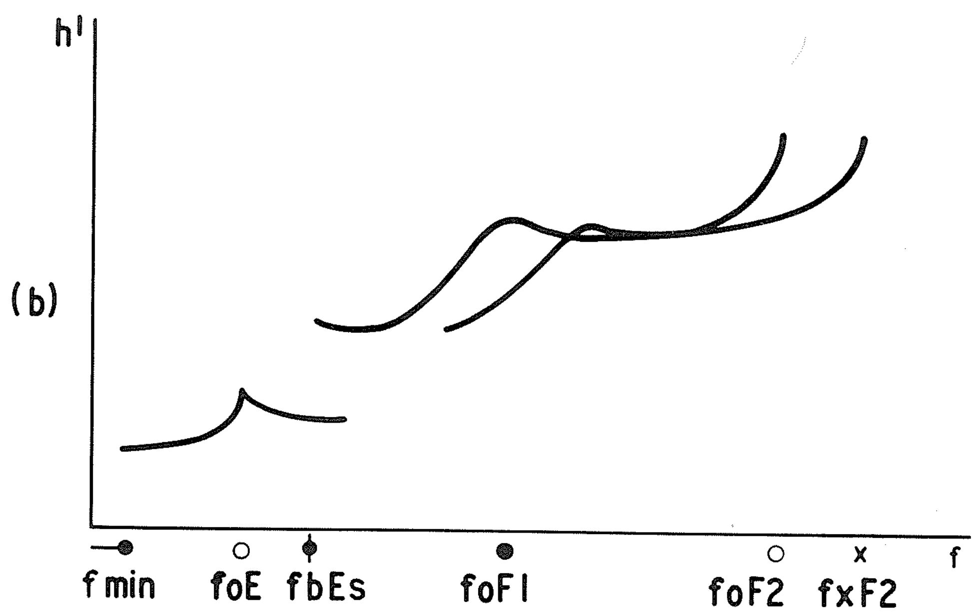


Fig. 6.11(b) Convention for plotting foF1

foF1 doubtful (foF1)UL

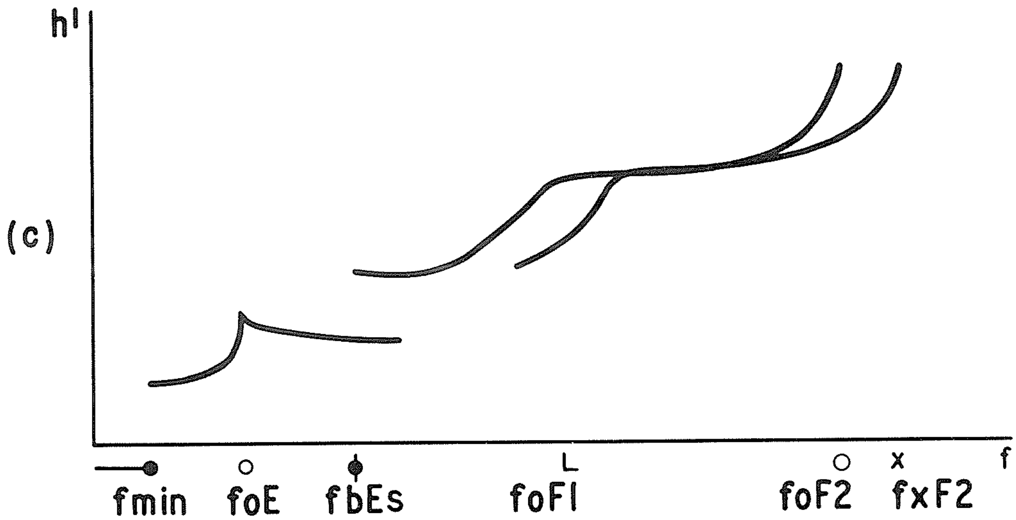


Fig. 6.11(c) Convention for plotting foF1

foF1 replaced by L in table and on f plot

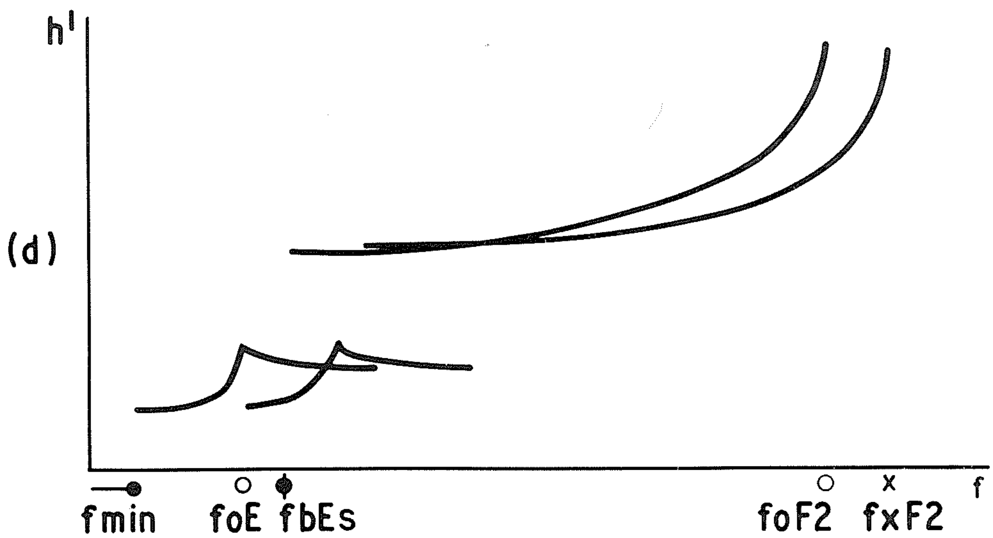


Fig. 6.11(d) Convention for plotting foF1

No entry in table or on f plot

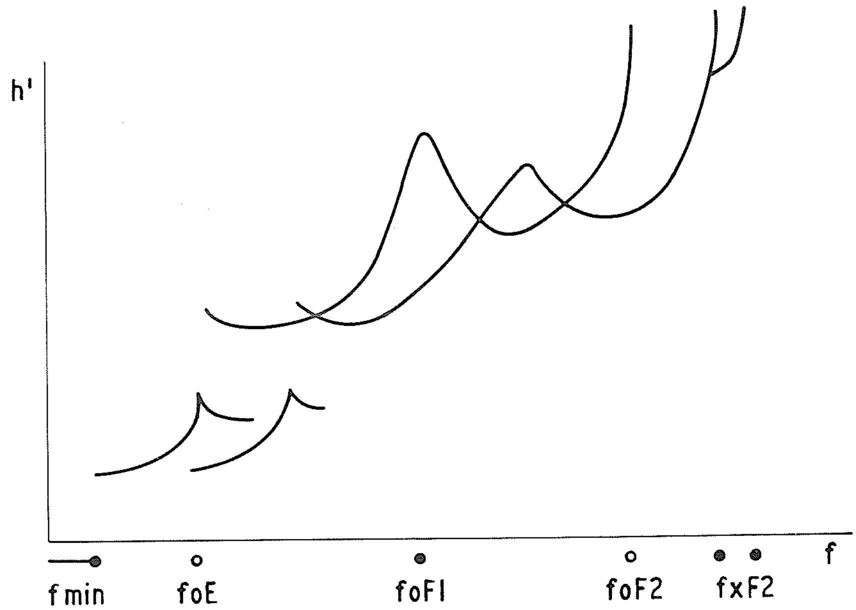


Fig. 6.12(a) Doubtful value of foF1

When the o and x traces are not similar in shape the critical frequencies are doubtful. (foF1)-H or (foF1)UH.
This type of pattern is often associated with satellite traces, forks, and distortion of the F2 trace. (The x trace is near normal, o trace distorted in this figure).

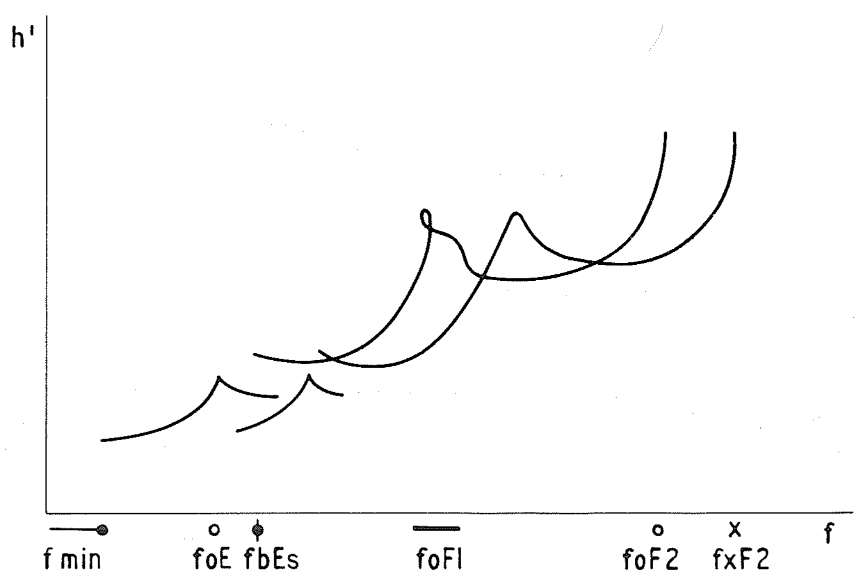


Fig. 6.12(b) Doubtful value of foF1

No simple cusp present. Numerical value (foF1)UH.

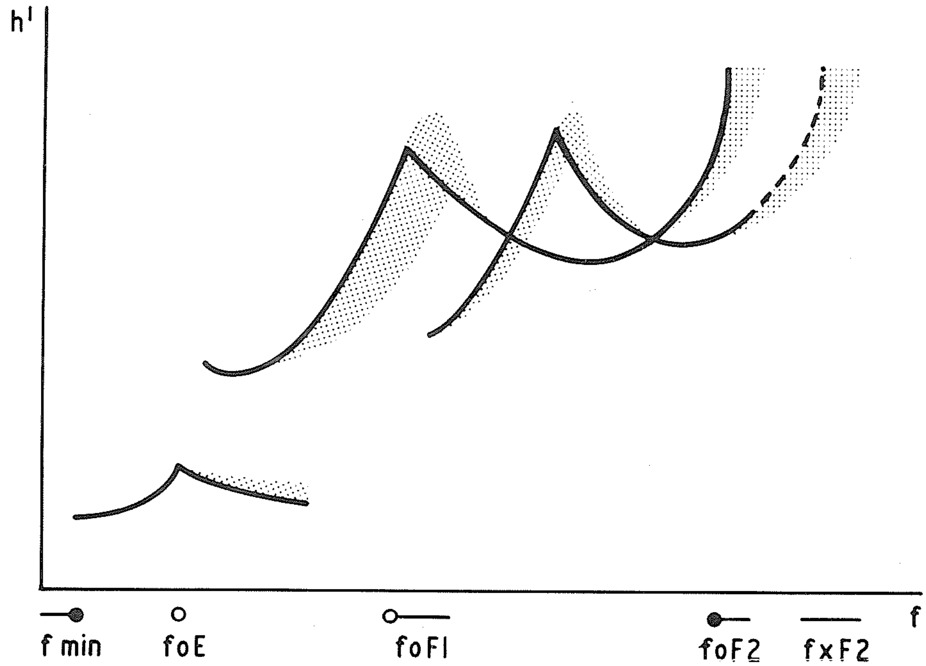


Fig. 6.13 Convention for foF1

(1) If F1 cusp visible, use o and line showing frequency spread (as above).
(2) If F1 cusp not visible on trace, use line alone.

6.4 Conventions for Plotting foF1

(a) When foF1 is well defined, Fig. 6.11(a), foF1 is plotted as an open circle.

(b) When the cusp of foF1 is not well defined Fig. 6.11(b) (case UL in Chapter 3) the value is denoted by a solid dot. Note the maximum of the cusp is shifted in frequency (usually upwards) as it flattens out. Thus, the doubt due to interpretation difficulties is usually much greater than the doubt due to measurement difficulties.

(c) When there is no maximum of foF1, letter L is placed on the f plot at the highest frequency where the F2 trace is concave downwards. (Fig. 6.11(c)).

(d) When the trace is not concave no entry is made. (Fig. 6.11(d)).

(e) When the F1 trace is distorted or the o and x traces are not separated by fB/2 (within the accuracy rules) the value of foF1 is denoted by a solid dot. (Fig. 6.12(a)).

(f) When the F1 trace is distorted so that there is no simple maximum or cusp, a line is drawn through the range of possible values with solid dots at any peaks. (Fig. 6.12(b)).

(g) When satellite traces are present showing cusps at different frequencies solid dots are given for each cusp. If the pattern is spread a line is drawn to show the width in frequency of the possible value of foF1. (Fig. 6.13).

6.5 Conventions for Plotting fmin

fmin is represented by a filled circle with a vertical line connecting it to the effective lower frequency limit of the ionosonde for the ionogram (see Figs. 6.3, 6.10, 6.11, 6.12, 6.13).

When fmin is determined by a band of strong noise or interference, e.g., the medium wave broadcast band in some zones, the true value will be lower than the band edge and the 'less than' sign 'V' should be used (Fig. 6.14). It is always presumed that 'V' applied to fmin implies the letter S. In the few cases where other letters apply the appropriate letter should be written in the bottom margin of the f plot. (Fig. 6.15 at 2130).

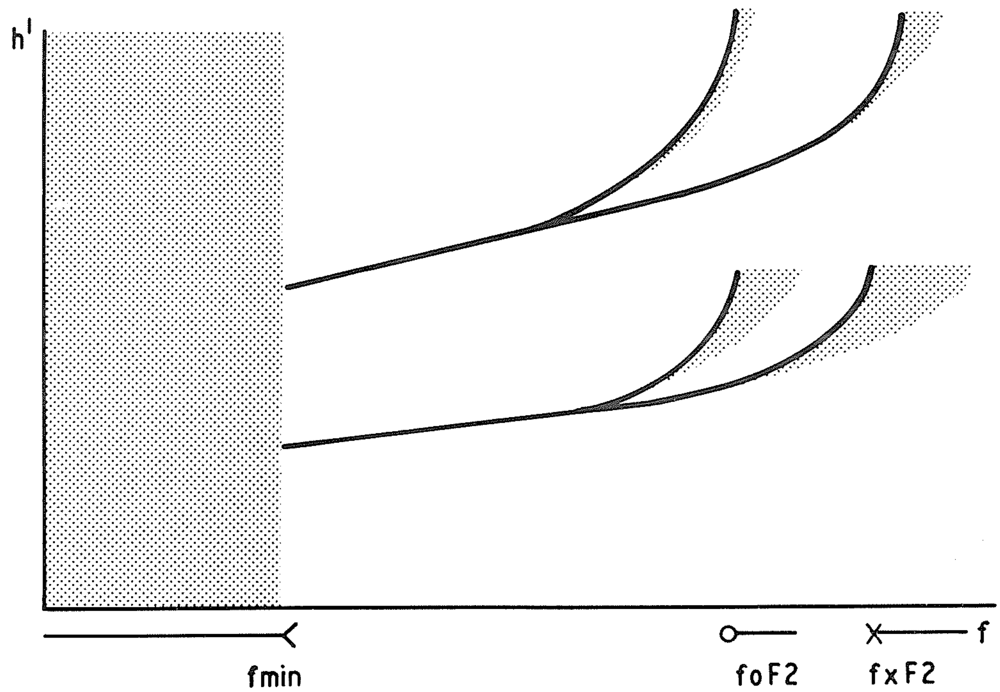


Fig. 6.14 Convention when fmin is determined by a strong band of interference

Strong interference below lowest reflection frequency (e.g., broadcast band at night). fmin given by (fmin)ES.

Ionograms showing no echoes due to high absorption are indicated by a solid vertical line from the bottom to the top frequency of the actual ionogram. This is also used when weak Es d traces are the only traces visible.

Prolonged periods of no echoes due to high absorption may be indicated on the f plot by vertical lines at the beginning and end of the period with the horizontal pattern '-B-' between them. (Fig. 6.15).

6.6 Conventions for Plotting Es and Es Types

foEs is not plotted on normal f plots. Values of fbEs are plotted as filled circles with a horizontal line through them. Alternatively when consecutive values of fbEs are present which are attributable to the same Es trace they are linked by straight lines.

When fbEs exceeds foF2 the 'less than' symbol 'V' is placed at the numerical value of foEs, or if fbEs can be deduced using rules (a)(b) of section 4.6, at the deduced value of fbEs. (Fig. 6.16).

When the F-layer trace shows group retardation at fbEs, Fig. 6.17, i.e., the corresponding thick lower layer trace is screened by the Es, the normal solid dot for fbEs should be replaced by an open circle, plus dashes which show that the value is fbEs. This is particularly important at high latitudes where night E is common and often associated with Es type r.

The types of Es occurring during each sounding are plotted as open circles at the intersection of the vertical line denoting the time of the sounding and horizontal line indicating the type of Es using the small graph on the f plot sheet. If identification of the Es type is considered doubtful, it is noted by a filled circle, Figs. 6.1, 6.2, 6.15.

The types of Es commonly observed at each station are marked at the left end of the small graph. The unclassified type (n), if needed, should occupy the bottom line. An effort should be made to identify the most common types at the station. Where possible, these should be entered in the same position on the graph each day. Any one station will probably observe only 4 or 5 of these types. The types are described in Chapter 4.

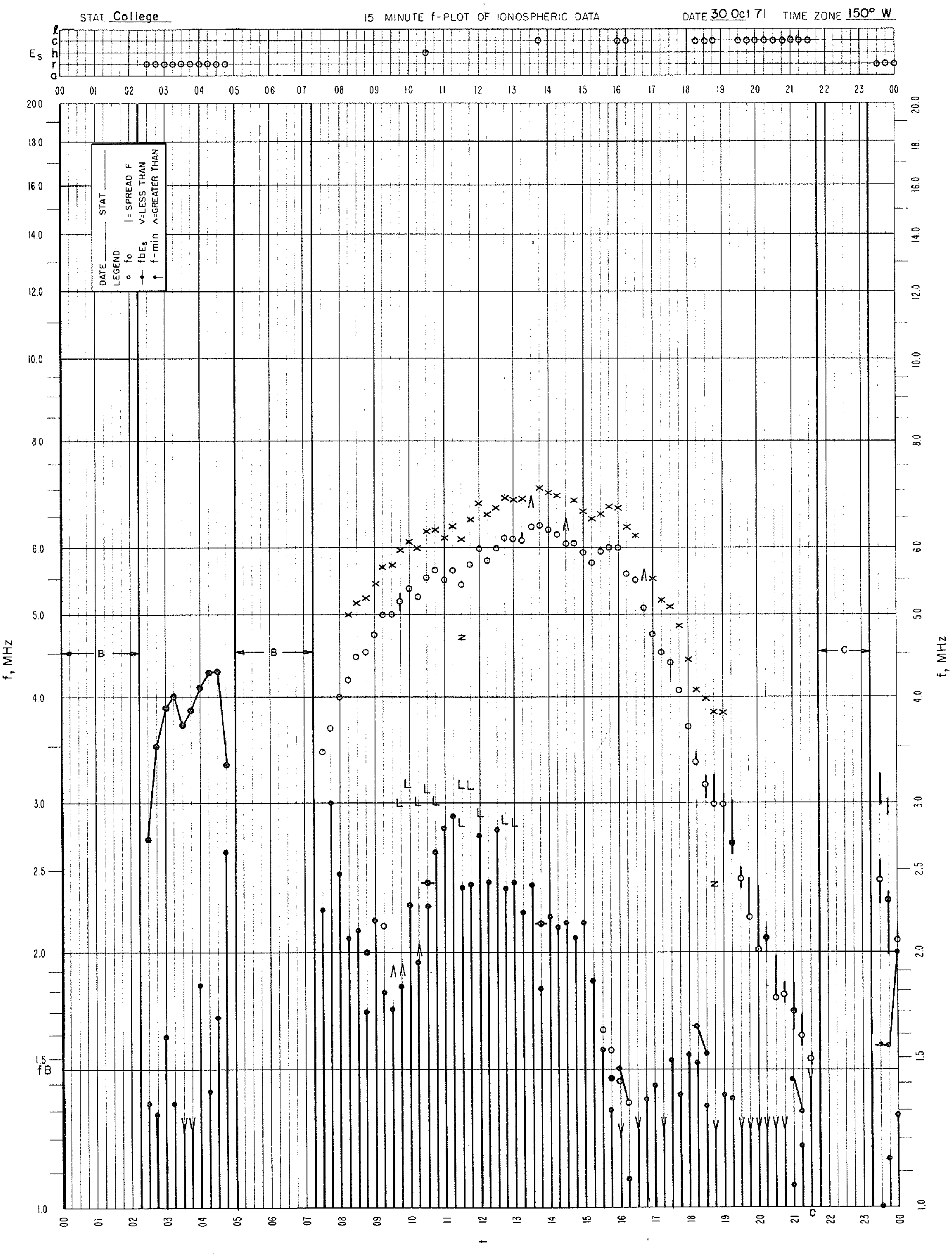


Fig. 6.15 Note fB calculated at 200 Km.

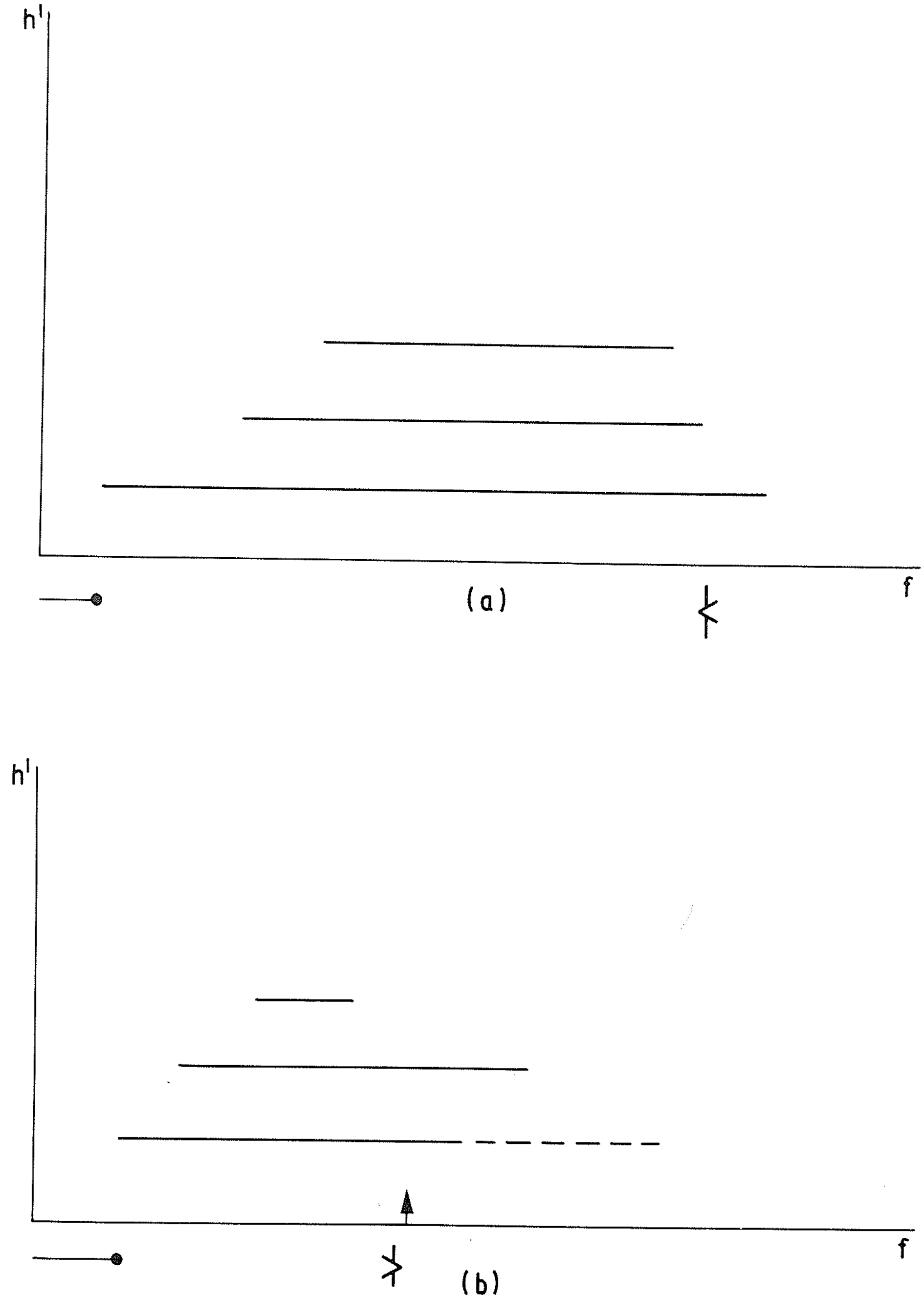


Fig. 6.16 fbEs with total blanketing

(a) o trace solid and multiples agree use -V- at foEs.
(b) foEs uncertain and multiples disagree use -Λ- at expected value of foF2

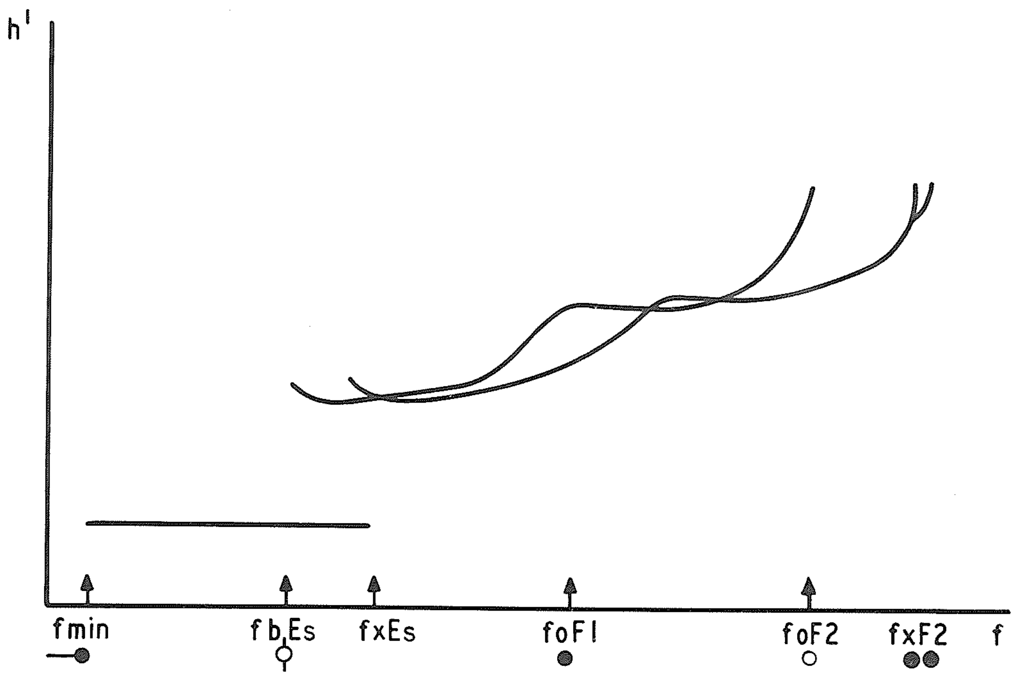


Fig. 6.17 Convention for fbEs when retardation present at bottom end of higher trace.

6.61. Provisional f plot Indication of fxEs: A number of stations are experimenting with the addition of the top frequency of Es (ftEs) to the f plot. To encourage conformity the following conventions are recommended:

(a) The standard f plot rule that the f plot shows what was actually observed should be strictly obeyed.

(b) An open triangle Δ is recommended when ftEs is equal to fxEs.

(c) A closed triangle ▲ is recommended

- (i) if the value is doubtful
- (ii) if the interpretation, fxEs, is doubtful
- (iii) if the observed value of ftEs is foEs.

(d) Limit values are indicated by adding the appropriate descriptive letter above the solid triangle if the true value is greater than that given, below if less.

The additional information appears valuable provided it is restricted to the Es trace used to give foEs.

Note: For G conditions the symbol for foE takes precedence over the symbol for Es, i.e., use an open or closed circle, not a triangle, in these cases. The plotting of ftEs or fxEs on f plots is purely voluntary and is not at present recommended internationally.

6.7 Missing Traces

f plot symbols are determined by the accuracy rules (section 2.2), accurate data being given by the standard symbols, uncertain data by solid dots, but there are no accuracy rules for the width of spread which is given by a line. When the frequencies cannot be observed, 'greater than' (D,

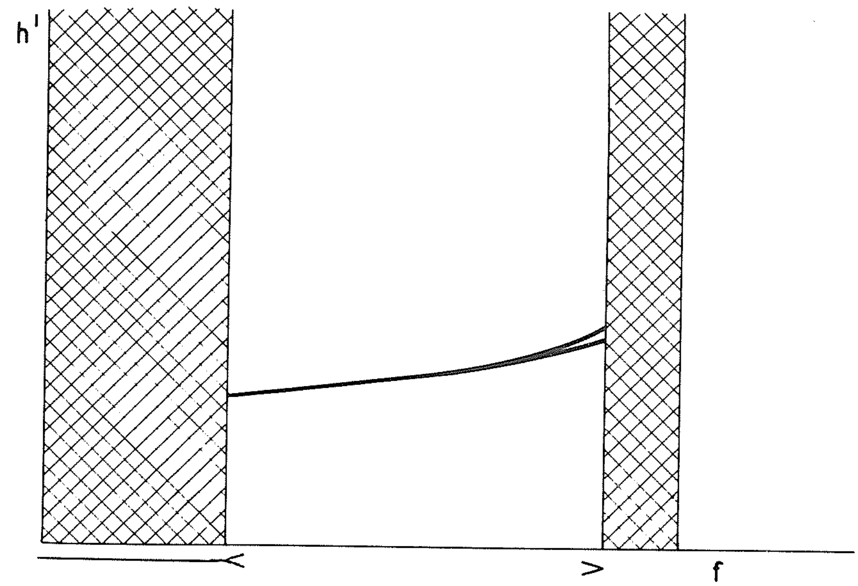


Fig. 6.18 Use of limit symbols

Interference is shown hatched.
fmin is (fmin)ES with less than sign
foF2 is (foF2)DS with greater than sign

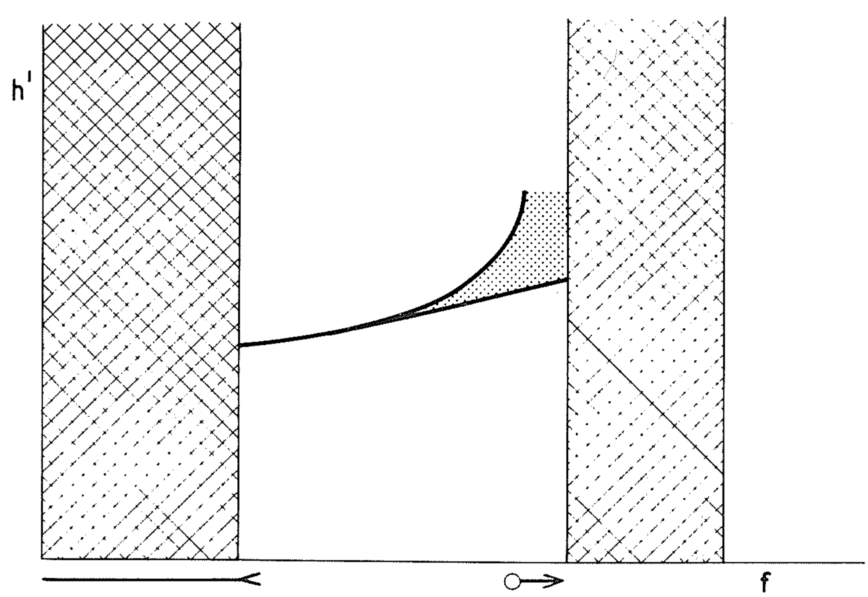


Fig. 6.19 Use of limit symbols

fmin given by (fmin)ES
foF2 reliable
Upper limit of spread hidden by interference

f plot symbol Λ) and 'less than' (E, f plot symbol V) are used where appropriate. When the daily work sheets are constructed from the f plots it is necessary to distinguish between values to be recorded xxxDX or xxxEX (X a descriptive letter) and those replaced by X. For the former, use the appropriate sign with the descriptive letter where needed to make the interpretation of the f plot clear, for the latter use the descriptive letter alone. The rules are as follows:

(a) When a trace has to be extrapolated to give the critical frequency and the extrapolation in frequency is less than the accuracy limitation for unqualified data use the appropriate standard symbol o, x, or z .

(b) When a trace has to be extrapolated by a greater amount than in (a) use a solid dot.

(c) When only a limit value is available use the greater than Λ or less than V signs (rules as for use of D or E) (Fig. 6.18).

(d) When part of a spread trace pattern is missing but the spread is seen on both sides of the missing band the line representing the spread is continued through the missing band.

(e) When one edge of the spread is missing use the greater than or less than signs Λ, V as appropriate (Fig. 6.19).

Experience shows that it is not advisable to use descriptive letters freely on an f plot (with the exception of L) - they are too difficult to read when reproduced. It is sufficient to put S or C (the most common letters) at the appropriate frequencies near the edges of the f plot when the pattern would otherwise not be interpretable. Note the standard broadcast bands are common to all stations and thus do not need special indication.

6.8 Other Conventions

6.81. A vertical line is used to show the possible range of values of foE when the traces on the ionogram do not indicate a numerical value allowed by the accuracy rules (Fig. 6.20).

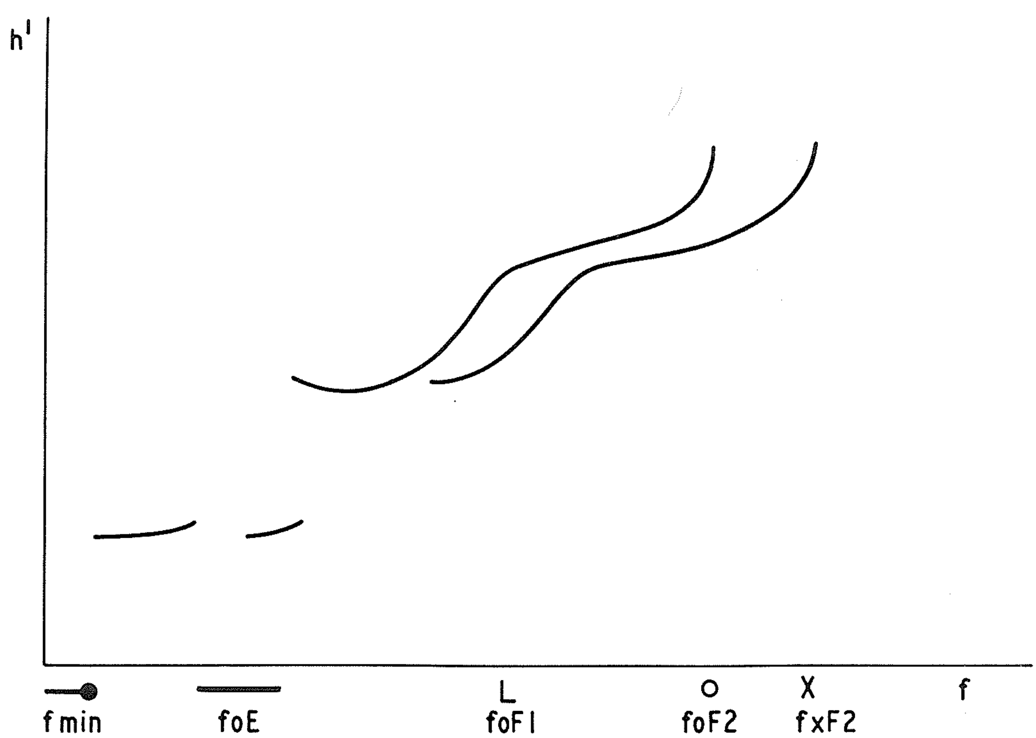


Fig. 6.20 f plot convention where foE is doubtful

6.82. When the 'greater than' symbol 'Λ' is used to denote a critical frequency (usually foF2) it should be plotted at the highest frequency of the appropriate trace and it is always assumed that this symbol used alone implies the descriptive letter R. In the case where another descriptive letter is required (interference, noise, lack of equipment response at high frequencies, etc.) the appropriate descriptive letter is noted on the f plot near the symbol.

6.83. Prolonged periods of missing data owing to equipment faults (letter C) may be indicated by the horizontal pattern '-C-' extending over the period involved (Fig. 6.15).

6.84. When a common descriptive letter applies to all the frequency characteristics seen on one ionogram this letter is placed at the top of the f plot column. This simplifies the tabulation of numerical values.

6.85. Additional rules for frequencies below the gyrofrequency: The following conventions should be used in the frequency band below the gyrofrequency:

- ● fmin lowest frequency at which any echoes are observed (no rejection rules);
- -●- fminF, except when equal to the critical frequency of a lower layer, when -O- should be used. When fminF = fmin, the fmin convention is used;
- o any ordinary-mode critical frequency or cusp frequency;
- z any z-mode critical frequency;
- x any cusp in a trace attributable to a maximum or a minimum in the ionization profile below the reflecting layer not already denoted by o.

The distinction between o and x depends on the presence or absence of retardation in the trace of the lower layer. Thus, if both lower and upper traces show retardation at the critical frequency and the upper layer is effectively blanketed by the lower near this frequency, use o. When it is clear from the sequence of events that the cusp is due to the formation of a ledge in the F layer, e.g., near sunrise and sunset, the symbol o is used and the critical frequency tabulated with the values for the appropriate layer. Care is needed to distinguish between foF1 and foE when the ledge first appears in the morning.

When the magneto-electronic modes are closely coupled, additional retardation occurs in the x mode when the working frequency is equal to the plasma frequency. Thus, an echo trace due to coupling often shows retardation at frequencies where the underlying ionization has a maximum or a minimum. The symbol x is introduced to denote maxima in h' due to this phenomenon.

6.86. Special regional conventions: Special conventions for denoting particular phenomena may only be used at a station if they are not liable to cause confusion with standard parameters, i.e., those representing characteristic frequencies. The dashed or broken line has been used to denote particular local phenomena. However, this cannot be distinguished from broken lines representing groups of frequency spread traces. The most common need is for a method of representing range spread or oblique F-region traces in zones where these are common. The q convention, section 6.3 (g), can be used if it is restricted to the frequency range not occupied by other frequency or frequency spread symbols. When both phenomena are present in the same frequency range, the normal frequency spread takes precedence and q must be placed so that this can be readily recognized. Special regional conventions have been found useful to denote the presence of three different types of phenomena whose incidence is otherwise difficult to study, viz.:

(i) The presence of very weak, low echo traces at frequencies below the value of fmin given by normal traces.

(ii) The presence of equatorial spread F phenomena.

(iii) The presence of a stable F-layer pattern of traces at frequencies above the vertical incidence critical frequency of the F2 layer.

These phenomena have considerable practical and scientific importance and the following local rules are allowed for cooperative regional studies:

(a) The presence of very weak low echo traces is now indicated by an entry in the Es type d row (section 4.8) on the f plot. (The IGY convention was to put a small d at the top or bottom of the f plot).

(b) The presence of equatorial spread F patterns in which the main trace has been completely replaced by a diffuse horizontal band with little or no sign of group retardation may be indicated by a line, using the q convention.

(c) The presence of a second pattern of F-region traces, e.g., polar spurs (Fig. 3.39(3)) can be conveniently shown using the q convention. Note that the lower limit for q cannot be set lower than fxF2, or the upper limit of frequency spread associated with fxF2 without causing possible misinterpretation.

6.87. Conventions for plotting ftEs on an f plot: As a special project it is allowed to show the top frequency, ftEs, of the Es trace used to evaluate foEs on the f plot. This is at present voluntary and experimental.

As the top frequency of the Es trace (using the normal selection rules) is usually fxEs the rules are written so that they normally give the value of fxEs.

The provisional rules have been summarized in section 4.9. Note that reliable values of fxEs are denoted by Δ, unreliable values of those giving foEs by ▲.

6.9 Transcribing Data from the f Plot

6.91. Numerical values: Numerical values with the applicable qualifying and descriptive letters may be transferred from the f plot to the appropriate frequency column on the daily tabulation sheet.

The limiting numerical values of fmin, indicated by 'V', are transcribed with the qualifying letter E and the descriptive letter S unless another descriptive letter applies as shown by a note on the f plot. For fbEs the symbol 'V' is always transcribed by the numerical value plus AA (see detailed rules in section 4.6 and section 3.2, letter A).

The limiting numerical values of critical frequency indicated by 'Λ' are transcribed with the qualifying letter D and the descriptive letter R unless a note on the f plot shows that another letter applies.

6.92. Interpolation: If the hourly value of a critical frequency is missing and interpolation is allowable, a graphical interpolation should be made on the f plot. The interpolated numerical value is qualified by letter I together with the descriptive letter indicating the cause for the missing value.

6.93. Inconsistent doubtful values: If the actual plotted hourly value of foF2 is doubtful and not consistent with the trend set by the adjacent values it should not be tabulated as a representative value but should be replaced by a value obtained by graphical smoothing through the hour in question. In this case the value tabulated will be qualified by the letter T and described by the letter appropriate to the reason the value is doubtful. Note that the original (inconsistent) value must be shown on the f plot and is available to those who may later use the f plot for special studies of short-time variations. When the ionospheric conditions are transiently abnormal at the hour the appropriate descriptive letter is T.

NOTES

7.0 General

Hourly tabulated data tables provide representative data of those features of the ionosphere which may be studied effectively using hourly data alone and should be sufficiently complete and homogeneous to satisfy this requirement without reference to the original ionograms. Es characteristics and fmin, however, always represent the instantaneous value at the hour.

Machine computing methods are in wide and increasing use for tabulation, checking, and statistical analysis of ionospheric data as well as for research and practical applications. Therefore, to assure maximum usefulness, all tabulations of ionospheric data should be in form suitable for convenient transfer to punched cards. Standard forms for exchange of ionospheric data tabulations and punched cards are designed to facilitate convenient and economical use of all ionospheric data in research and practical applications.

Since punched cards will usually be prepared from these forms, either locally or centrally, it is important that the instructions for completing the forms be followed accurately. Most entries involve tabulating a numerical value, three digits, a qualifying symbol and at least one descriptive symbol. Where space for more than one descriptive symbol is provided only the first symbol can be used for further tabulation using computers and this must always be the most important symbol.

7.1 Daily Tabulation Sheet (Daily Worksheet)

The hourly values of the various parameters obtained from the f plot or scaled directly from the ionograms are commonly recorded on a daily tabulation sheet of hourly values, usually named the "Daily Worksheet" so as to prevent confusion with the monthly day-by-hour tabulation sheet (Chapter 8) and with tables of monthly median characteristics. The format of this worksheet is usually arranged to suit the particular circumstances at individual stations. A typical example is shown in Fig. 7.1.

Most stations list the various characteristics horizontally along the top of the table and the hour of the day vertically. The table is usually arranged to give the standard international parameters:

fxI, foF2, foF1, foE, foEs, fbEs, fmin;
M(3000)F2, M(3000)F1, or the corresponding MUF, MUF(3000)F2, MUF(3000)F1;
h'F, h'F2, h'E, h'Es;
Es types.

A remarks column also appears on the form usually directing attention to a more detailed entry on a separate "Scaling Notes" sheet. Special parameters regularly scaled for local or regional purposes are also included on the main worksheet or similar supplementary tables, whichever is convenient.

Each sheet must show the more important identifying information viz.:

Station name or symbol
Date
Standard time meridian used at the station
Initials of scaler and person who checks the data.

A number of local practices have developed which provide more than the basic minimum of information but, in general, depend on the format of the worksheet. The most widely used of these are given below as subparagraphs, each of which is titled local rule. These practices cannot conveniently be followed unless the worksheet is in a suitable form. Fig. 7.1 is a typical example of a daily worksheet which was designed for convenience in both scaling and subsequent key punching. With this layout, note that M(3000)F2 must have the same qualifying and descriptive letters as foF2.

7.2 Conventions for Tabulation on Daily Worksheet

7.21. Identifying information: The necessary identifying information should be entered on every sheet.

7.22. Time: Interpolation should be made to replace missing data whenever allowed by the conventions for qualifying letter I. Deviations from the routine time schedule should be corrected in this way. This is particularly important when the critical frequencies are changing rapidly with time, e.g., near sunrise or sunset at some seasons, since a time error may introduce a systematic shift in the numerical values.

When the sequence indicates that conditions are varying slowly, any ionogram obtained within five minutes of the hour may be used to scale the hourly value of the characteristics with an appropriate entry in the Remarks column and "Scaling Notes"; otherwise interpolation must be made.

HOURLY VALUES
IONOSPHERIC SOUNDINGS

SCALED BY ________ DATE ________ TIME ZONE ________

CHECKED BY ________ STATION ________

	f-min			E REGION																F REGION																							
					SPORADIC E							NORMAL E						E2														HEIGHTS											REMARKS
Hour	fo	QUA	DES	fbEs	foEs	QUA	DES	h'Es	QUA	DES	TYPE OF Es	foE	QUA	DES	h'E	QUA	DES	foE2	h'E2	foF1	F1 M3000	QUA	DES	foF2	F2 M3000	QUA	DES	fmI	fxI	QUA	DES	h'F	QUA	DES	h'F2	QUA	DES	hpF2	QUA	DES			
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FORM 7-E REVISED 9-9-69

Fig. 7.1 Daily worksheet

Local rule: The exact time of the ionogram used and the descriptive letter explaining why the hourly ionogram was unsuitable is inserted in the time column whenever the hourly ionogram is not used.

7.23. Gain runs: Local rule — The gain of the ionogram used to scale any characteristic can be tabulated as follows using the space provided for the corresponding descriptive letters:

Low gain ionogram — Enter a dash below the normal position of the descriptive letter so that the letter can be read clearly. High gain ionogram — Enter a dash above the normal position of the descriptive letter so that the letter can be read clearly. Normal gain ionogram — Leave blank so that the descriptive letter appears alone. This convention is seldom used.

7.24. Numerical values: All data must be in exactly the same form for efficient key punching and it is therefore essential that:

(a) three integers be used for all numerical values,
(b) qualifying and descriptive letters are always placed after the numerical values and in the correct order with the qualifying letter first.
(c) decimal points are omitted.

The conventions to be followed in the tabulation of numerical values on the daily tabulation sheet are shown by the following examples:

Characteristic	Sample value	Daily tabulation	When tabulated
fmin	1.3 MHz	013	Every hour
foF2	9.6 MHz	096	
M(3000)F2	2.95	295	
h'F	255 km	255	
h'F2	370 km	370	When present (Mainly daylight hours)
foF1	4.7 MHz	470	
M(3000)F1	3.45	345	
foE	3.85 MHz	385	All daylight hours and when present at night
h'E	111 km	111	
foEs	5.1 MHz	051	Every hour
h'Es	103 km	103	
fbEs	4.6 MHz	046	
Es types	see 7.26 below		When observed

Both foF1 and foE are tabulated in units of 0.01 MHz to satisfy the punched card conventions. The last figure is always 0 for foF1 and either 0 or 5 for foE. All MUFs are scaled in units of 0.1 MHz (foF2 convention).

7.25. Letter symbols: When no separate columns are provided for qualifying and descriptive letters, these letters follow the numerical value. A dash is always inserted when there is a descriptive letter but no qualifying letter, e.g., 096, 096-H, 096UF.

When separate columns are provided for qualifying and descriptive letters it is essential that each is entered in the appropriate column.

Local rule: When space for more than one descriptive letter is provided the most important descriptive letter is entered immediately after the qualifying letter.

Some daily worksheets (e.g., Fig. 7.1) provide space for only one qualifying and one descriptive letter for each of the following pairs of characteristics: foF2 and M(3000)F2; foF1 and M(3000)F1; foEs and fbEs. In most cases the same qualifying and descriptive letters apply to both parameters in each pair. Otherwise the following rules may be adopted:

Local rules:

(a) When the qualifying and descriptive letters which apply to foEs do not apply to fbEs, put the qualifying and descriptive letters for fbEs in the fbEs column above the numerical value.

Descriptive or qualifying letters which apply only to fbEs are put in the fbEs column.

(b) When qualifying and descriptive letters that apply to M(3000) differ from those used with the critical frequency, the letters for M(3000) are entered in the remarks column or scaling notes. For example, if foF2 is 062US and M(3000)F2 is 280UF, the remark is M(3000)F2...UF.

(c) An alternative practice is to put the letters over the numbers with qualifying first and descriptive second. This is only possible when the space is adequate. The qualifying letter should be put above the first digit, the descriptive letter above the third digit to avoid confusion when only one letter is appropriate.

7.26. Type of Es: The conventions for recording the types of Es on the daily tabulation sheets are:

The types of Es are tabulated in lower case letters (e.g., r, f, s, etc.).

When more than one type of Es is present on the ionogram, the type for the trace used to determine foEs, fbEs and h'Es must be written in the first position. If other Es types are present, they are arranged in order of descending number of multiple reflections. The first two types tabulated are each followed by a number indicating the number of traces seen up to 9, including the first reflection. If only the first reflection is present, the number 1 must be used to prevent confusion when key punching the data for a computer. When night E is shown by retardation of the F trace only (no E trace) KO may be used (local rule).

The number of Es echoes should be judged from the normal gain ionogram.

7.27. Inspection for errors or omissions: Each daily tabulation sheet should be inspected upon completion to insure that it is free from omissions, gross scaling errors, tabulation and transcription errors, and that all necessary references to the scaling notes are complete.

The daily tabulation sheet should be carefully compared with the f plot, whenever one has been prepared, to insure that the hourly values properly represent the diurnal variation (see letter T, Chapter 3).

7.3 Use of Punched Cards for Ionospheric Data

7.31. General: Tabulation, checking, and statistical analysis of ionospheric data are now often performed by computers programmed to process punched cards, which were key punched in a standard format from the daily worksheets. The standard ionospheric data card form is the result of several years of development, principally by R. M. Gallet, in France, Germany, and the U.S.A. The design is quite flexible, can be adapted for all types of geophysical data, and can evolve to meet changing requirements as the geophysical sciences progress, but, as yet, this standard card form has been adopted internationally only for ionospheric data.

The body of the standard card contains a number field, consisting of 80 columns of the ten digits from 0 to 9 plus two additional rows above which are used for special indications. All key information (e.g., time, date, station, characteristic, etc.) as well as the data itself are punched within the array of numbers. The card equipment, of course, senses the position of a punched hole in the card.

Note: There are some significant changes from the corresponding section 6.3 of the previous edition of the Handbook.

7.32. Identifying information: The first thirteen columns of the card contain the following identifying information:

(a) Type of card

Column 1 — identifies the type of numbers recorded:
1 signifies the hourly measurement,
2 signifies the monthly summaries.

Column 2 — identifies the hours (in local standard time) of data contained on the card:
0 signifies the hours 06-18,

	1	signifies the hours 00-11,
	2	signifies the hours 12-23,
	5	signifies height vectors, i.e., a sequence of height values.
Columns 1 and 2	39	signifies conversion matrix.

(b) Station

Stations are identified by a three symbol code in columns 3, 4 and 5, which has been adopted internationally. This replaces the older code of section 6.3 of the first edition of this Handbook. To avoid possible duplication and confusion, code numbers for new stations are assigned through World Data Center A for Solar-Terrestrial Physics, NOAA, Boulder, Colorado 80302, U.S.A., and should not be created arbitrarily. A complete list of stations for which codes have been issued up to January 1971 is given in Table 7.1. Future additions will be announced in the INAG Bulletin, and an up-to-date complete list is available in the latest edition of the WDC-A Catalogue, which can be requested from the same address.

Stations are arranged in geographical order, since alternative names exist for some stations and names may be changed from time-to-time. In addition, Table 7.1 gives the standard International two letter identification of the station, which is also assigned by WDC-A. This is convenient for identifying stations on maps, for telegrams, and on other occasions where abbreviations are needed.

The three symbol computer station code (punch card columns 3, 4, 5) indicates the approximate geographical location of the ionosphere station. The following notes describe the scheme used for assigning station codes.

The first symbol denotes longitude band. The 12 longitude bands are each 30° wide. In the listing below the bands are given in degrees east of Greenwich meridian and in conventional east and west longitude:

Band	East	Conventional	Code
0	345°-15°	15°W-15°E	0
1	15°-45°	15°E-45°E	1
2	45°-75°	45°E-75°E	2
3	75°-105°	75°E-105°E	3
4	105°-135°	105°E-135°E	4
5	135°-165°	135°E-165°E	5
6	165°-195°	165°E-165°W	6
7	195°-225°	165°W-135°W	7
8	225°-255°	135°W-105°W	8
9	255°-285°	105°W-75°W	9
10	285°-315°	75°W-45°W	J
11	315°-345°	45°W-15°W	A

The second and third symbols denote actual geographic latitude in degrees. In a few areas, it is necessary to modify the third symbol arbitrarily to distinguish between different stations in the same longitude band and the same latitude. No two stations have the same code. For example, compare the codes in Table 7.1 for Lindau and Slough, or for Dourbes and Pruhonice.

To show whether the station is in the South or North hemisphere an "eleven punch" is put over the last digit for South hemisphere stations. This converts the numerical code into an alphanumeric code, as indicated by the sample punched card in Fig. 7.2. See Table 7.1 for examples.

Table 7.1

Station	Geographic Lat	Long	Indi-cator	Comp. Ident. Code
ARCTICA (NP 6)	87N		XG	
ALERT	82N	297	AL	J82
FLETCHERS ICE	82N		XC	982
ARCTICA(NP 13)	81N		XL	
ARCTICA (NP 8)	80N		XI	
EUREKA	80N	274	EU	980
HEISS IS	80N	57	BT	280
ARCTICA (NP 7)	79N		XH	
ARCTICA(NP 11)	79N		XK	
ARCTICA(NP 10)	78N		XJ	
LONGYEARBYEN	78N	15	LG	178
ARCTICA(NP 16)	78N	176	XM	676
THULE/QANAQ	77N	290	TH	J77
THULE/TUTO	76N	291	TH	J76
RESOLUTE BAY	74N	265	RB	974
DIXON	73N	80	DI	373
BARROW	71N	203	BW	771
TIXIE BAY	71N	128	TX	471
CLYDE	70N	291	CR	J70
GODHAVN	69N	306	GO	J69
MURMANSK	68N	33	MM	168
TROMSO	69N	19	TR	169
CAPE SCHMIDT	68N	181	CE	681
KIRUNA	67N	20	KI	167
SODANKYLA	67N	26	SO	166
SALEKHARD	66N	66	SD	266
LULEA	65N	22	LU	165
BAKER LAKE	64N	264	BL	964
COLLEGE	64N	212	CO	764
FORT NORMAN	64N	234	FN	864
LYCKSELE	64N	18	LY	164
PROVIDENYA	64N	186	PD	664
REYKJAVIK	64N	338	RK	A64
FROBISHER BAY	63N	291	FB	J63
YAKUTSK	61N	129	YA	461
YELLOWKNIFE	62N	245	YE	862
ANCHORAGE	61N	210	AN	761
NARSSARSSUAQ	61N	314	NQ	J61
KJELLER	60N	11	OS	059
LENINGRAD	59N	30	LD	160
NURMIJARVI	60N	24	NU	159
UPPSALA	59N	17	UP	158
CHURCHILL	58N	265	CH	958
FORT CHIMO	58N	291	FC	J58
INVERNESS	57N	355	IN	056
GORKY	56N	44	GK	156
SVERDLOVSK	56N	61	SV	256
TOMSK	56N	84	TK	356
EMMABODA	56N	15	EM	157
MOSCOW	55N	37	MO	155
JULIUSRUH/RU	54N	13	JR	055
MEANOOK	54N	246	ME	855
GOOSE BAY	53N	299	GS	J53
CHITA	52N	113	CX	452
DE BILT	52N	5	DT	053
IRKUTSK	52N	104	IR	352
MIEDZESZYN	52N	21	MZ	152
ADAK	51N	183	AD	651
LINDAU	51N	10	LI	050
SLOUGH	51N	0	SL	051
DOURBES	50N	4	DB	049
PRUHONICE	50N	14	PQ	052
WINNIPEG	49N	265	WI	949
FREIBURG	48N	7	FR	048
KHABAROVSK	48N	135	KB	548
PARIS SACLAY	48N	2	SC	047
VICTORIA	48N	236	VI	848
GARCHY	47N	3	GY	042
GRAZ	47N	15	GZ	146
ROSTOV	47N	39	RV	149
ST JOHNS	47N	307	SJ	J47
YUZHNO SAKHALI	47N	143	SA	547
BAIE ST PAUL+	47N	289	PL	J48
SEATTLE+	47N	237	SE	847
BUDAPEST	46N	21	BU	147
POITIERS	46N	0	PT	046
SCHWARZENBURG	46N	6	SZ	045
OTTAWA	45N	284	OT	945
WAKKANAI	45N	141	KK	545
BEOGRAD	44N	20	BE	145
GENOVA	44N	9	GV	044
SIMFEROPOL	44N	34	SF	144
ALMA ATA	43N	76	AA	343
MILLSTONE HILL+	43N	288	MH	J45
HANOVER+	43N	287	HN	J44
BILLERICA/BOSTN	42N	288	BO	J43
MAYNARD	42N	288	MY	J42
ROMA	41N	12	RO	041
TBILISI	41N	44	TB	142
BOULDER	40N	254	BC	840
FORT MONMOUTH	40N	285	FM	940
TORTOSA	40N	0	EB	040
AKITA	39N	140	AK	539
ATHENS	38N	23	AT	138
WASHINGTON	38N	282	WA	938
ASHKHABAD	37N	58	AS	237
SAN FRANCISCO+	37N	237	ST	837
WALLOPS IS+	37N	284	WP	937
SEOUL+	37N	127	SU	437
POINT ARGUELLO+	35N	239	PA	836
TEHRAN	35N	51	TE	236
TOKYO	35N	139	TO	535
CAPE ZEVGARI	34N	33	CV	135
CASABLANCA	33N	352	CA	033
RABAT	33N	353	RT	034
WHITE SANDS	32N	253	WS	832
HAIFA+	32N	34	HA	132
YAMAGAWA	31N	130	YG	431
QUETTA	30N	67	QT	230
EGLIN AFB+	30N	273	EG	930
CAPE KENNEDY+	28N	279	CC	929
DELHI	28N	77	DH	328

Table 7.1 Cont'd.

Station	Geographic Lat	Long	Indicator	Comp. Ident. Code
GRAND BAHAMA	26N	281	GB	926
OKINAWA	26N	127	OK	426
TAIPEI	25N	121	TP	424
SAN SALVADOR+	24N	285	SS	924
AHMEDABAD	23N	72	AH	223
CALCUTTA	23N	88	CU	322
CUBA	23N	277	CD	923
MACAU	22N	113	MC	422
TAMANRASSET	22N	5	TN	022
HONG KONG	22N	114	HK	423
MAUI	20N	203	MA	720
BOMBAY	19N	72	BM	219
MEXICO CITY	19N	260	MX	919
JAMAICA+	18N	283	JA	918
PUERTO RICO+	18N	292	PR	J18
ARECIBO+	18N	293	AR	J19
HYDERABAD	17N	78	HY	317
BAGUIO	16N	120	BF	416
DAKAR	14N	342	DK	A14
MANILA	14N	121	MN	414
BANGKOK	13N	100	BK	314
MADRAS	13N	80	MD	313
BARBADOS+	13N	300	BS	J13
OUAGADOUGOU	12N	358	OU	012
DJIBOUTI	11N	42	DJ	111
KODAIKANAL	10N	77	KO	310
TIRUCHIRAPALLI	10N	78	TI	311
TOGO	10N	0	TG	011
FT ARCHAMBAULT	09N	18	FA	109
PANAMA	09N	280	PN	909
THUMBA	08N	76	TC	309
TRIVANDRUM	08N	77	TM	308
IBADAN	07N	3	IB	007
PARAMARIBO	05N	304	PM	J06
ACCRA+	05N	359	AG	005
BANGUI	04N	18	BI	104
BOGOTA	04N	285	BG	905
POPAYAN	02N	283	PP	984
BUNIA	01N	30	BN	102
SINGAPORE	01N	103	SI	301
NAIROBI	01S	36	NR	10J
HOLLANDIA	02S	140	HL	50K
LWIRO	02S	28	LW	10K
VANIMO	02S	141	VA	50L
KINSHASA BINZA	04S	15	LB	10M
TALARA	04S	278	TA	90M
NATAL+	05S	324	NL	A0N
CHICLAYO	06S	280	CY	90P
CHIMBOTE	09S	281	CM	90R
PORT MORESBY	09S	147	PY	50R
ZARYA SHIP	10S		XF	
ELIZABETHVILLE	11S	27	EZ	11J
JICAMARCA+	11S	283	JI	91J
COCOS IS	12S	96	CS	31K
HUANCAYO	12S	284	HU	91K
JULIACA	15S	289	JU	J1N

Station	Geographic Lat	Long	Indicator	Comp. Ident. Code
LA PAZ	16S	291	LP	J1Ø
ILO	17S	288	IL	J1P
SALISBURY/RHOD	17S	31	SY	11P
TAHITI	17S	210	TT	71P
TANANARIVE	18S	47	IV	21Q
TOWNSVILLE	19S	146	TV	51R
TSUMEB	19S	17	TS	11R
RAROTONGA	21S	200	RA	72J
LA QUIACA	22S	294	LQ	J2K
SAO PAULO	23S	313	SP	J2L
JOHANNESBURG	26S	28	JO	12Ø
TUCUMAN	26S	294	TU	J2Ø
BRISBANE	27S	152	BR	52P
KERMADEC	29S	182	KC	62R
NORFOLK IS	29S	168	NI	63v
WOOMERA	30S	136	WO	53J
MUNDARING	32S	116	MU	43K
GRAHAMSTOWN	33S	26	GR	13L
BUENOS AIRES	34S	301	BA	J3M
CAPE TOWN+	34S	18	CT	13M
SALISBURY	34S	138	SR	53M
HERMANUS	34S	19	HE	13N
CANBERRA	35S	149	CB	53N
CONCEPCION	36S	287	CP	J3Ø
AUCKLAND	37S	175	AU	63P
HOBART	42S	147	HO	54K
GODLEY HEAD	43S	172	GH	64L
TRELEW	43S	294	TW	J4L
MARION IS	46S	37	MR	14Ø
KERGUELEN	49S	70	KG	24R
PORT STANLEY	51S	302	PS	J5J
CAMPBELL IS	52S	169	CI	65K
MACQUARIE IS	54S	159	MQ	55M
USHUAIA	54S	291	UA	J5M
SOUTH GEORGIA	54S	323	SG	A5M
SOYA SHIP	60S		XD	
DECEPCION	63S	300	DE	J6L
ARGENTINE IS	65S	295	AI	J6N
CASEY	66S	110	CW	46Ø
MIRNY	66S	92	MI	36Ø
TERRE ADELIE	66S	140	DU	56Ø
WILKES	66S	110	WL	46Ø
MAWSON	67S	62	MW	26P
SYOWA BASE	69S	39	SW	16R
BAUDOUIN	70S	23	BB	17v
SANAE	70S	357	QM	07v
CAPE HALLETT	72S	170	HT	67K
EIGHTS+	75S	282	EI	97N
HALLEY BAY+	75S	333	HB	A7N
BELGRANO+	77S	321	GE	A7Q
ELLSWORTH	77S	318	EL	A7P
SCOTT BASE	77S	166	SB	67P
LITTLE AMERICA	78S	197	LA	77Q
VOSTOK	78S	106	VO	47Q
BYRD STATION	80S	240	BD	88v
SOUTH POLE	90S	0	PO	09v

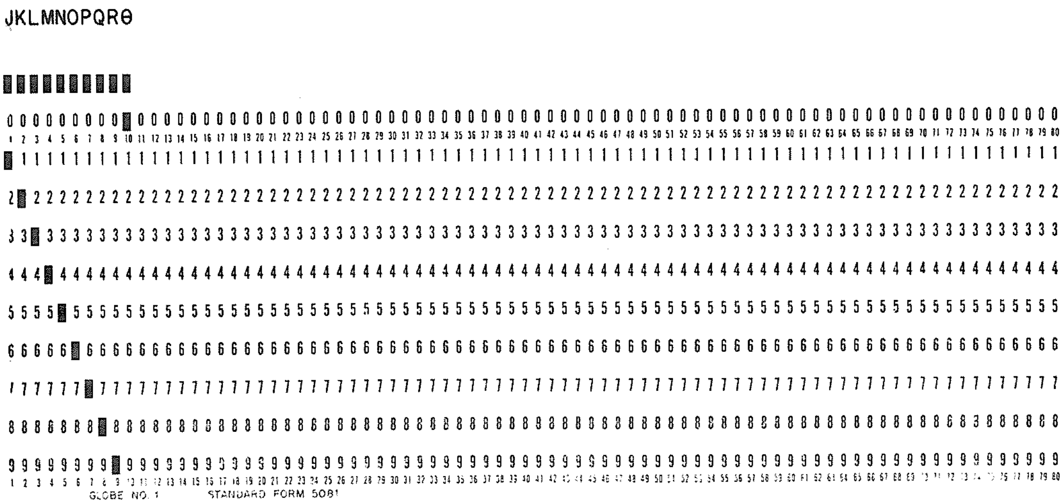


Fig. 7.2 "Eleven punch" for station codes

(c) Date

Columns 6 and 7 identify the year (e.g. 57 implies 1957).
Columns 8 and 9 identify the month (e.g. 09 = September).
Columns 10 and 11 identify

(i) for hourly measurements: the day (e.g. 08 signifies 8th of month).

(ii) for monthly summaries:
40 the median,
50 the median count,
60 the upper quartile,
70 the lower quartile,
80 the quartile range.
77 the upper decile
87 the lower decile

(d) Characteristic

Columns 12 and 13 identify the ionospheric characteristic by using the unified two-digit code given in Table 7.2 in section 7.34. Characteristics normally interchanged are marked with an asterisk.

7.33. Hourly measurements: The ionospheric data for one characteristic for 12 (or 13) hourly observations are punched on a single card. Five columns are devoted to each observation as follows:

(a) Characteristics normally expressed as numerical values

Columns 14, 15, 16 (for example): The numerical value. This is always punched with three digits in the following way:

a 7.9	value of	foF2	is punched as 079,
a 3.5	value of	foF1	is punched as 350,
a 2.45	value of	foE	is punched as 245,
a 9.4	value of	foEs	is punched as 094,
a 3.7	value of	fbEs	is punched as 037,
a 2.6	value of	fmin	is punched as 026,
a 2.95	value of	M(3000)F2	is punched as 295,
a 245	value of	h'F	is punched as 245,
a 97	value of	h'Es	is punched as 097,
27.6	value of	MUF(3000)F2	is punched as 276.

Column 17 (for example): Qualifying letter.
Column 18 (for example): Descriptive letter.

Further groups of five columns are used in the same way.

(b) Type of Es

To accommodate the standard 5-column allotment to each hourly observation, Es types are punched in the following way:

Column 14 (for example): First tabulated type.
Column 15 Number of Es traces of type punched in preceding column (maximum of 9 traces permitted).
Columns 16, 17 (for example): Type and number of traces for second tabulated type.
Column 18 (for example): Type (only) for third tabulated type.

Nothing is punched for vacant spaces on the tabulation sheets.

7.34 Code of characteristics: It is essential that all groups use the same characteristic code for key punching ionospheric data. The standard characteristic code assignments of Table 7.2 was adopted internationally in January 1970, for punch card columns 12 and 13.

Table 7.2

Codes of Characteristics, Card Columns 12 and 13

Characteristics normally interchanged are marked with an asterisk (*).

CHARACTERISTIC CODES USED FOR IONOSPHERIC MEASUREMENTS Jan. 1970											
		FREQUENCIES			PARAMETERS			HEIGHTS			
CARD COL 13 / CARD COL 12 / LAYER		0	1	2	3	4	5	6	7	8	9
F2	0	00 foF2*	01 fxF2	02 fzF2	03 M(3000)F2*	04 h'F2*	05 hpF2	06 h'Ox	07 MUF(3000)F2	08 hc	09 qc
F1	1	10 foF1*	11 fxF1		13 M(3000)F1*	14 h'F1		16 h'F*	17 MUF(3000)F1		
E	2	20 foE*		22 foE2		24 h'E*		26 h'E2			
Es	3	30 foEs*	31 fxEs	32 fbEs*	33 fEs	34 h'Es*		36 Type Es*			
Other	4	40 foF1.5		42 fmin*	43 M(3000)F1.5	44 h'F1.5			47 fm2	48 hm	49 fm3
Spread F and Oblique	5	50 foI	51 fxI*	52 fmI	53 M(3000)I	54 h'I			57 dfS		
N(h)	6	60 fh'F2	61 fh'F		63 h'mF1	64 h1	65 h2	66 h3	67 h4	68 h5	69 H
T.E.C.	7	70 I(2000)	71 I	72 I(xxxx)							79 T

The table lists characteristics that should be exchanged internationally by all stations, with the addition of some characteristics regularly measured at some stations for voluntary interchange by special arrangement. In a few cases, an arbitrary code assignment was adopted, but, in general, the WWSC system has been followed.

This table differs slightly from that given in the first edition. The following changes and additions have been adopted: Card column 12 (Layer identification), index 5 was originally reserved for solar indices, but has not been used for this purpose since an independent solar code has been developed. Therefore, index 5 in column 12 was adopted for parameters associated with spread F and oblique reflections. Index 6 is adopted for electron density profile parameters and index 7 for total electron content parameters.

02 fzF2 (new)

07 MUF(3000)F2 (change of code number)

17 MUF(3000)F1 (change of code number)

26 h'E2 (new)

44 h'F1.5 (new)

47 fm2 (minimum frequency of second order trace) (new)

49 fm3 (minimum frequency of third order trace if required) (new)

50 Reserved for foI if required

51 fxI (new standard parameter)

52 fmI, lowest frequency of spread (in use at some stations only) (new)

53 M(3000)I, factor deduced from upper frequency edge of spread traces and fxI (in use at some stations on experimental basis only) (new)

54 h'I, minimum slant range of spread (in use at some stations only) (new)

70 I_{2000} or I(2000) Definition: Ionospheric electron content up to 2000 km (for a geostationary satellite measured by Faraday technique).

71 I Definition: Total electron content up to a geostationary satellite.

72 I_{xxxx} or I(xxxx) Definition: Ionospheric electron content up to satellite height xxxx for nongeostationary satellites.

The following allocations have been requested to facilitate interchange of electron density profile data. They will be reviewed in the future to see whether they have been used in practice, and may be changed.

Additional parameters needed to enable profiles to be calculated using conventional parameters (e.g., foF2, M(3000)F2, h'F2, foF1, M(3000)F1, h'F, foE, h'E, fmin).

60	fh'F2	Definition:	The frequency at which h'F2 is measured.
61	fh'F	Definition:	The frequency at which h'F is measured.
63	h'mF1	Definition:	The maximum virtual height in the o-mode F1 cusp. (i.e., the value of h' at foF1).

Profile characteristics calculated using Titheridge's method (Chapter 10).

48	hm	Definition:	The height of maximum density of the F2 layer calculated by Titheridge's method.
79	T	Definition:	The total sub-peak content calculated by Titheridge's method.
69	H	Definition:	The effective scale height at hmF2 calculated by Titheridge's method (H is similar to qc physically but liable to greater experimental errors).

64 h1 65 h2 66 h3 67 h4 68 h5	Definition:	True heights calculated by Titheridge's method at the sampling frequencies f1, f2, f3, f4, f5. Note: At night h1 represents f1.

Among the recent additions only fxI (51) is now recommended for general use, but data available for other additions should conform to the recommended code when punched.

The following definitions are generally accepted but have not been standardized internationally. It should be noted that such local conventions may change with development and research.

x- and z-mode characteristics: For extraordinary-wave mode or z-wave mode (columns 1 and 3 Table 7.2), follow the corresponding definitions for o-wave mode characteristics.

44 h'F1.5 This is defined to be analogous to h'F2.

05 hpF2 This code may also be used for parameters analogous to hpF2 where this parameter is not measured at the station, e.g., hmF2 deduced by curve fitting without correction for underlying ionization, but a note showing the exact parameter used must be included with the cards.

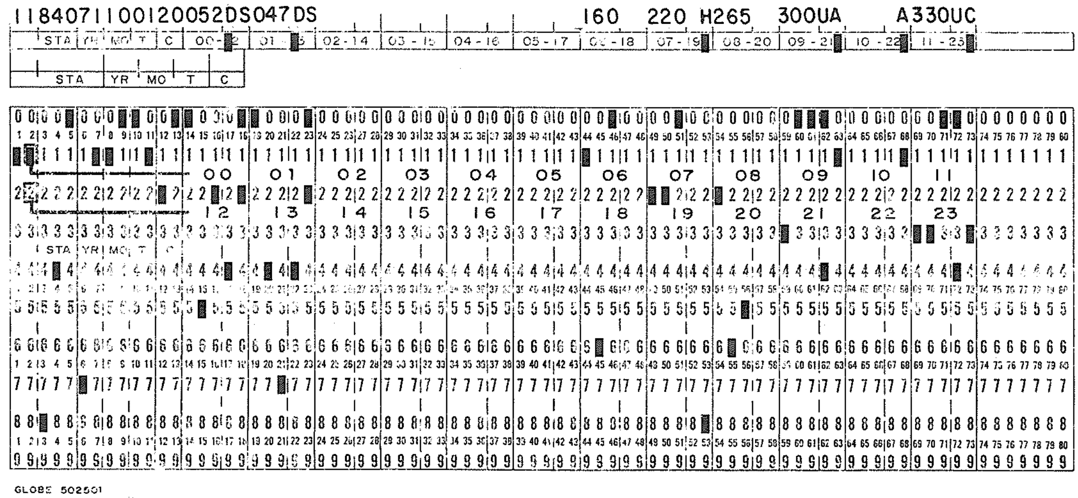
06 h'Ox Height of extraordinary-wave trace at frequency equal to foF2.

57 dfS Frequency range of spread. This is normally equivalent to fxI-foF2, but can denote total frequency range of spread when foF2 or fxF2 cannot be identified, e.g., for equatorial scatter, when dfS = fxI - fmI may be used.

Note: The URSI/STP Vertical Incidence consultant or members of the INAG should be consulted when preparing local conventions for regional use to insure that scaling and reduction personnel receive instructions consistent in form with those of standard characteristics included in the current international exchange program.

Some typical ionospheric data punched cards are shown in Fig. 7.3, 7.4, 7.5 and 7.6. The interpretation of the punched codes and data is printed at the top of each card and in the figure caption.

(a)



(b)

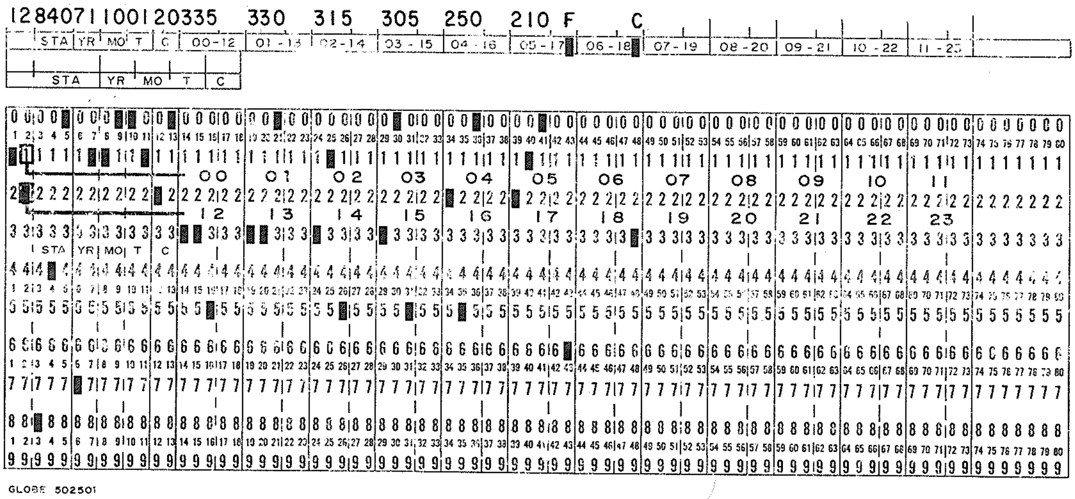


Fig. 7.3(a)(b) Punched cards for hourly values of foE, for station 840 (Boulder), for October 1, 1971, (a) for hours 00-11, and (b) for hours 12 to 23.

(a)

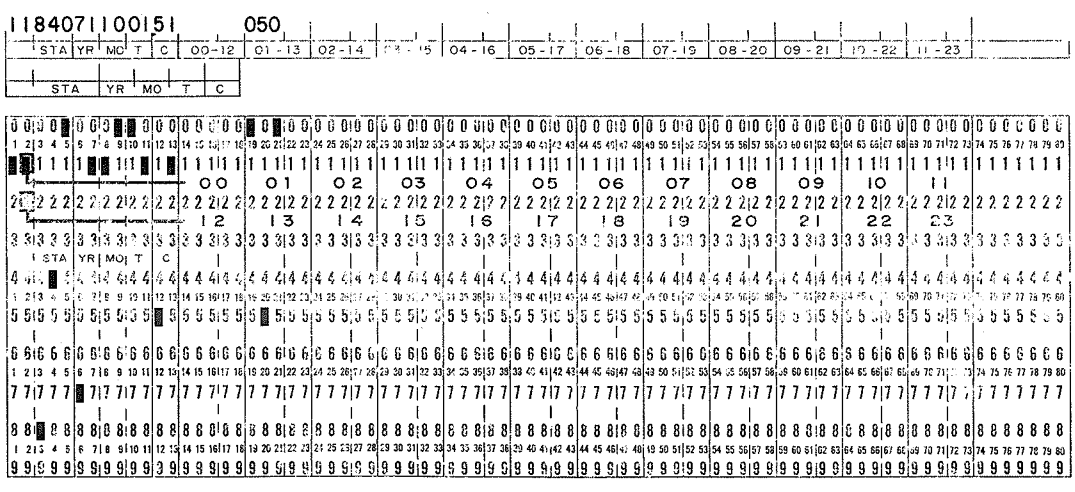


Fig. 7.4(a) Punched card for hourly values of fxI, for station 840 (Boulder), for October 1, 1971 for hours 00 to 11.

(b)

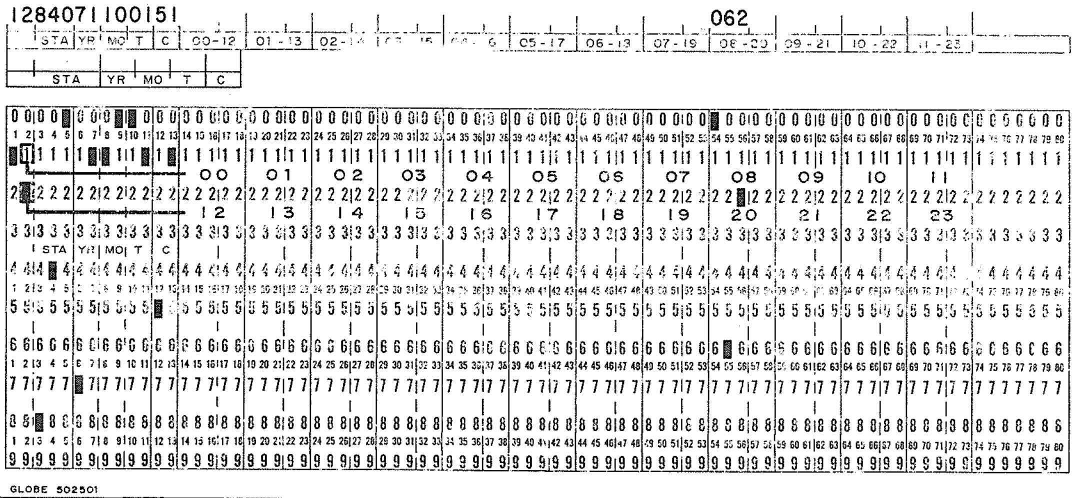
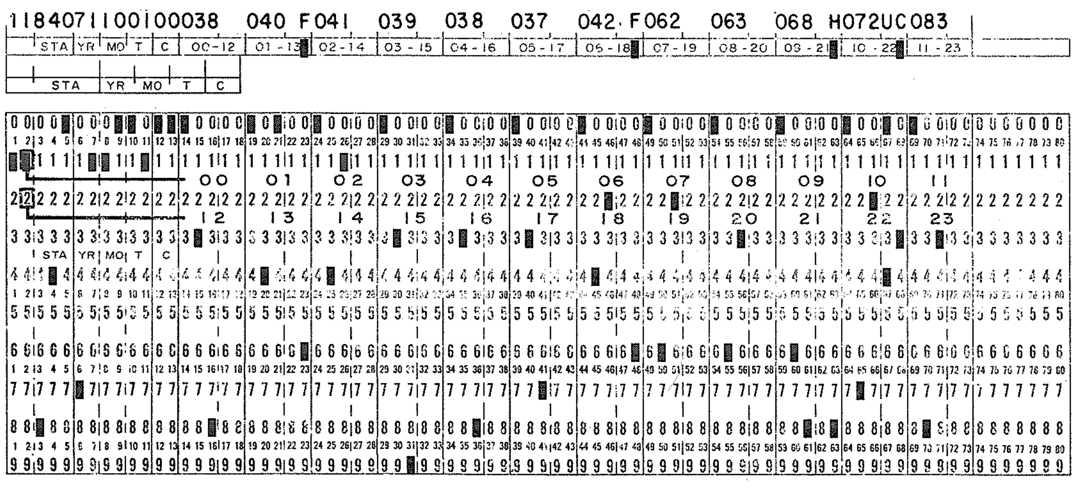


Fig. 7.4(b) Punched card for hourly values of fxI, for station 840 (Boulder), for October 1, 1971 for hours 12 to 23.

(a)



(b)

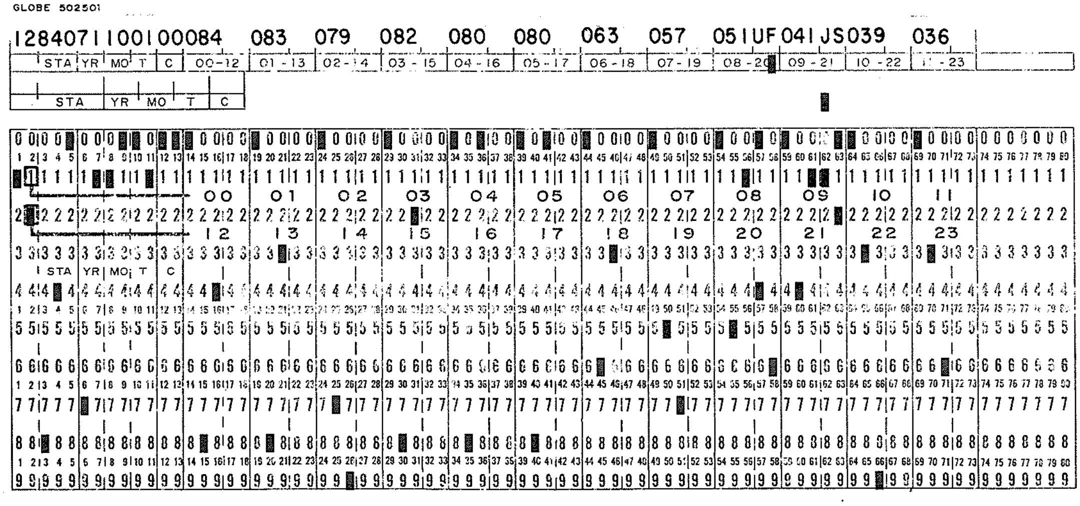
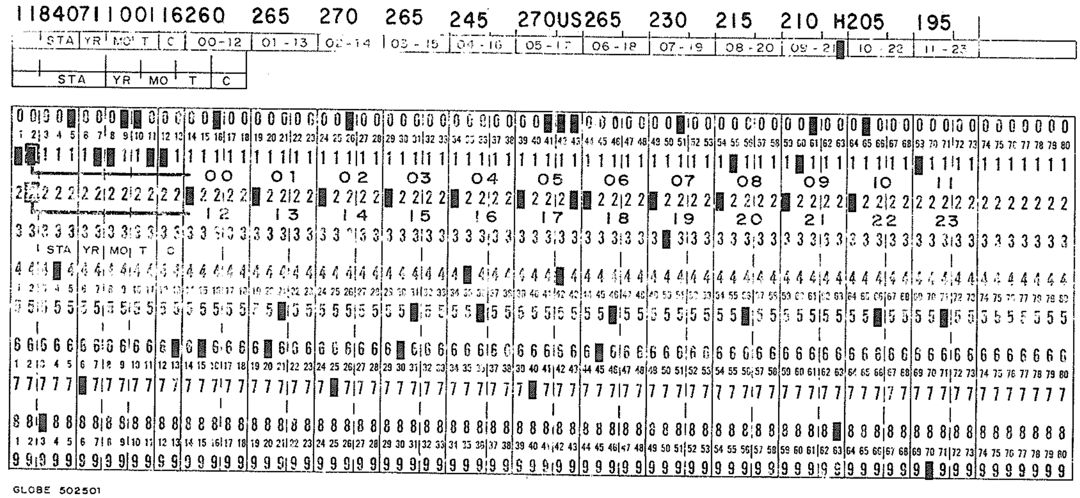


Fig. 7.5(a)(b) Punched cards for hourly values of foF2, for station 840 (Boulder), for October 1, 1971, (a) for hours 00 to 11, and (b) for hours 12 to 23.

(a)



(b)

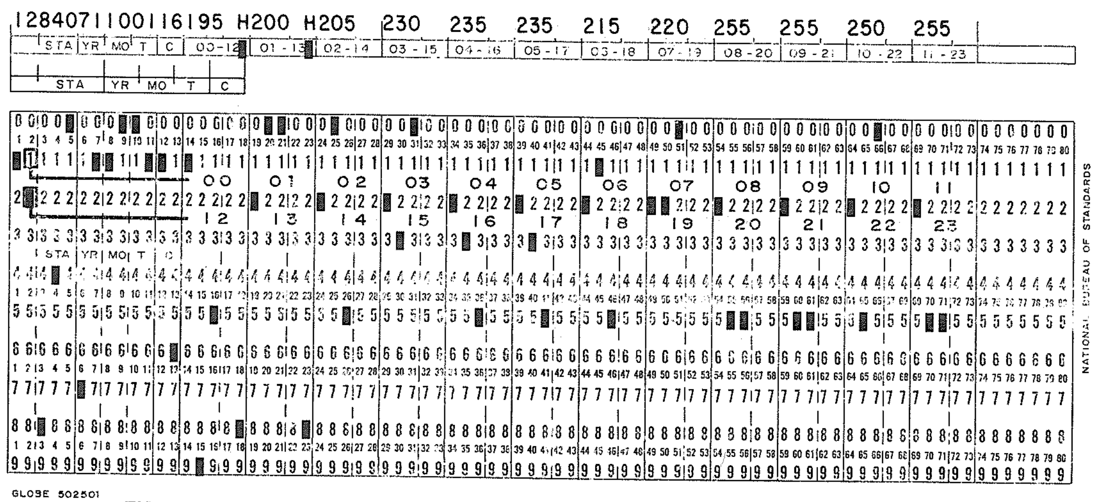


Fig. 7.6(a)(b) Punched cards for hourly values of h'F, for station 840 (Boulder), for October 1, 1971, (a) for hours 00 to 11, and (b) for hours 12 to 23.

NOTES

8 MONTHLY TABLES OF DATA, MEDIANS AND QUARTILES

8.0 General

Normally, stations prepare the day-by-hour tabulations for all the characteristics routinely scaled using the original daily tabulation sheets. In many cases this is done mechanically, e.g., using punched cards prepared from these work sheets and a special computer program.

The conventions summarized in section 8.2 and in Table 8.1 are designed to allow all data to be put on punched cards which is now general practice. These conventions also apply to median values.

The rules concerning the computation of the median and quartile values are given in section 8.3 (Median) and 8.4 (Quartile Values). The same rules and conventions apply to decile values, when computed.

All data must be in exactly the same form before key punching and it is therefore essential that:

(a) three integers be used for all numerical values,
(b) qualifying and descriptive letters are always placed after the numerical values and in the correct order with the qualifying letter first,
(c) decimal points are not used.

Conventions used to record numerical values directly on magnetic tape from modern digital ionosondes (see section 11.4) should be made as consistent as possible with the standard punched card system.

8.1 Identifying Information

All necessary identifying information, such as station name, location, time zone, month, year, characteristic measured, and units used must be entered in the appropriate places on the form.

8.2 Numerical Values and Letters

Numerical values and letters should be entered on the tabulation sheet as indicated in the examples in Table 8.1 below (which have been chosen arbitrarily to illustrate typical cases).

Note: Qualifying letters are entered in the first letter column and descriptive letters in the second. The examples assume that the normal accuracy rules (sections 2.1, 2.2) apply at the station. Otherwise the uncertainty limits are increased as shown in section 2.22 (see Note).

The standard manual tabulation is given in column 2 of Table 8.1, and will be reproduced in the same form unless a special computer program is used. It is usually more convenient to tabulate the data in the form shown in column 3 when computers are used, so that the program is arranged to give the data in this form.

Table 8.1

Characteristic	Manual format	Computer format	Meaning and accuracy (see section 2.22)
foF2	096	096	Reliable value, uncertainty less than ± 2% or ± Δ, whichever is greater.
	096-F	F 096	Spread near the high frequency end of F trace; uncertainty of value less than ± 2% or ± Δ, whichever is greater.
	096UF	U F 096	Spread at high frequency end of F trace; uncertainty in value between limits (± 2% or ± Δ) and (± 5% or ± 2Δ).
	F	F	Severe spread; uncertainty of value exceeds 10% or 3Δ from boundary of possible values.
	071TN	T N 071	Actual observations could not be interpreted (because of transient phenomena, e.g., oblique reflections, traveling waves, etc.); value obtained from smoothing on the f plot.
	071TT	T T 071	Actual observations not representative of value for hour, tabulated value obtained by smoothing on the f plot. (Used for transient phenomena when hourly value alone is perturbed).

Table 8.1 (continued)

Characteristic	Manual format	Computer format	Meaning and accuracy (see section 2.22)
foF2	062EG	E G 062	Measurement on F2 trace impossible because foF1 was greater than foF2 (foF1 = 6.2 MHz).
foF1	460IC	I C 460	Measurement unsuccessful because of equipment failure; value has been obtained by interpolation in time.
	520-L	L 520	No definite cusp present, but uncertainty of value considered to be less than ± 2% or ± Δ, whichever is greater.
fxI	060	060	Top frequency fxI reliable.
	060OB	O B 060	fxI deduced from ordinary wave value, absorption too high for x mode to be seen.
	060DC	D C 060	Instrumental fault, fxI definitely greater than top frequency seen.
	030-X	X 030	No spread present, fxI = fxF2.
foEs	066	066	Accurate value, read from the o trace.
	072-X	X 072	Top frequency identified as corresponding to the x trace.
	072-M	M 072	Top frequency, identification with that of the o or x trace unknown.
	066JX	J X 066	Observed top frequency interpreted to be fxEs, numerical value has been obtained by subtracting 1/2 fB from observed value.
	041EG	E G 041	No Es present, foEs equal to or less than foE (foE = 4.1 MHz).
	025-G	G 025	Low Es present, foEs less than foE.
fbEs	050	050	Accurate value of fbEs.
	041EG	E G 041	No Es present, fbEs equal to or less than foE (foE = 4.1 MHz).
	023-G	G 023	Low Es present, fbEs less than foE
foE	310DR	D R 310	Deviative absorption was so important that only a lower limit could be given; the true value is higher by less than 20% or 5Δ, whichever is the greater.
	325-H	H 325	E trace showed stratification near the critical frequency.
fmin	016ES	E S 016	Interference prevented an accurate observation being made; the true value must be smaller but the error is unknown.
h'F	275EA	E A 275	Blanketing of the low frequency end of the F trace was such that only a limiting value could be given; the true value must be smaller but the error is unknown.
	250UB	U B 250	Absorption was so high that the low frequency end of the F trace could not be observed; a doubtful value has been obtained by extrapolation, the probable error does not exceed 5% or 2Δ, whichever is the greater.

Table 8.1 (continued)

Characteristic	Manual format	Computer format	Meaning and accuracy (see section 2.22)
h'E	107	107	Reliable, accurate value.
	095UC	U C 095	Measurement uncertain because of a non-ionospheric cause (e.g., failure of height markers), the probable error does not exceed 5% or 2Δ, whichever is the greater.
M(3000)F2	325UH	U H 325	Stratification influenced the measurement so that the recorded value is unreliable; the probable error does not exceed 5% or 2Δ.
	W	W	Point of tangency with the trace was outside the height range of the ionogram.
Es types	c3h1ℓ	C3H1L	Cusp Es with three traces, one high Es, low Es also present.
	r1k1	R1K1	Retardation Es with one trace. Group retardation in F trace shows night E present. (Local rule allows r1KO R1KO for this case).
	k3	K3	Night E with three traces. (Note lower case letters are not available on the computer).

8.3 Median and Quartile Values

8.31. Choice of average: It is desirable that the hourly average value of any parameter given for each month should be representative in the sense of being both typical and near the most probable value. This causes serious difficulties in practice since the distribution of values is nearly always skew. Variable numbers of values are usually found which are greatly displaced from the most probable average value, and often it is only possible to give an upper or a lower limit for a particular observation. For these reasons the median is usually more representative of average conditions than the mean. It has, therefore, been adopted as the standard measure of average value to be used internationally.

For the same reasons, the quartile values and the quartile range are adopted to show the variability of the data at each hour.

The significance of an average value always depends on the shape of the distribution of the original individual values. For the skew distributions usually found with ionospheric parameters, reliability of the average decreases rapidly when the number of observations is small. Thus it is important, whenever possible, to avoid omitting values when computing a median or quartile. The conventions given below give the simplest procedure for calculating representative medians and quartiles which is consistent with these principles. They also avoid the difficulty that the median can be completely indeterminate when limit values are present. When the distribution is badly defined, the mean and median values are often non-representative in that small chance fluctuations in the number of observations used could change the numerical value considerably. In these cases the procedure which gives the largest number of countable values is likely to give the most representative value.

8.32. Definitions: The median, quartiles and median count may be defined as follows:

(a) The median of a set of numbers is the middle value when the numbers are arranged in order of magnitude, or the average of the two middle values if there is an even number of values.

(b) The upper quartile is the median value of the upper half of the values when they are ranked according to magnitude; the lower quartile is the median of the lower half.

(c) The quartile range is the difference between the upper and lower quartile values.

(d) The median count is the number of values from which a median has been computed. In addition to numerical values, the count may include certain descriptive letters.

8.33. Conventions for determining the median count: The median 'count' is the number of values used to determine the median. These include all numerical values and 'less than' and 'greater than' values and, in addition, certain descriptive letters which have the force of 'less than' or 'greater than' values.

Note: Giving the limit values in full, xxxEE, xxxEG, xxxDD, etc., simplifies the calculation of the median.

The following conventions are used to include non-numerical values in the median count:

(a) Always omit from the median count values of any ionospheric characteristic replaced by A, C, F, H, L, N, R, S, Y. (These letters are found in the column for descriptive letters.)

(b) Values of parameters replaced by the following letters are treated as shown below:

A - For fbEs, count as greater than the median. (Now obsolete, use new rules in sections 3.1, 3.2 and 4.6 to give a numerical value).

B - For fmin, count as greater than the median.

Note: B is often used when fmin is greater than the normal value of the characteristic. In this case it does not contribute to the median. The logical form (fmin)EB adds little or no real information and involves proceeding to a second median. For foEs, fbEs the full form, (fmin)EB, should be used when (fmin) is numerical and determines these characteristics.

D - For frequency characteristics, count as greater than the upper frequency limit of the ionosonde.

E - For frequency characteristics, count as less than the lower frequency limit of the ionosonde.

E - For values of minimum virtual heights (except h'Es) replaced by E, count as equal to or greater than the median.

G - For foF2, count as equal to or less than the value of foF1.

G - For foEs and fbEs, count as equal to or less than median foE. When foEs or fbEs are less than foE, which may occur when low type Es is the dominant Es type, the numerical values are described by G and treated as equal to or less than foE.

G - For M(3000) and MUF(3000), count as equal to or less than the median.

G - For h'F2, hmF2, hpF2, hc, qc, count as equal to or greater than the median.

W - For all height characteristics, count as equal to or greater than the median.

W - For M(3000) or MUF(3000) count as equal to or less than the median.

8.34. Conventions for the evaluation of medians: The median is the middle value of the group of measurements to be summarized, the values having first been ranked according to their magnitude. If the number of values is odd, the median will be uniquely determined, e.g., the 16th of 31 values. If there is an even number of values, the median is taken as the average of the two middle values, e.g., average of 15th and 16th of 30 values, (see section 8.6). This average may or may not be integral in the smallest unit of measurement. If it is not, the result is rounded off to the nearest even value of the smallest unit of measurement, e.g., 6.55 MHz rounds to 6.6 MHz, 6.45 MHz rounds to 6.4 MHz.

Special consideration is needed when a median falls on a limit value, D or E. In general the distribution clusters around the median value so that the representative median is unlikely to be as far displaced from the numerical value as would be allowed by the limit rules. In these cases the accident that a limit value is found is likely to weaken the value of the median disproportionately. This does not hold when the next numerical non-limit value is outside the accuracy limit. A simple compromise is required which will usually give an acceptable result. This is given in the rules below. For quartiles more weight is put on obtaining a non-limit value and the rules are simplified.

The first trial median is determined ignoring all qualifying letters.

(i) If more than half the values are qualified by D, the median is the first trial median qualified by D.

(ii) If more than half the values are qualified by E, the median is the first trial median qualified by E.

(iii) If more than half the values are replaced by D, the median is D.

(iv) If more than half the values are replaced by E, the median is E.

(v) If exactly half the values are qualified by D and these are all above the median, the median is the top unqualified number qualified by D.

(vi) If exactly half the values are qualified by E and these are all below the median, the median is the lowest unqualified value qualified by E.

(vii) If the median is the average of a value qualified by D or E, and an unqualified value the median is the average value (rounded if necessary) qualified by D or E as appropriate. If the next nearest unqualified value is within the accuracy limit of the median value, the qualification is omitted. U values are treated as accurate for this purpose.

(viii) If all the values qualified by D are above or equal to the first trial median and all the values qualified by E are below or equal to the first trial median, the first trial median is the median.

(ix) If any of the values qualified by D are below the first trial median or any of the values qualified by E above, it is necessary to proceed to a second trial median (see below). This includes cases with exactly half the values qualified by D or E, not all above or below the median respectively. The second trial median is determined taking all those values qualified by D as large values (greater than the median) and all those values qualified by E as small values (less than the median).

(x) If the first and second trial medians are the same, this is the final median and is given without qualification (unless more than half the values in the count are qualified by letters which carry the connotation of doubt (section 8.35) (I, T, U, Z) in which case the median is qualified by U). Note that rounding changes are not to be taken as significant here.

(xi) Otherwise, if the first and second trial medians are numerical, their average is taken as the median and is qualified, where necessary, using the rules given in section 8.35.

(xii) If one trial median coincides with a limit value, it is replaced by D or E. The rules are as shown in the following examples:

For frequency characteristics:

032 and E gives 032EE
042 and G gives 042EG (for foF2, foEs, fbEs only)
174 and D gives 174DD
042 and B gives 042DB (for fmin only)

For height characteristics (with the exception of h'Es):

225 and E gives 225DE
240 and G gives 240DG
380 and W gives 380DW

For MUF factors:

295 and G gives 295EG
270 and W gives 270EW

(xiii) No median can be given if both trial medians are replaced by different letters.

Note: Except for hours when a characteristic is outside the limit frequencies of the ionogram, it is unusual for D or E to be used for median values. (The main exceptions are the Es characteristics and fmin limited by interference.) Thus, if these rules are often needed, it is worth checking to make sure that D or E have been used correctly and that the ionosonde is set up correctly.

8.35. Reliability of a median: The most important indication of the reliability of a median is the median count. Medians are determined in all cases regardless of the number of observations. The median count is tabulated with each median value.

If more than half of the individual values are qualified by a certain letter, the median is also qualified by this letter. The same applies for descriptive letters.

If no one qualifying letter applies to more than half the values in the count, but more than half of these values are qualified by letters which carry the connotation of doubt (I, T, U, Z), then the median should be qualified by letter U, and described by the descriptive letter most frequently used for the doubtful value.

If the first and second trial medians differ by more than twice the uncertainty allowed by the accuracy rules (section 2.2) the average of the first and second medians is uncertain and must be qualified by letter U. This is the only case where the qualifying letter U can be used without a descriptive letter. It is preferable not to show a descriptive letter in this case as the main cause of doubt is the large difference between trial medians.

Note: This limit difference is usually 10% or 4Δ, whichever is the greater.

8.36. Procedure: The procedure for calculating medians is summarized below:

(i) Omit from median count values of any ionospheric characteristic replaced by A, C, F, H, L, N, R, S, V and Y.

(ii) Values replaced by A (old convention only), B, D, E, G and W count as an equivalent numerical value where specified in section 8.33.

(iii) Arrange all numerical values in order of magnitude omitting all descriptive letters except G, but include

(a) the qualifying letters D or E with those values so qualified

(b) letters where appropriate for the characteristic being evaluated in accordance with their value as given in section 8.33.

(iv) The first trial median is determined ignoring the qualifying letters.

(v) If qualification is necessary, apply the rules of section 8.34(i) through (vii). The appropriate descriptive letter should be added in this case.

(vi) If all the values qualified by D are above (or equal to) the first trial median and all the values qualified by E are below (or equal to) the first trial median, the first trial median is the final median.

(vii) If any values qualified by D appear below the first trial median and/or values qualified by E appear above the first trial median, it is necessary to produce a second trial median.

(viii) Proceed as follows: move all E values to the bottom of the order and all D values to the top and take the second trial median.

(ix) The final median is the average of the first and second trial medians. (If the average is not a multiple of the unit of measurement round to nearest even unit of measurement.)

(x) If the second trial median differs from the first trial median by more than 10% or 4Δ, whichever is the greater, then the final median must be qualified by U with no descriptive letter.

(xi) Check the original column of values on 'Hourly values' sheet; if more than half the values in the count carry a descriptive letter the median must be described by a descriptive letter. If one descriptive letter dominates, then this letter should be used; if not, use letter N as the descriptive letter.

(xii) Check the original column of values on 'Hourly values' sheet; if more than half the values in the count carry qualifying letters, U, I or T only, then the median must be qualified by U. (D, E and J are not included in determining whether the median should be qualified).

Note: A median value with letter U but without a descriptive letter can only be used when the median is inaccurate due to a large difference between the 1st and 2nd trial median.

8.37. Use of a computer for determining medians: The complex rules given in sections 8.33 - 8.35, the procedures for calculating trial medians and choice of appropriate letter symbols can be programmed for computation by a computer. Many groups operate such programs, which greatly reduce the labor of calculating medians. The details vary with the type of computer available, though essentially the same flow diagram is used by all groups. In practice the accuracy of computer derived medians is greater than those calculated manually as fewer errors can occur. Those wishing to derive medians by computer are advised to ask for help from a group already operating a similar type of computer, if necessary through INAG. An example of a typical program (with IGY rules) has been given by L. Bossy in the IQSY Instruction Manual (London 1963), reprinted in Annals of the International Quiet Sun Years, Vol. 1 (M.I.T. Press, Cambridge, Mass. 1968)

8.4 Quartile Values

The upper quartile is the median value of the upper half of the values when they are ranked according to magnitude; the lower quartile is the median of the lower half. Note that all numerical values should be used without regard to qualifying letter in the determination of quartile values, in the same fashion as in the determination of the trial median.

The exact rule to be followed is: Regardless of whether the 'median count' consists of 2n (even count) or 2n + 1 (odd count) values, the lower quartile shall be the median of the n smallest values and the upper quartile shall be the median of the n greatest values when arranged for finding the first trial median.

Rounding-off of quartile values follows the same conventions as for medians.

If the quartile value is the average of two values one of which is qualified by D or E, the quartile should not be qualified. If the quartile value is the average of two values, both qualified by the same letter D or E, the quartile should be qualified by D or E as appropriate.

For a quartile value which is the average of two values, one qualified by D and the other by E the quartile should not be qualified.

Note: (i) It is possible for the upper quartile to be below the final median or lower quartile above it when the first and second trial medians are different.

(ii) Quartiles are unqualified unless they are limit values qualified by D or E as above.

(iii) Quartile values may only carry letters D or E. These should only be used if the quartile value is itself qualified by D or E or the quartile value is the average of two values both qualified by D or both qualified by E.

(iv) Quartile values are always obtained when finding the first trial median.

8.5 Quartile Range

The quartile range is the difference between the upper and lower quartile values. If an upper quartile should fall on a 'greater than' value or a lower quartile on a 'less than' value, the quartile range will be 'greater than' the difference computed.

A special difficulty can arise when the upper quartile for fmin is given by replacement letter B. In this case the best procedure is to take the upper quartile as the highest value of fmin for the hour, xxx, qualified by DB: xxxDB. The quartile range will then be qualified by D. A simpler alternative is to replace the quartile range by B. This gives no numerical data for a time when the range in fmin is abnormally great.

(a) The qualifying letter D or E needed in the Quartile range when the Quartiles are qualified is determined as follows:

Upper Quartile	Lower Quartile	Quartile Range
D	E	D
D	-	D
D	D	U
E	E	U
E	D	E
E	-	E
-	D	E
-	E	D

(b) Values of parameters replaced by the following letters count as shown:

A - For fbEs, count as greater than the median (old convention)

B - For fmin, count as greater than the median

D - For all frequency parameters, count as greater than the upper limit of the ionosonde

E - For all frequency parameters, count as less than the lower frequency limit of the ionosonde

E - Values of minimum virtual heights, except h'Es, count as equal to or greater than the median

E - For h'Es, is omitted

G - For foF2, count as equal to or less than the value of foF1

G - For foEs and fbEs, count as equal to or less than the value of foE

G - For height parameters, h'F2, hmF2, hc, qc, count as equal to or greater than the median

G - For MUF factors or MUF's, M(3000), MUF(3000), count as equal to or less than the median

W - Rules as for G, except that W does not refer to Es characteristics.

8.6 Location Table

The following table has been prepared on the basis of these rules to indicate which values are used for the median and quartiles for every possible median count.

It is assumed that the data are ranked according to magnitude. The count is the number of values from which the median is found. To obtain the median, count from either end to the middle value(s) shown. ('Less than' or 'greater than' values must be treated as described in section 8.33.)

Examples:

(i) With a count of 13, the median is the 7th value from either end.

(ii) With a count of 22, the median is the average of the 11th and 12th values from either end.

(iii) With a count of 31, the lower quartile is the 8th value from the 'low' end; the upper quartile is the 24th value from the 'low' end. The counts are reversed when starting from the 'high' end.

(iv) For a count of 29 values, the quartiles will be the average of the 7th and 8th, and the 22nd and 23rd values from either end.

Table 8.2

Showing Location in the Count
on the Upper and Lower Quartiles and Median

Count	Lower Quartile	Median	Upper Quartile	Count	Lower Quartile	Median	Upper Quartile
1	-	1	-	17	4/5	9	13/14
2	-	1/2	-	18	5	9/10	14
3	1/2	2	2/3	19	5	10	15
4	1/2	2/3	3/4	20	5/6	10/11	15/16
5	1/2	3	4/5	21	5/6	11	16/17
6	2	3/4	5	22	6	11/12	17
7	2	4	6	23	6	12	18
8	2/3	4/5	6/7	24	6/7	12/13	18/19
9	2/3	5	7/8	25	6/7	13	19/20
10	3	5/6	8	26	7	13/14	20
11	3	6	9	27	7	14	21
12	3/4	6/7	9/10	28	7/8	14/15	21/22
13	3/4	7	10/11	29	7/8	15	22/23
14	4	7/8	11	30	8	15/16	23
15	4	8	12	31	8	16	24
16	4/5	8/9	12/13				

Note: 1/2, for example, means the average of values 1 and 2.

NOTES

9.0 Introduction

Progress in understanding the many geographical and time complexities of the behavior of the ionosphere has been a practical possibility only because data from far flung stations have been brought together and analyzed jointly. In the early days of ionospheric studies this could be done through normal correspondence among workers in the field. As activity in scientific and practical studies increased, there was a natural evolution to coordination through international scientific and technical bodies and an evolution to more organized data exchange through data centers. For ionospheric vertical soundings this has been an important and useful development for another reason, since these data are more and more used as aids in interpreting satellite, rocket and specialized ground-based surveys and experiments, in addition to their use by themselves. For example, rocket sensors can give very detailed data about the physics or chemistry of the atmosphere at ionospheric height, but only at a particular time. Ionospheric phenomena are essentially dynamic so it is necessary to know whether conditions at the time of the rocket experiment were normal or abnormal, representative or peculiar -- questions which can perhaps best be answered from systematic vertical soundings. In fact, because of the immense amount of information available on an ionogram, the technique is of first importance in the study of the high atmosphere. The data obtained show close connections with conditions of the Earth's magnetic field, the airglow and aurora, stratospheric and mesospheric meteorology, particle activity in the magnetosphere and ionosphere, and solar activity. Interdisciplinary as well as international coordination is needed to assure that the necessary data are taken and made available.

The data are often used by scientists who have little expert knowledge of ionospheric phenomena as manifested by vertical soundings. Thus it is most important that the regular data are uniform from all stations.

There has been a long tradition of international cooperation in Geophysics and, in particular, in Ionospherics. This has developed in two parallel forms:

(a) International discussions of scientific problems and their solution, usually with the stress changing rapidly as the subjects develop.

(b) The systematic use of monitoring data so that regional and world studies can be made and so that long period changes in the environment can be measured.

In ionospheric problems the international cooperation has been stimulated and organized by the International Union for Radio Science (U.R.S.I. - Union Radio Scientifique Internationale), Secretary General Dr. C. M. Minnis, URSI, 7 Place Danco, Brussels 18, Belgium. Commission III of URSI is responsible for ionospheric problems.

All synoptic measurements made by radio methods were coordinated by a special URSI/STP Committee up to 1972. This work is now done by Working Groups of the Commissions. In particular the Ionospheric Network Advisory Group, INAG, created by the URSI/STP Committee, becomes Working Group 1 of URSI Commission III.

The steering committee of Working Group I is identical with the old INAG, but the Working Group is enlarged to include Consultants to INAG and representatives of the scientific community. Anyone interest in the operation of the ionospheric vertical incidence network or the data produced by the network is entitled to be a representative and to receive the INAG Bulletin. This is obtained from the Secretary of INAG. Many problems in Geophysics involve the collaboration of workers in different disciplines and thus inter Union collaboration. This collaboration has been nurtured by a series of Special Committees of the International Council of Scientific Unions (ICSU), the body which coordinates the operations of the international scientific community. Such Special Committees are set up, as occasion demands, to plan and encourage international cooperation for major projects involving several disciplines and are dissolved when the projects are completed. A classical example is the Special Committee for the International Geophysical Year (CSAGI) which directed the planning and execution of the International Geophysical Year 1957-1958 (IGY).

In 1967 the collaboration was put on a continuing basis through the formation of the Inter-Union Commission on Solar-Terrestrial Physics (IUCSTP or STP for short). In collaboration with the Scientific Unions, IUCSTP created and dissolved its cooperative projects according to the desires of the scientific community, concentrating on problems which are timely and of wide interest and depend on interdisciplinary cooperation. However, for the long term project of monitoring and data exchange, the formal structure of IUCSTP is, at the time of writing, being changed into that of a Special Committee of ICSU to be known as The Special Committee on Solar-Terrestrial Physics (COMSTEP). A steering committee for MONSEE has been formed under the auspices of COMSTEP. This is responsible for the policy of MONSEE which remains a permanent coordinating organization. Monitoring of the Solar-

Terrestrial Environment, is considered a permanent coordinating organization made up from all groups involved in monitoring solar-terrestrial phenomena. This is known as MONSEE, International MONitoring of the Sun Earth Environment.

Proposals for international projects are coordinated by COMSTEP though in most cases projects involving only one discipline are organized by the appropriate Union. Proposals and program plans are published in STP Notes, URSI Information Bulletin, IAGA News, etc. Those specifically involving the V.I. network are republished in the Bulletin of the Ionospheric Network Advisory Group (INAG) obtainable from Miss J. V. Lincoln, Secretary of INAG, WDC-A for Solar-Terrestrial Physics, NOAA, Boulder, Colorado, 80302, U.S.A. This group now reports to URSI Commission III.

The international programs involving ionospheric vertical soundings fall into three groups:

(i) Standard programs for monitoring the ionosphere

(ii) Special programs to supplement (i) when more detailed or extra data are needed

(iii) Collaborative programs to solve particular problems; these may be local, regional or worldwide. (These include local programs since some worldwide problems can only be solved in particular parts of the world).

The standard programs are reviewed periodically and changed, usually only slightly, to meet changing needs. The current program is given in section 9.2. This should be used unless a later version is available.

The special programs are reviewed annually and are often based on the International Geophysical Calendar (see section 9.31) or the system of Alerts (9.32), or Retrospective Intervals (9.33).

Collaborative programs may be arranged by working groups of URSI Commission III, by COMSTEP project groups or by working groups of other Unions or COSPAR. Regional programs can be arranged and some have been initiated by special recommendation of international symposia. It is, however, most desirable that proposals for such collaboration should be submitted to the appropriate international body; namely, URSI Commission III for collaboration using radio methods only, COMSTEP for interdisciplinary programs, INAG for programs referring only to the ionosonde network. These bodies make sure that the proposals are scientifically justified and that the operational planning is adequate.

9.1 The World Data Center System

It is of no use to have an international program unless the data obtained are made generally available. It is also essential to minimize the cost of circulating the data. Data interchange has been organized internationally so as to maximize the use of the data for the least cost. If the data would be very costly to reproduce and are not widely needed it is sufficient to send lists of the data available to the World Data Centers (see sections 14.8 and 14.9 for fuller details) with a small sample to allow scientists to check that the data would be useful before requesting it. Normally easily analyzed parameters are deduced from the raw data and circulated in the most convenient form. Details are given below. It is a general principle of international interchange that those contributing to the international pool of data are entitled to draw equivalent amounts of data from the pool. This is usually interpreted broadly so that a given organization or nation can receive data in associated fields if preferred.

The World Data Center (WDC) system for international exchange of scientific data in the various disciplines related to geophysics was initiated for the International Geophysical Year Program, 1957-58, in order to carry out the objective of making IGY data readily available to the scientific community. While a unique World Data Center has technical advantages, several parallel centers were, in fact, set up. Some of the main reasons were:

(i) To meet the geographical convenience of, and provide easy communication for, workers in different parts of the world.

(ii) To insure against catastrophic destruction of a single center. The basic collections of data are common to WDC-A, WDC-B and WDC-C1, and C2.

After the IGY the exchange of data through the WDCs continued under the auspices of the International Committee on Geophysics (CIG) and, for the solar-terrestrial disciplines, under the guidance of the IQSY Committee. As of 1967, the responsibility for detailed guidance of international data exchange and the WDCs in the solar-terrestrial disciplines devolved on the Inter-Union Commission on Solar-Terrestrial Physics (IUCSTP). In 1969, IUCSTP authorized its Working Group on Monitoring of the Solar-Terrestrial Environment to establish a permanent panel on STP-WDC operations, which sponsored a first meeting of WDC operators in Moscow in 1971. In October 1968, the International Committee of Scientific Unions (ICSU) created a Panel on World Data Centers which is expected to oversee from a policy standpoint the WDC system in all aspects of geophysics, including solid earth, oceanographic, atmospheric, solar-terrestrial and space sciences.

The original IGY World Data Centers were designated by the international IGY Committee (CSAGI) for each of the 15 IGY disciplines. The centers were selected from nominations made by the participating committees. The U.S. and U.S.S.R. participating committees offered to establish WDCs for each of the disciplines, and these were designated WDC-A and WDC-B, respectively. Other participating committees offered to establish WDCs in one or more individual disciplines. Those located in Western Europe were designated WDC-C1; those in other parts of the world were designated WDC-C2.

Since the IGY, there have been some shifts in the physical location of some WDC discipline centers, the current (1972) list of centers is given in sections 14.8, 14.9 (sources of data). Future changes will be listed in the "Guides for International Exchange of Solar and Geophysical Data".

9.11. Guides for international exchange of Solar and Geophysical Data: The IGY Guide, published in IGY Annals, Vol. 7, collected the recommendations on data exchange of CSAGI (the International IGY Committee) and included the understandings on the conduct of the exchange through the WDCs and the availability of data to the scientific community. The IQSY Committee compiled a revised Guide which was issued in pamphlet form by CIG and was subsequently published in IQSY Annals, Vol. 1. The current STP Guide (S.T.P. Notes. Special Issue No. 6, "Guide for International Exchange of Data in Solar-Terrestrial Physics", October 1969, COMSTEP Secretariat, 2101 Constitution Ave., Washington, D. C., 20418, USA) was compiled under the auspices of the IUCSTP and is modified in line with actual experience in data exchange and the modern needs of the scientific community.

The 1969 Guide is intended to apply for exchange of STP data for the period beginning 1969. The IQSY Guide applied to data for 1960-68, with special provisions for the IQSY observing period 1964-65. The IGY Guide applied to the period of IGY, 1957-58 and for IGC-1959. Each guide lists the understandings concerning data interchange, the current WDC and Permanent Service organization, the programs of observation, the programs of data interchange and give other information useful to those participating in international cooperation. A further revision is expected in 1973.

9.12. Data exchange through STP WDCs: Scientists and institutions of all countries in the world, both members of international scientific unions and other international organizations and non-members as well, can use the facilities of the WDCs.

Participation may be initiated or continued by notifying the IUCSTP Secretariat, stating the kind of data that will be sent to the WDCs; the organization that will be responsible for communication with the centers; and with which centers it will be in close contact. This information is then distributed by the IUCSTP to all interested centers and national committees.

Scientific organizations and individual scientists may order materials from the centers directly or through their national organization responsible for communication with the WDCs. In those cases in which materials are ordered directly, it is desirable for the centers to inform the organization responsible in that country for communication with the WDCs what materials were sent to other organizations in that country. For the purpose of assuring to scientists greater accessibility of materials from the center, it is recommended that materials received from the centers be concentrated in one or in several scientific organizations of the country from which they can be obtained for work by any interested scientist of the country.

WDCs supply copies of the available material to any scientific body or investigator in any country for a cost not to exceed the cost of copying and postage. WDCs also, by appropriate arrangement, enable scientists to work directly with the materials at the Center. To the extent possible, each WDC gives to each contributor a body of data equivalent to that received; this may be from the same or another discipline, depending on availability and need. On request, and when feasible, the WDCs lend their materials to responsible scientific institutions for reasonable periods of time, especially where additional copies exist so that original material is not jeopardized.

9.13. Data transmittal to WDCs: Data are transmitted to WDCs in the forms recommended in the Guide, including tables and drawings on paper, microfilm, photographic film or prints, punched cards, magnetic or punched paper tape, etc. Stations should insure that the material sent to WDCs is self-contained and self-explanatory, in particular clearly identified as to station, date, year, time zone, units used, characteristics of computer format, etc. Particular attention should be given to legibility. Where interchange of data is called for in graphical or tabular form, they may alternatively be sent in equivalent computer form, e.g., as punched cards or (and preferably) punched paper or magnetic tape.

The Guide provides that data and information about data be available to all of the (comprehensive) WDCs for the discipline. Stations should if practical send the data directly to each of the WDCs, making clear in their transmittal note that this has been done. If the data are sent to one of the WDCs only, the transmittal note should clearly indicate this so that the WDC can copy or inform the other WDCs as appropriate.

Data should be sent on the time scale recommended in the Guide or otherwise at convenient intervals. Participants should note that the greatest use of data by the scientific community is for recent periods of time and therefore unnecessary delays should be avoided in the interest of the progress of scientific research; there are obviously reciprocal benefits to those providing data.

9.14. Quality of data: WDCs are not generally responsible for accuracy of data in their possession. However they are encouraged to correspond with those providing data regarding calibrations, operating characteristics of instruments, incompleteness, etc., and to provide information to requestors of data as appropriate. Cooperating stations can assist in making their data as useful as possible in scientific analyses if they will indicate to the WDCs their own assessment of the overall quality of the data provided or indicating the time periods when the data may be compromised and the reasons. Sample reviews of data accuracy are made by the main networks and by members of INAG.

In the case of ionospheric vertical soundings, the URSI-STP Committee has recommended those stations which are prepared to guarantee that international standards of data quality are maintained, should mark their data quality I (for International) and stations using modified international standards (the particular modifications being stated) use the quality symbol I*. A special effort will be made to check samples of such data at random intervals so that the standards are maintained.

9.15. Data in computer-usable form: Requests for data in computer-usable form (magnetic tape, punched paper tape, punched cards) are rapidly increasing and WDCs are encouraged to provide facilities for such data, to reformat as necessary, and to put existing analog data and tables into this form, starting with current data. The users would be assisted if the WDC had facilities to convert such data into a form usable on the computers available to the data users. Similarly contributors of data should use computer-usable forms wherever practical. Considerable difficulty still exist in exchanging computerized data because the formats and codes of different computers are frequently incompatible. Guidance can be obtained through the local WDC.

Stations using computer processing are requested to send details of their program (computer type, special conventions, format) to the WDCs. In many cases this can show that the original tapes can be copied and read, thus eliminating the need to repunch all the data.

9.16. Data in the form of publications: Many useful details or summaries of data appear in publications or "reports" which are given limited distribution or in journals which are not widely available. It is suggested that the WDCs be used as one of the mechanisms for making the existence of such data known and available to users. Two copies of such reports, publications or journal reprints, should be sent to each WDC concerned (or 8 copies to one WDC with request to interchange with the others). This can provide a valuable service to the scientific community even if the type of data and the amount of detail is beyond the minimum recommendations of the Guide. It is particularly of benefit for the smaller groups who often have great difficulty in obtaining even standard scientific periodicals.

9.17. Data catalogs: It has been customary for each of the comprehensive STP WDCs to issue a catalog of their holdings at convenient intervals. Some WDCs publish in quantity a summary or "users" catalog which is sufficient for most purposes; the complete, detailed catalog is then usually available only at the WDC.

The WDC-C1 catalogs for the Ionosphere are available in quantity. A special effort has been made by WDC-A to provide a comprehensive interdisciplinary catalog with much additional information of general value to the stations and to scientists using the data. WDC-B and WDC-C2 also issue catalogs periodically.

9.2 Program of Synoptic Observations

The preferred program of synoptic ionospheric observations is to obtain ionograms every 15 minutes (10 minutes where this is not convenient). This is adequate to enable reasonable interpretation for most of the time in most parts of the world. During eclipses or where rapid changes are occurring in time, e.g., near the auroral zone, more rapid recording is valuable.

For numerical analysis, it is usually only practical to evaluate the observations at hourly intervals and this is the minimum recommended (sections 9.3, 9.4). The reliability of the hourly measurements can be considerably improved by recording three or more successive sweeps of the ionosonde at the hours. It is valuable to record these at different gain levels, the low gain ionogram showing main traces more clearly in the presence of scattered signals, the high gain showing scattered traces and those weakened by absorption more clearly. The sequence can often be used to identify transient distortion of the traces.

Even at stations where the normal ionospheric behavior is regular and changes slowly with time there is an advantage in recording at quarter hours. For these cases, the hourly ionograms are analyzed and the quarter hourly used only for continuity, interpreting transient or difficult cases or for the study of special events, e.g., Retrospective World Intervals. The additional cost of the recording is usually recovered in saving of analysis time and reliability. Without some redundancy it is often not possible to distinguish between alternative interpretations and this causes the standard of reduction to fall. At high latitudes, or wherever the ionosphere changes rapidly with time, the minimum recommended program is quarter hourly plus the additional gain changed recordings at the hour.

Stations operating continuous monitoring of the ionospheric parameters (section 11.3) should tabulate the characteristics monitored (usually h', fE, fF, MUF) at least according to the minimum recommended schedule and produce normal ionograms at hourly intervals. It is particularly important that representative ionograms be produced from ionosondes using new techniques so that any differences in the data due to the technique can be studied and recognized (e.g., Chirp or Digital Ionosondes).

9.3 Periods Selected for Special Study

"World Days" appear on the International Geophysical Calendar issued annually by the International Ursigram and World Days Service (IUWDS) and distributed and published widely; copies are available at WDCs. There are also different types of special periods of unusual activity forecast or announced by the World Alert system operated by the IUWDS (see section 9.32). For the IQSY onwards, periods of special interest have been selected "after the fact". These Retrospective World Intervals are chosen by the MONSEE organization in consultation with other international groups and are usually announced in circular letters and in publications like STP Notes or INAG Bulletin. Similarly, the leaders of certain URSI and IUCSTP projects may select events or periods for special study, and the project may involve sharing of data through the WDCs or among the participants. In all these cases the purpose of the selected periods is to provide for interchange of more data or more detailed data than usual, or for speedier interchange than usual, or for involving additional observing stations which do not interchange their data systematically. In many cases, special publication or symposia are organized on the geophysical phenomena occurring in these intervals. Participants in the data interchange program should be alert for announcements of the retrospective periods and especially be as cooperative as may be practical when requests are directed to them from WDCs or the leaders of special projects. This phase of the data interchange program is equally or even more valuable than the systematic data interchange.

9.31. International Geophysical Calendar: This Calendar continues the series begun for the IGY years 1957-58, and is issued annually to recommend dates for solar and geophysical observations which cannot be carried out continuously. Thus, the amount of observational data in existence tends to be larger on Calendar days. The recommendations on data reduction and especially the flow of data to World Data Centers (WDCs) in many instances emphasize Calendar days. The Calendar is prepared by the International Ursigram and World Days Service (IUWDS) with the advice of spokesmen for the various scientific disciplines. For greater detail concerning explanations or recommendations your attention is called to information published periodically in STP Notes, IAGA News, IUGG Chronicle, URSI Information Bulletin or other scientific journals.

The definitions of the designated days remain as described on previous Calendars. Universal Time (UT) is the standard of time for all world days. Regular Geophysical Days (RGD) are each Wednesday. Regular World Days (RWD) are three consecutive days each month, always Tuesday, Wednesday and Thursday near the middle of the month. Priority Regular World Days (PRWD) are the RGD which fall on Wednesdays. Quarterly World Days (QWD) are one day each quarter and are the PRWD which fall in the World Geophysical Intervals (WGI). The WGI are fourteen consecutive days in each season, beginning on the second Monday of the selected months, and normally shift from year to year.

The Solar Eclipses: Geophysical stations in the eclipse zones and their conjugate areas treat these days as world days and undertake special programs to study eclipse effects on the earth's atmosphere.

Meteor Showers include important visual showers and also unusual showers observable mainly by radio and radar techniques. The dates are coded to indicate whether the shower is observable in the northern or southern hemisphere.

The occurrence of unusual solar or geophysical conditions is announced or forecast by the IUWDS through various types of geophysical 'Alerts' which are widely distributed by telegram and radio broadcast on a current schedule. Stratospheric warmings (STRATWARM) are also designated. The meteorological telecommunications network coordinated by WMO carries these worldwide Alerts once daily soon after 0400 UT. For definitions of Alerts see IUWDS "Synoptic Codes for Solar and Geophysical Data, Third Revised Edition 1972" and its amendments. Retrospective World Intervals are selected and announced in STP Notes and elsewhere to provide additional analyzed data for particular events studied in the Inter-Union Commission on Solar-Terrestrial Physics (IUCSTP) projects.

Stations operating on an ad hoc basis are requested to make measurements whenever possible, in priority order, on:

PRWD - RWD - RGD

and days notified for special international cooperation. It should be noted that there are much more data for these days so that the value of special experiments is enhanced when they are used.

9.32. The Alert system: Geophysical Alerts are widely distributed by telegram and radio to meet the needs of special international cooperation to study particular phenomena.

The types of Alerts are: magnetic storm (in telegrams MAGSTORM), solar activity (SOLALERT, PROTONALERT or XRAYALERT) together with number of sunspot centers designated QUIET, ERUPTIVE, ACTIVE or PROTON, and cosmic ray event (COSMIC EVENT). Sudden and unusual stratospheric warmings (STRATWARM) are also designated. These Alerts are issued by the IUWDS World Warning Agency or under certain circumstances by one of the solar-geophysical Regional Warning Centers. The meteorological telecommunications network coordinated by WMO carries these worldwide Alerts once daily soon after 0400 UT. A voice announcement on WWV and WWVH carries additional solar and geophysical data once hourly. Many geophysical stations in the various disciplines increase their program, or carry on special experiments to take advantage of the special solar or geophysical conditions during the period of Alert.

In general rapid changes of ionospheric conditions occur during these periods and rapid recording is needed to identify the start times of the phenomena. With classical ionosondes, five minute recording is of great value for this purpose alone and is therefore recommended whenever practical.

It is important that the quarter hourly data are made widely available for periods of special interest and this is done by making f plots for these days. It is advantageous to increase the frequency of recording to one ionogram every five minutes on these days where this is practical, making the interpretation of the quarter hourly ionograms exact and identifying rapidly changing phenomena. At many stations this is not possible and the program is then kept at quarter hourly or 10 minute intervals.

Continuous records of ionogram parameters are acceptable as an alternative to f plots at stations where these are available provided that the calibrations are also included.

9.4 Data Interchange for Vertical Soundings

9.41. Ionosonde observatories should send to one or preferably all WDCs copies of the results of their observations according to the program adopted as detailed under sections 9.44 to 9.46 below. Mr. W. R. Piggott (address: Radio and Space Research Station, Ditton Park, Slough, SL3 9JX, England). Chairman of the Ionospheric Network Advisory Group (INAG), has volunteered to advise on any proposed variations in the standard programs in particular cases.

International Geophysical Calendar for 1973

(See other side for information on the use of this Calendar)

JANUARY

S	M	T	W	T	F	S
	1	2	[3	[4]	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

FEBRUARY

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28			

MARCH

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31*

APRIL

S	M	T	W	T	F	S
1*	2*	3*	4*	5*	6*	7
8	9	10	11	12	13	14
15	16	17	18	19	20	[21
[22	23	24	25	26	27	28
29	30					

MAY

S	M	T	W	T	F	S
		1	2	3	[4]	[5]
[6]	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

JUNE

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	[8]	[9]
[10]	[11]	[12]	13	14	15	16
17	18	19	20	21	22	[23]
[24]	25	26	27*	28*	29*	30*

JULY

S	M	T	W	T	F	S
1*	2*	3*	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26]	[27]	[28]
[29]	[30]	31]				

AUGUST

S	M	T	W	T	F	S
			1]	2	3	4
5	6	7	8	9	[10	[11
[12	[13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

SEPTEMBER

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23*	24*	25*	26*	27*	28*	29*
30						

OCTOBER

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	[20]
[21]	[22]	23	24	25	26	27
28	29	30	31			

NOVEMBER

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

DECEMBER

S	M	T	W	T	F	S
						1
2	3	4]	5]	6]	7	8
9	10	11	[12]	[13]	[14]	[15
16	17	18	19	20	21*	22*
23*	24*	25*	26*	27*	28	29
30	31					

S	M	T	W	T	F	S
		1	2	[3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

(16) Regular World Day (RWD)

(17) Priority Regular World Day (PRWD)

◇21 Quarterly World Day (QWD) also a PRWD and RGD

6 Regular Geophysical Day (RGD)

[4] Day of Solar Eclipse

* Micropulsation Interval Day

[12 13] World Geophysical Interval (WGI)

[3 Day with unusual meteor shower activity, Northern Hemisphere

31] Day with unusual meteor shower activity, Southern Hemisphere

[2 3] Airglow and Aurora Period

Notes: GATE: GARP Atlantic Tropical Experiment Field Tests June-August 1973.
Atmospheric Electricity Intensification Intervals of Ten Year Program are Jan. 15-Feb. 15, 1973 and Oct. 15-Dec. 17, 1973 (first priority Nov. 7-10 and second priority Nov. 5-Dec. 3).

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9.42. Special stations with ionosondes which are operated on irregular schedules or primarily in connection with other experiments such as rocket launchings or incoherent scatter programs are requested to notify one of the WDCs annually or oftener of the general nature of their program since their last report. Preferably this notification should be in March and also at the end of each campaign or period of observation, or upon request from a WDC. This should include information on the periods of observation, the usual observing schedule during these periods, what systematic scalings are normally made and where the ionograms are kept. The WDC will catalog the information and refer any inquiries to the station.

9.43. Automatic stations or stations which cast their data in computer format should provide data described in sections 9.44, 9.45 and 9.46 in equivalent form. The preferred form is a magnetic tape containing the data in such a form that the parameters in Program A (section 9.44) and the detailed electron density profiles can be abstracted conveniently. It is valuable to add the appropriate geomagnetic data (Kp, Ap, local K or Q), where available, to the identifying parameters for each set of data. Where practical, the data should be cast in formats compatible with the major computerized analysis groups so that data can be interchanged without confusion. Requests for station identification conventions and preferred codes and standards should be made to WDC-A. (See section 7.32).

9.44. Data reduction and interchange Program A (slightly modified from the corresponding IQSY program) is suited for high latitude stations and representative stations at lower latitudes. It provides for:

(i) Monthly tables of hourly values, medians and quartiles of the following parameters: foF2, foF1, foE, foEs, fbEs, fmin; fxI; h'F, h'Es, and where height accuracy allows, h'E; M(3000)F2 or MUF(3000)F2; Es types.

(ii) Tables of some profile parameters (e.g., hc, qc or Titheridge hm, H, T) hourly on Regular World Days; or hourly monthly median profiles.

(iii) f plots for all days.

9.45. Data reduction and interchange Program B (slightly modified from the corresponding IQSY program) is suited for temperate and low latitude stations. It provides for:

(i) Monthly tables of hourly values, medians and quartiles of the following parameters: foF2, foF1, foE, foEs, fbEs, fmin; fxI where practical; h'F, h'Es, and where height accuracy allows, h'E; M(3000)F2 or MUF(3000)F2; Es types

(ii) Tables of some profile parameters (e.g., hc, qc or Titheridge hm, H, T) hourly on Regular World Days; <u>or</u> hourly monthly median profiles; copies of other profile data made regularly or plotted for particular events (storms, eclipses, Retrospective World Intervals, etc.) should also be deposited at WDCs.

(iii) f plots should be prepared and provided for Retrospective World Intervals of types IONOMAGSTORM and INTERPLANET. Any f plots made for other occasions should also be copied to the WDCs if possible.

9.46. Data reduction and interchange Program C (slightly modified from IQSY Program D) is suited for stations which conduct mainly an electron density profile program. It provides for:

(i) Monthly tables of hourly values, medians and quartiles of the following parameters: foF1, foE1, fbEs, fmin, by direct scaling of ionograms; fxI where practical; foF2, foE, indirectly computed from the profile data; M(3000)F2 or MUF(3000)F2 from direct scaling or computed data, as is most convenient; Es types.

(ii) Hourly monthly median profiles in tabular form (N as function of height, or height of constant N).

(iii) Hourly values of electron density with height for all occasions when special measurements by sophisticated techniques (rockets, satellites, Thomson scatter, etc.) are in use at or near the station.

9.47. For all stations, regardless of whether the data reduction program is according to the sections 9.44. 9.45 and 9.46 it is recommended that:

(i) Copies of ionograms for at least the Priority Regular World Days (one day each month) be provided to one of the WDCs for interchange with the other WDCs; stations are encouraged to make arrangements with one of the WDCs for having copies of all their ionograms available; stations are invited to make available copies of ionograms on request for periods selected for special study, e.g., Retrospective World Intervals or other special projects. If this is not possible, it is recommended to send a sequence of ionograms to INAG, together with scales and analysis, so that the reduction of the ionograms can be monitored and advice given. It is essential that WDCs also receive all calibrations and scaling indications necessary for the use of the data.

(ii) Information on what other analyzed data are available from the ionosonde observations, with indication of parameter or type of observation and the periods involved, should be notified to one of the WDCs annually (e.g., in March) or oftener; where convenient, copies of such data should be sent regularly.

(iii) Reprints or preprints of reports or papers summarizing ionospheric behavior, dealing with special events or presenting regional or morphological studies should be sent to the WDCs.

(iv) A statement at least annually (e.g., in March) indicating dates and times of significant changes in the ionosonde characteristics such as changes in frequency, height or timing calibrations or in the sensitivity of the equipment which could affect fmin, foEs or fxI should be sent to one of the WDCs.

9.48. New stations in particular are encouraged to circulate additional parameters, e.g., foE2, h'E2, M(3000)F1, or MUF(3000)F1, foF1.5, h'F1.5, where the corresponding phenomena are observed at the station and should establish relations between profile parameters (e.g., hc, qc) and the factor M(3000)F2 and, if possible, M(3000)F1.

9.49. To date, no programs for interchange of data obtained by digital ionosondes have been established other than the interchange of standard parameters as given above. When such proposals have been formulated and approved internationally they will be published in the INAG Bulletin, URSI Information Bulletin and WDC Guide.

Note 1: The attention of investigators is drawn to the use of international quality symbols I, I* to denote data guaranteed to conform to the international standards.

Note 2: At least one copy of the data listed above should be sent to at least one WDC. Where the data are available in duplicated form, four copies should be sent to a WDC so that copies may be provided to each of the WDCs for the Ionosphere.

9.5 Data Interchange for Associated Techniques

Full instructions for program and data interchange for the following techniques are given in the Guide. If these are in operation at the station, even on a temporary basis, it is recommended that the Guide be consulted and data or information interchanged. Note that IGY Instruction Manuals exist for most of these techniques and, in some cases, these have been revised and brought up to date (Chapter 14).

9.51. Absorption: The following methods are in use:

A1 - Pulse absorption

A2 - Cosmic noise absorption (riometer)

A3 - CW field strength

- Field strength of satellite transmissions.

9.52. Ionospheric drifts: The various methods of drift measurements are as follows:

D1 - intercomparison of fading signals at three or more antennas spaced a few wavelengths apart

D2 - radio observations on drifting meteor trails

D3 - radio-star or geostationary satellite beacon scintillations with three or more antennas spaced many wavelengths apart

D4 - observations of characteristic reflection features at widely spaced sites

D5 - chemical or chaff releases from rockets

9.53. Incoherent scatter sounding

9.54. Ionospheric back- and forward-scatter

9.55. Oblique incidence soundings

9.56. Satellite beacons

(a) Total electron content

(b) Ionospheric scintillations

9.57. Topside-vertical incidence soundings and satellite probe data

9.58. Whistlers and VLF emissions

9.59. Atmospheric radio noise

Data from ionospheric or aeronomic rockets and satellites are normally interchanged directly between interested groups, but can be obtained through the WDCs for Rockets and Satellites (see section 14.82).

NOTES

10.0 Introduction

Physically the most meaningful results obtainable from ionospheric soundings would be the true heights of the maxima of the reflecting layers and the variation of electron density with height - the electron density profile. The maximum electron densities are given with great accuracy by the critical frequencies but the deduction of the profile parameters is time consuming and can be subject to serious error. It is, in general, seldom worth attempting unless the quality of the ionograms is good, heights and frequencies can be measured accurately and the frequency range of the ionogram is sufficient.

The following points should be considered:

(a) Profile parameters can only be obtained from conventional ionograms through a considerable investment of experienced effort. This involves both the selection of a suitable method of computation so that the required data are obtained with minimum effort and intelligent and accurate deduction of the virtual heights at the sampling frequencies.

(b) The factors which determine the accuracy of profiles and profile parameters are rather complicated and should be understood before attempting profile work. When comparing with rocket or standard atmosphere data note that the absolute height accuracy is usually less than the relative height accuracy and heights may be systematically wrong by several km even when using high quality ionograms and a powerful analysis method.

(c) Reference should be made to the literature before attempting any large profile problem, in particular to the special issue of Radio Science, Vol. 2, October 1967. It is expected that full details of a modern system using a fairly large computer will be available shortly in a NOAA Report This gives good guidance on the procedure necessary when using the NOAA system. Similar precautions are necessary with other modern procedures.

(d) It is seldom worth considering computing profile parameters unless the relative accuracy of the virtual height readings is not worse than ± 2 km and frequencies can be read to within ± 1%.

(e) In addition to natural losses due to blanketing Es and off-vertical reflections (tilts), limitations of ionosonde frequency range or insufficient sensitivity can result in missing echoes that are absolutely essential to obtaining a meaningful profile. Attempts to recover profiles in such cases may be little better than guesswork.

(f) The ratio of information yield to labor is particularly low for manual methods suitable for use in the field. Therefore these are most useful in problems where only a few ionograms need to be analyzed or where a few simple approximate parameters are needed.

(g) Those wishing to produce profile data systematically should either obtain suitable digital computing facilities or secure the cooperation of a center willing to undertake computations. A high quality ionosonde is essential both for accuracy and to provide sufficient frequency range and the method of analysis of the ionograms must conform exactly with the requirements of the computer program to be used. These differ with different problems.

(h) In practice the actual form of the computer programs used are influenced by the method or use of the final data and thus the scientific interests of the groups. It is strongly recommended that those interested in producing the highest quality profile data adopt the most advanced system which is compatible with their facilities and use the detailed instructions worked out for this system. The main groups who are active can be identified by reference to the papers published in the special electron density profile edition of Radio Science (loc. cit.).

The objectives of this Chapter are:

(i) To provide a simplified description of the principles of electron profile evaluation and the precautions necessary to obtain usable data (section 10.1).

(ii) To provide detailed rules for those wishing to use sample methods (sections 10.3 through 10.7).

The contents are strongly influenced by the present practice at stations. However, it should be noted that the Titheridge method (section 10.6) is particularly suitable for use with a small computer and can be exploited to analyze large numbers of ionograms economically. The average profile method (section 10.7) also offers a method of obtaining monthly median profiles economically. Such profiles have the same significance as other monthly median parameters; i.e., they are useful averages but need not represent conditions which were actually present on any day. Both of these techniques appear to merit wider use but have so far only been used intensively by the groups which developed them.

10.1 Principles and Limitations of Analysis Methods

10.11. Relations between virtual and real heights

When a radio pulse enters the ionosphere, the group velocity of propagation, v_g decreases with increasing electron density and becomes minimum at the level where it is reflected, h_r. At vertical incidence, the group velocity is zero at reflection and there is no difference between the upward velocity and the returning velocity at any given height. Therefore the total travel time τ is twice the time needed for the signal to travel from the ground to the reflection level h_r in the ionosphere and is given by

$$\tau = 2\int_0^{h_r} \frac{1}{v_g}\, dh \qquad (10.1)$$

The virtual height is given by h' where

$$h' = \int_0^{h_r} \frac{c}{v_g}\, dh = \int_0^{h_r} \mu' dh \qquad (10.2)$$

where μ' is called the group refractive index and is always greater than or equal to unity. It is convenient to rearrange (10.2) to give

$$h' = h_r + \int_0^{h_r} (\mu'-1) dh \qquad (10.3)$$

For a frequency f_r reflected by electron density N_r

$$h' = h_r + \int_0^{N_r} \frac{\mu'-1}{\frac{dr}{dh}}\, dN \qquad (10.4)$$

Thus, the retardation at each height depends on (μ'-1) and $\left(\frac{dN}{dh}\right)^{-1}$; i.e., it depends on the shape of the profile below h_r and critically on the slope of N(h) at that level.

A unique solution of the integral Eq. (10.4) only exists when $\frac{dr}{dh}$ is positive or zero at all heights. Thus if there is a valley between two reflecting layers, the exact electron density distribution cannot be recovered from the ionogram data even if this is complete.

In mathematical terms, the determination of the real heights requires the inversion of the integral Eq. (10.2). The group refractive index μ' is a rather complicated function of radio frequency, plasma frequency, electron gyrofrequency and the direction of the Earth's magnetic field, but its essential properties can be expressed by

$$\mu' = M(1 - N/N_r)^{-1/2} \qquad (10.5)$$

where N_r is the electron density at the reflection height, and usually

$$M \approx 1 \qquad (10.6)$$

For M = 1, the integral equation (10.2) is of Abel's type for which the solution is known. The older manual methods are all based on this type of analysis but most modern methods are based on the following procedure. The variation of the height with electron density over discrete intervals of electron density or over the entire profile are expressed in analytical form with an arbitrary number of parameters. The virtual heights for a corresponding number of frequencies are then related linearly to these parameters. The electron density profile calculation is then equivalent to determining the parameters from the observed virtual heights. This approach is very efficient because in most cases the profile is more smoothly behaved than the h'f curve; in other words, an adequate description of the virtual heights for the purpose of numerical integration requires a larger number of parameters than the description of the corresponding profile. The practical difficulties arise in choosing the sampling frequencies so that the virtual heights are representative of the average slope of the profile and contain enough information to define its features.

Generally it can be said that the numerical problem of the inversion of the integral equation (10.2) has been satisfactorily solved, even in the presence of the Earth's magnetic field. The practical complications result from technical and physical limitations.

10.12. Some fundamental limitations

The inversion of the ionogram into an electron density profile requires that the virtual heights be known at all frequencies, beginning with those which are reflected at zero electron density and ending at the critical frequency for the densest layer present. For the ordinary component, sounding should start at zero frequency, which is technically impossible; while the extraordinary component should be observed beginning with the gyrofrequency fB, which is also impractical.

In order to overcome this difficulty, most methods adopt some assumptions about the height variation at low electron densities, either directly, or in an indirect way by extrapolating the echo trace. In principle the use of both ordinary- and extraordinary-wave traces can be exploited to minimize the uncertainty at the lowest observed part of the profile. In practice this is only worthwhile when the extraordinary-wave trace can be observed at least down to a frequency below twice the gyrofrequency. The correction involves measuring the small height difference between corresponding points in the o and x traces accurately and computing the correction. Fundamental limitations are present when the electron density profile should show a valley between two layers.

Figure 10.1 gives a few models of profiles and the corresponding virtual height curves. It is obvious that the interpretation of the observed virtual height trace above foE depends largely on the shape of the 'valley'. Rocket experiments have shown that the 'valley' is almost but not completely filled up at noon, but that there is often an important decrease between the layers in the morning and evening hours and at night.

Existing numerical methods suffer from two difficulties in this respect. Most of them assume the valley to be completely filled, so that the electron density is a monotonic function of height up to the F2 peak. Thus, they adopt the greatest possible valley-correction, so that the computed profile assumes the lowest admissible heights for the F region. Secondly, many of these methods including all the manual ones, contain a smoothing process so that the discontinuity at the critical frequency foE is smoothed out during the calculations. This again decreases the height at the upper layer. With the often used 'matrix method' this error can be significant at plasma frequencies up to about twice foE and so may even influence heights near the F2 peak if foF2 is not large compared with foE.

The relative virtual heights of the x and o modes can be used to reduce the uncertainty though a unique solution cannot be found in most cases [Paul and Smith, 1968]. It is usually only possible to estimate the difference between the height of maximum of one layer and the reflection level of a frequency just above its critical frequency in the next higher layer. More information, such as minimum density in the valley, cannot be obtained except in very special cases; e.g., the presence of a sporadic E layer in the valley [Becker, 1959].

For all techniques, when the h'f curve is not smoothly varying between sample points; e.g., if there is a cusp between them, the information given by the departure of the h'f trace from a smooth curve will not be used in the analysis. Similarly, if a sample point falls on a cusp, the profile will be distorted.

The interpretation of traces observed below the gyrofrequency needs special care since the reflection condition for a z trace $fN^2 = f^2 + f \cdot fB$ (10.7)
is often found instead of the normal condition used in the analysis:

$$fN^2 = f^2 \tag{10.8}$$

10.13. The simple solution in the absence of a magnetic field

The following simple solution illustrates the principle of most manual techniques though it can only be used in practice near the magnetic equator where, for the ordinary wave, M = 1 in Eq. (10.5). The exact solution of the integral Eq. (10.2) is known as Abel's solution and reads:

$$h(f_N) = \frac{2}{\pi}\int_o^{\pi/2} h'\ (f_N \sin\ \Omega)\ d\ \Omega \tag{10.9}$$

The argument of h' is now $f_N \sin \Omega$ instead of f

$$\text{where } \Omega = \text{arc sin } (f/f_N) \tag{10.10}$$

The parameter f_N is called the plasma frequency and is related to the electron density N by:

$$\left(\frac{f_N}{\text{MHz}}\right)^2 \doteqdot 81\cdot 10^{-12}\left(\frac{N}{m^{-3}}\right) \tag{10.11}$$

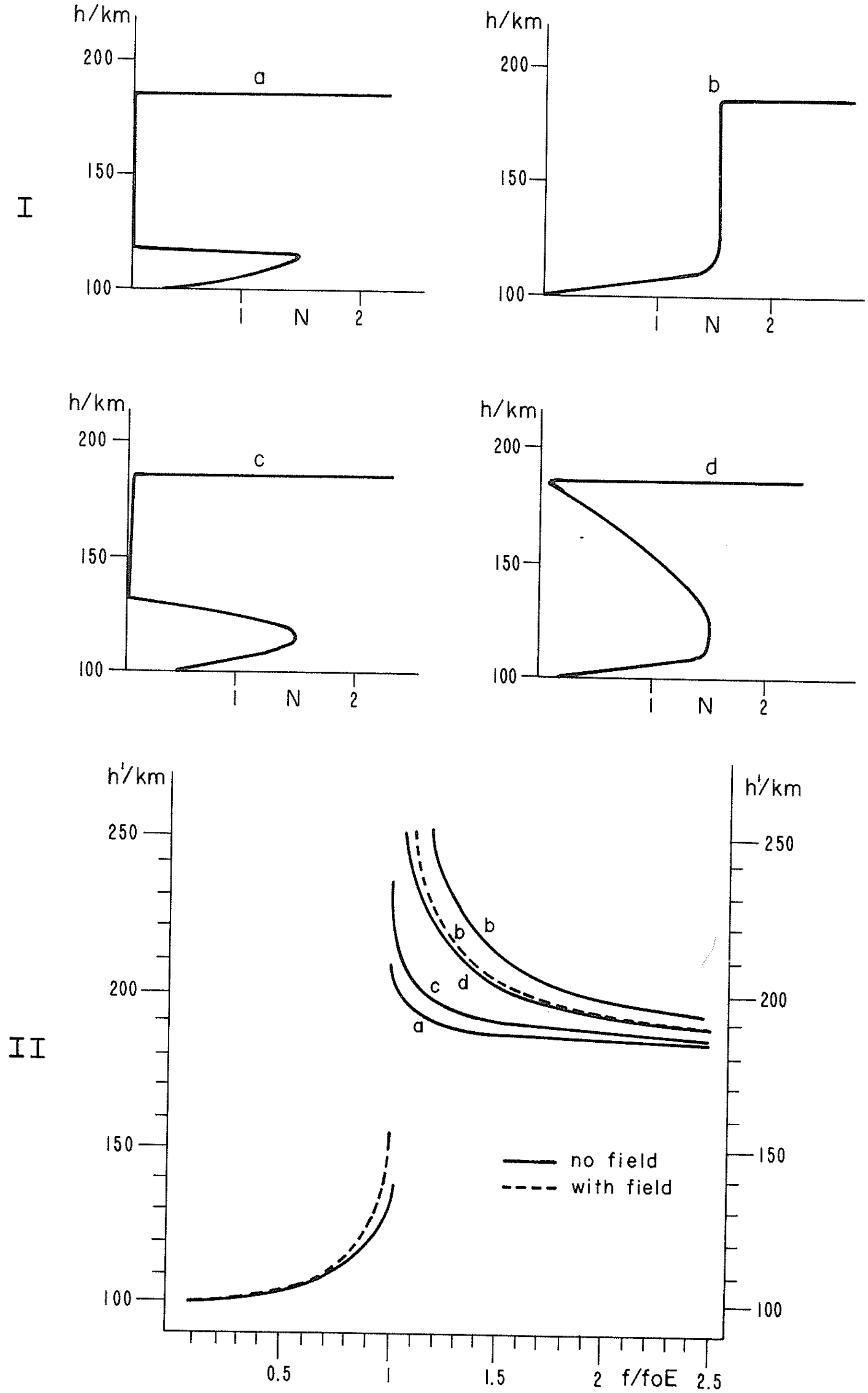


Fig. 10.1. The Valley Problem. Some computed h'(f) curves for different ionization distributions —computed with no magnetic field---computed including the magnetic field.

(I) Models of ionization. The electron density, N, is measured in units of $10^5 cm^{-3}$ ($10^{11} m^{-3}$).

(II) h'(f) patterns corresponding to the N(h) profiles (a) (b) (c) (d) when foE = 3.5 MHz.

To find the true height of a given electron density N one must transform the ionogram between frequencies 0 and f_N so as to depend on Ω instead of f and find the area under the curve by suitable integration. All other cases are equivalent to this but have more complicated relations between f and Ω.

Approximate integration is easily obtained by Gauss' method in which the surface below the curve is divided into strips of equal width along the Ω - axis. In practice, one does not draw the transformed h' (Ω) curve but measures the h' values at the corresponding sampling frequencies, f_i. The integration in Eq. (10.9) is now reduced to finding the average of the successive readings of virtual heights, h'_i. So for ten readings

$$h = \frac{1}{10}(h'_1 + h'_2 + \ldots\ldots\ldots + h'_9 + h'_{10}) \qquad (10.12)$$

The sampling frequencies, of course, bear fixed ratios to the plasma frequency, f_N, which corresponds to the required electron density, N. Thus different sets of sampling frequencies are needed for each electron density.

If a different type of approximation was chosen; e.g., Cebysev, some of the sampling ratios would be changed by more than 10%. In practice the factors given in Table 10.1 are most often used. These should be reduced to two figures (except 0.997) for manual work. When computers are used, it is preferable to use three places so as to achieve better apparent continuity between closely spaced f_N values.

Table 10.1

Sampling frequencies fi for ten point method usable for magnetic dip less than 10°

i =	1	2	3	4	5	6	7	8	9	10
fi/FN	.997	.972	.924	.853	.760	.649	.523	.383	.233	.078

This sampling procedure offers a quick technique for estimating probable errors when h' cannot be observed over part of the frequency range. It is easy to calculate the corresponding range on the Ω scale and the difference between limit, probable values of h' gives the desired estimate. Assuming, for example, that there are no data below 1.6 MHz and foE might lay in the band 0.5-1.0 MHz, the possible error in height at a sample frequency of 4 MHz due to the presence of the E layer can be estimated as follows:

For f_N = 4 MHz, the interval $0.5 \le f \le 1$ MHz corresponds to an interval $0.125 \le \Omega \le 0.252$ (Eq. 10.10). So $\Delta\Omega = 0.127$.
If h'(Ω) below the E-layer critical frequency is taken to be 100 km, $\Delta h'(\Omega) \approx 250-100 = 150$ km.
The maximum range of uncertainty of the integral would be the product $(2/\pi)\Delta h'(\Omega)\Delta\Omega \approx 12$ km.
The probable error would be half of this or $\approx \pm 6$ km.

The influence of the magnetic field is significant at most stations and modifies the group refraction index μ so that it becomes more difficult to invert the integral equation (10.2). To a good approximation, the inversion can be evaluated by slightly changing the set of reading frequencies in a way which depends on f/fB and the angle of dip (section 10.3). The corrections to the no-field values vary fairly slowly with magnetic dip, so it is sufficient to adopt a standard family of sets of sampling frequencies. Each of these may be applied over a certain range of plasma frequencies, f_N, and for certain ranges of magnetic dip and gyrofrequency, fB, (see section 10.3).

10.14. Indirect or model methods

For some purposes, it is quicker and more convenient to assume that the electron density profile has a definite analytical form and then to evaluate the constants of this which give the closest fit to the observed ionogram traces. In practice the ionosphere can often be adequately represented by a relatively sample model, the parameters of which define the profile. This offers a very simple method of summarizing changes in profile shape. The virtual heights are calculated for a set of different layer shapes, usually one or more of a parabola, cosine, or Epstein type, and usually three parameters: the type of model, the height of the electron density maximum, and the layer thickness are determined in addition to the critical frequency (equivalent to the maximum density) [Becker, 1959 J. Atmos. Terr. Phys., 16, 67-83]. After measuring the critical frequency f_c, three readings of h' at given ratios f/f_c arc enough to determine the three parameters. The effect of the magnetic field can be included by adjusting these frequency ratios depending on the ratio of gyrofrequency to the critical frequency for a given dip angle (section 10.3). In practice, much greater accuracy can be obtained by constructing theoretical h'f patterns and matching them to the observed ionogram. Such sample model methods are particularly valuable for summarizing the main characteristics of one layer.

Where it is desired to obtain an approximate representation of a complicated ionosphere a combination of a parabolic model for the F2 layer plus a polynomial for the distribution at lower heights is particularly convenient. Naturally the number of scaling points and amount of computation increases with the complexity allowed.

Thus there is a continuous transition from simple models through sophisticated models to the lamination methods. In the lamination method the frequency range over which virtual heights are observed is subdivided into a number of intervals each of which usually provides one model parameter. In each interval the model is a polynomial of second or higher degree for the reflection height, where f_N, log f_N or other simple functions of the electron density are used as variables.

A linear interpolation would imply a constant slope in each interval with corners at the interval limits. Such corners produce cusps in the virtual height curve, [Paul, 1967, Radio Sci. 2, 1135-1155] and therefore give a poor fit to the observed ionogram. A polynomial of the second degree provides the possibility of a continuous slope at the interval limits. The model parameter is now the rate of change of the slope which is assumed constant within the interval limits. This quantity can be negative or positive and permits a better fit to 'tail' or 'peak' of a profile.

Special care is necessary if higher order polynomials are assumed [Titheridge, 1959, J. Atmos. Terr. Phys., 17, 96-109; 1967, Radio Sci. 2, 1237-1253] since they rapidly become unstable. The instability is revealed by the occurrence of large positive and negative values in the calculated polynomial coefficients. Model methods have been extensively used by Becker to give standardized F2-layer profile shapes but as these are fixed by foF2 the profile near hmF1 is ill-defined.

10.15. Median profiles

Just as it is convenient to produce tables of median values of ionospheric parameters and to use these to show the average conditions present, it is also useful to know the most probable average electron density profile. The physical significance of this profile is subject to the same type of limitations as are the median values; an ionogram built using the median values of all parameters could differ from every ionogram included in the average. Such medians have useful application to practical problems but their geophysical significance is sometimes obscure.

The optimum method for obtaining a median profile for a block of ionograms is partly dependent on the use to be made of the average but in practice is mainly determined by the effort needed to produce the data.

There are at least three main methods of producing monthly median profile data:

(a) The analysis of every ionogram for a given hour and determining from them either

- (i) a profile which lies along the median of all profiles
- (ii) the median heights for given densities
- (iii) the median densities for given heights
- (iv) median shapes for the distribution near layer maxima, after standardizing the peak density

or any combination of these.

(b) To form a 'monthly median h'f curve' and analyze this curve. The significance depends on the care taken to make the basic curve representative.

(c) To pick an occasion (or occasions) when the ionogram shows median values of ionosonde parameters (critical frequencies, virtual heights and M(3000) factors for the normal layers) and to analyze this ionogram.

Of these, probably (b) has been most widely used.

The most common controversies are whether adequate accuracy is obtained in practice to define thickness parameters which are very sensitive to small errors in shape with frequency and on the compatability of incomplete ionograms which differ significantly from the average pattern.

Rather crude estimations of the height of maximum electron density have been widely used in the past, viz.:

(i) hm derived from the observed M(3000) by an empirical average relation, for example, Eq. (1.9), (1.10) of section 1.08; such relations are still being developed for CCIR problems (e.g, CCIR field strength estimation).

(ii) hp given by the virtual height read at 0.834 fo, i.e., at a fixed ratio of the critical frequency. Neglecting magnetic field effects and assuming a parabolic profile this should be equal to hm.

(iii) hm obtained by curve fit with computed virtual height/frequency curves obtained for parabolic models of different thickness.

It is common to all these estimations that they neglect effects of underlying ionization. This is particularly serious for hmF2 when foF1 or foE are not small compared with foF2 and cause serious retardation.

A convenient two step process for determining the height of maximum density, hc, using a ten point method and a thickness parameter, qc, is described in detail in Sections 10.3, 10.4. Direct methods of determining the height of maximum density, e.g., by applying a ten point method at the critical frequency, are very inaccurate.

In the Titheridge method (section 10.6) the parameters computed are the height of the electron density maximum, HM (corresponding approximately to hc), an equivalent to the scale height, H, (roughly equal to the thickness parameter qc), and the sub-peak electron content which is expressed as an effective slab thickness, T. Rather crude estimates of the true height at the five sampling frequencies are also available (h_1, h_2, h_3, h_4, h_5).

10.2 Manual Methods of Evaluating Electron Density Height Profiles or Profile Parameters

Manual methods can be used either to give complete electron density profiles or profile parameters. The accuracy available for the former is rather limited so that manual methods are used only occasionally to this end. A few groups with advanced computer programs have announced that they are willing to analyze a limited number of ionograms from other groups on request - contact your W.D.C. for the latest information. A simple method which can be used either manually or with a small computer is given in section 10.6.

Simple profile parameters can be rapidly evaluated and, in spite of their limited accuracy, are still useful for research purposes as well as for propagation studies. Regular synoptic evaluations at fixed hours, e.g., noon and midnight, are useful for general morphological studies.

Before starting any long term manual program or a computer program using simplified methods, it is always desirable to analyze some typical ionograms at a center operating an advanced computer program so that the errors introduced by the simplifications can be estimated.

10.21. Scaling practices and conventions

All methods necessarily assume that the shape of the h'(f) curve is completely known from zero frequency up to the highest critical frequency, and that all reflections are from thick layers, normal E, E2, F1 and F2. In consequence, it is necessary to adopt conventions for replacing parts of the trace which lie below fmin, are blanketed by Es, or are missing for other causes.

The detailed rules given below are based on the following general rules:

(i) No measurements may be made using oblique or thin layer traces; for example, Es.
(ii) Extrapolation should not be used unless other information shows the appropriate method to be applied.
(iii) Information from other ionograms must always be considered and used to fill in missing values, in particular to decide whether the missing value was reflected from the normal E or F layers.

It is valuable to keep an index showing the number of sampling frequencies for which missing values have had to be assumed and the dominant cause for the values missed. This is particularly important when a sequence is to be studied, different numbers of missing values can cause jumps in the deduced height which are misleading. A convenient procedure is to describe missing sampling values with the appropriate letter symbol (section 10.2).

The object of the rules and conventions is always to obtain a representative value for the 'real' height and, in particular, to treat missing parts of the ionogram in a consistent manner, using all information available to estimate the most probable distribution likely to be present.

10.22. Rules for extrapolating missing F-region heights values

If the probable value of a missing value can be deduced from other ionograms, section 2.4, this is the preferred method. Always check that the common section of trace agrees before extrapolation, (e.g., Figures 2.3, 2.4, 2.5, section 2.4).

At night it is necessary to extrapolate, using the physically probable assumption that the layer is parabolic in shape and that there is an E layer below it with critical frequency as given in section 10.23. Standard h'(f) patterns for parabolic layers have been computed by W. Becker 1960 [Max Planck Institut für Aeronomie D3411, Lindau/Northeim Harz Germany] and an abbreviated form of his tables for the o mode are reproduced in Table 10.2 below. The shape of the h'(f) pattern is a slow function of the ratio of the critical frequency to gyrofrequency and depends on the angle of magnetic dip at the station.

The procedure is as follows:

(i) Select the tables with dip nearest to that at the station and interpolate between them to construct standard tables for the station. It is usually convenient to graph these so as to facilitate interpolation, Figure 10.2.

(ii) Select the table which is closest to the required ratio: critical frequency to gyrofrequency.

(iii) Select two convenient measurable ratios of working to critical frequency from the set given in the table and measure the corresponding vertical heights h'_1, h'_2 and subtract: $(h'_1 - h'_2) = \Delta 1$.

(iv) Find (h'_1/ym) (h'_2/ym) for the same ratios from the table and subtract: $(h'_1/ym) - (h'_2/ym) = \Delta 2$.

(v) Then $ym = \Delta 1/\Delta 2$

(vi) The decrease in h' for any lower frequency ratio in the Table can be deduced from the difference $\Delta 3$ of the tabulated values and the value of ym calculated in (v).

If preferred, any ratio can be used with differences found from the graphical representation in (i).

(vii) $h'_3 = h'_2 - ym\,\Delta 3$.

Note:

(a) It is usually sufficient to use the nearest sampling point from the table when deducing missing values.

(b) It is not advisable to extrapolate a trace on the ionogram below fmin since this implies an arbitrary type of electron density profile determined by the frequency scale and type of extrapolation adopted. Use the procedure given above.

(c) The extrapolation should not be continued below the frequency for foE given in section 10.23 below.

10.23. Missing E-layer sample values

During the day it is normally sufficient to assume that the missing values are replaced by h'E. This puts the E layer slightly too high.

At night it is essential to make the best guess possible of the value of foE so as to determine which sampling frequencies should be reflected from the normal E layer and which from the F layer. The appropriate value of foE should be deduced from the sequence on the day, or by comparison with corresponding times on other days whenever this is possible. In the absence of more precise data, the Tables 10.3 and 10.4 should be used. These are not reliable under disturbed conditions, particularly at high latitudes or in the subauroral zones where night E may be present. At high latitudes, the slow variation of foE near sunrise and sunset, due to slow changes in solar zenith angle, also gives larger values of foE than shown in the table at the appropriate seasons. In this condition a reasonable guess of the value of foE can be obtained by extrapolating the observed variation through sunset and sunrise taking into account the changes in solar zenith angle (section 14.1)

Table 10.2

Values of h'/ym for a parabolic layer as a function of f/fc for bands with given foF2/fB and different dip angles, φ.

		$\frac{h'}{ym}$ for Band						$\frac{h'}{ym}$ for Band			
φ	f/fc	1	2	3	4	φ	f/fc	1	2	3	4
10°	0.995	3.0061	3.0085	3.0098	3.0103	20°	0.995	3.0737	3.0879	3.0981	3.9036
	0.900	2.6142	1.6441	2.6454	1.6459		0.990	2.6946	2.7081	2.7179	2.7232
	0.950	2.2685	2.2708	2.2719	2.2723		0.980	2.3079	2.3201	2.3293	2.3343
	0.950	1.7515	1.7533	1.7543	1.7547		0.950	1.7759	1.7857	1.7933	1.7975
	0.550	1.2173	1.2187	1.2195	1.2197		0.880	1.2312	1.2379	1.2433	1.2462
	0.760	0.7610	0.7618	0.7622	0.7623		0.760	0.7688	0.7727	0.7759	0.7775
	0.580	0.3827	0.3865	0.3807	0.3867		0.580	0.3902	0.3921	0.3934	0.3961
	0.400	0.1704	0.1705	0.1705	0.1705		0.400	0.1724	0.1731	0.1735	0.1737
	0.250	0.0642	0.0642	0.0642	0.0642		0.250	0.0651	0.0653	0.0654	0.0654
	0.100	0.0100	0.0100	0.0101	0.0101		0.100	0.0103	0.0103	0.0103	0.0103
	0.040	0.0016	0.0016	0.0016	0.0016		0.040	0.0017	0.0016	0.0016	0.0016
30°	0.995	3.1761	3.2136	3.2441	3.2640	40°	0.995	3.3134	3.3887	3.4544	3.5026
	0.900	2.7716	2.8064	2.8353	2.8545		0.990	2.8705	2.9387	3.0001	3.0461
	0.980	2.3627	2.3934	2.4199	2.4378		0.980	2.4298	2.4552	2.5432	2.5854
	0.950	1.8077	1.8312	1.5526	1.8675		0.950	1.8443	1.8868	1.9295	1.9639
	0.880	1.2482	1.2636	1.2783	1.2887		0.880	1.2667	1.2933	1.3216	1.3453
	0.760	0.7779	0.7871	0.7959	0.8017		0.760	0.7878	0.8033	0.8191	0.8336
	0.580	0.3950	0.3995	0.4035	0.4059		0.580	0.4002	0.4079	0.4157	0.4216
	0.400	0.1749	0.1768	0.1782	0.1789		0.400	0.1777	0.1811	0.1842	0.1861
	0.250	0.0663	0.0690	0.0673	0.0674		0.250	0.0677	0.0690	0.0698	0.0702
	0.100	0.0105	0.0106	0.0106	0.0106		0.100	0.0109	0.0110	0.0110	0.0111
	0.040	0.0017	0.0017	0.0017	0.0017		0.040	0.0018	0.0018	0.0018	0.0018
50°	0.995	3.4892	3.6225	3.7453	3.8421	54°	0.995	3.5715	3.7359	3.8901	4.0148
	0.990	2.9909	3.1079	3.2202	3.3112		0.990	3.0451	3.1871	3.3265	3.4427
	0.980	2.5073	2.6037	2.7011	2.7831		0.980	2.5407	2.6556	2.7747	2.8783
	0.950	1.8838	1.9500	2.0222	2.0866		0.950	1.8999	1.9769	2.0632	2.1431
	0.830	1.2856	1.3253	1.3712	1.4141		0.880	1.2930	1.3383	1.3922	1.4444
	0.760	0.7976	0.8202	0.8467	0.8714		0.760	0.8014	0.8269	0.8578	0.8877
	0.580	0.4052	0.4166	0.4293	0.4404		0.550	0.4072	0.4201	0.4350	0.4484
	0.400	0.1804	0.1857	0.1910	0.1949		0.400	0.1815	0.1875	0.1939	0.1987
	0.250	0.0691	0.0712	0.0728	0.0738		0.250	0.0697	0.0621	0.0741	0.0754
	0.100	0.0113	0.0115	0.0116	0.0117		0.100	0.0114	0.0117	0.0119	0.0119
	0.040	0.0018	0.0019	0.0019	0.0019		0.040	0.0019	0.0019	0.0019	0.0019
60°	0.995	3.7005	3.9313	4.1462	4.3259	67°	0.995	3.8965	4.2095	4.5255	4.8011
	0.990	3.1327	3.3190	3.5090	3.6738		0.990	3.2451	3.4971	3.7663	4.0119
	0.980	2.5929	2.7390	2.8970	3.0406		0.980	2.6564	2.8456	3.0605	3.2688
	0.950	1.9241	2.0183	2.1284	2.2355		0.950	1.9519	2.0698	2.2098	2.3557
	0.880	1.3039	1.3577	1.4243	1.4923		0.880	1.3158	1.3797	1.4623	1.1551
	0.760	0.8068	0.8368	0.8745	0.9129		0.760	0.8126	0.8477	0.8936	0.9430
	0.580	0.4100	0.4251	0.4434	0.4609		0.580	0.4130	0.4307	0.4529	0.4756
	0.400	0.1830	0.1902	0.1981	0.2047		0.400	0.1847	0.1932	0.2030	0.2118
	0.250	0.0705	0.0734	0.0761	0.0779		0.250	0.0714	0.0749	0.0784	0.0810
	0.100	0.0117	0.0120	0.0122	0.0124		0.100	0.0119	0.0124	0.0128	0.0130
	0.040	0.0019	0.0020	0.0020	0.0020		0.040	0.0020	0.0021	0.0021	0.0021

Table 10.2 (continued)

		$\frac{h'}{ym}$ for Band						$\frac{h'}{ym}$ for Band			
φ	f/fc	1	2	3	4	φ	f/fc	1	2	3	4
70°	0.995	3.9803	4.3401	4.7103	5.0394	80°	0.995	4.2941	4.8697	5.5201	6.1517
	0.990	3.2929	3.5767	3.8860	4.1744		0.990	3.4583	3.8717	4.3642	4.8673
	0.980	2.6822	2.8910	3.1328	3.3706		0.980	2.7655	3.0463	3.3977	3.7743
	0.950	1.9626	2.0877	2.2436	2.4075		0.950	1.9948	2.1502	2.3557	2.5852
	0.850	1.3203	1.3852	1.4773	1.5753		0.880	1.3330	1.4135	1.5239	1.6529
	0.700	0.8148	0.8519	0.9019	0.9540		0.760	0.8208	0.8638	0.9231	0.9920
	0.5800	0.4141	0.4228	0.4566	0.4814		0.580	0.4172	0.4388	0.4675	0.4991
	0.400	0.1853	0.1943	0.2049	0.2146		0.400	0.1870	0.4976	0.2106	0.2233
	0.250	0.0718	0.0755	0.0793	0.0823		0.250	0.0727	0.0773	0.0821	0.0862
	0.100	0.0120	0.126	0.0130	0.0132		0.100	0.0123	0.0130	0.0137	0.0140
	0.0400	0.0020	0.0021	0.0021	0.0021		0.040	0.0021	0.0022	0.0022	0.0023

Band 1 For foF2/fB between 2.2 and 7.5
Band 2 For foF2/fB between 7.5 and 3.8
Band 3 For foF2/fB between 3.8 and 1.9
Band 4 For foF2/fB less than 1.9.

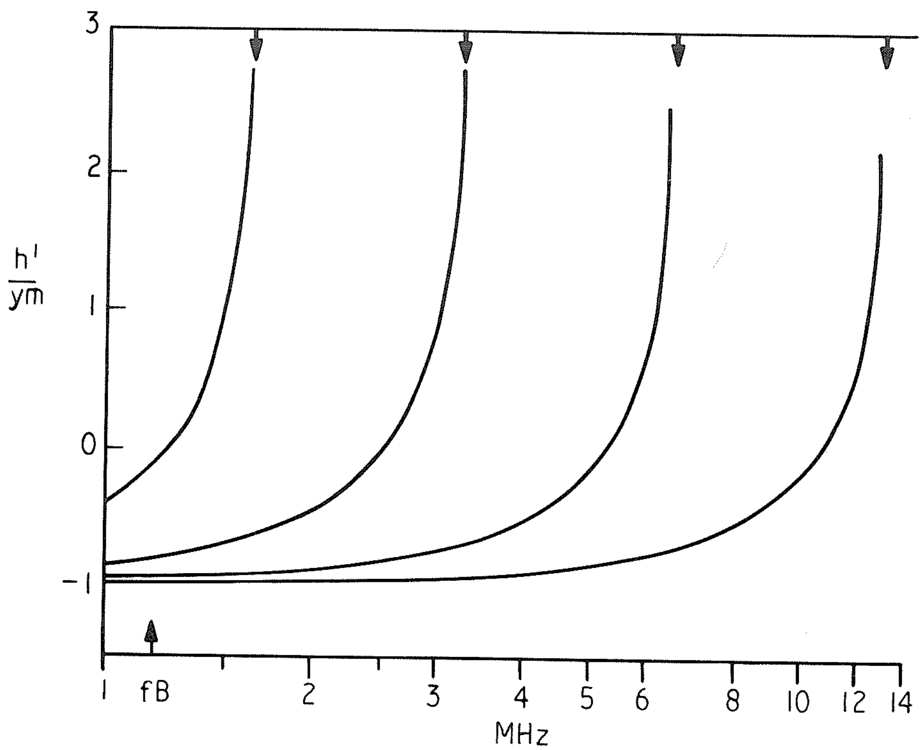


Fig. 10.2 Standard h'f patterns for dip 67.6° fB = 1.19 MHz o-mode.

The tables give the most probable value of foE as a function of time after sunset and before sunrise, the higher value shown being adopted where the tables overlap. To provide continuity with the daytime data, the times are given relative to the time when foE had the value given in the column marked 0 hours. The line corresponding to the lowest reliable foE value observed should always be used. Sampling frequencies falling below the normal value of fmin are then treated as follows:

(1) if the sampling frequency is above the adopted value of foE: use the minimum virtual height value observed above fmin, extrapolated where necessary as discussed in section 10.22 above.

(2) if the sampling frequency is below the adopted value of foE: use the arbitrary value 100 km.

Table 10.3

foE for Evening Period

	0	0.25	0.5	0.75	1.0	1.5	2.0	2.5	3.0	3.5	4.0	>4.0	hours
foE	1.6	1.35	1.20	1.10	1.00	0.85	0.80	0.75	0.70	0.65	0.60	0.55	MHz
	1.5	1.30	1.15	1.05	1.00	0.85	0.80	0.75	0.70	0.65	0.60	0.55	
	1.4	1.25	1.10	1.00	0.95	0.85	0.75	0.70	0.65	0.60	0.60	0.55	
	1.3	1.15	1.05	1.00	0.90	0.80	0.75	0.70	0.65	0.60	0.60	0.55	
	1.2	1.10	1.00	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.55	
	1.1	1.00	0.95	0.90	0.85	0.75	0.70	0.65	0.60	0.60	0.55	0.55	

Table 10.4

foE for Morning Period

	>2.0	2.0	1.5	1.0	0.75	0.5	0.25	0	hours
foE	0.55	0.65	0.75	0.90	0.95	1.10	1.30	1.6	MHz
	0.55	0.65	0.75	0.85	0.95	1.05	1.20	1.5	
	0.55	0.65	0.75	0.85	0.90	1.00	1.15	1.4	
	0.55	0.65	0.75	0.80	0.90	0.95	1.10	1.3	
	0.55	0.65	0.70	0.80	0.85	0.95	1.05	1.2	
	0.55	0.60	0.70	0.75	0.80	0.90	0.95	1.1	

In both cases the sample values are described by the appropriate letter (see below). When the number of missing sampling frequencies exceeds five, no numerical value is used. Replace by appropriate letter.

10.24. Use of Letter Symbols

The normal use of letter symbols should be applied, giving:

(a) Limitation by Es blanketing - A.

(i) Strong blanketing makes it impossible to obtain meaningful values. Replace numerical value of real height by letter A.

(ii) If partial blanketing by Es is present, find the most probable value of foE for the time of day from other ionograms or, at night, from Tables 10.2, 10.3 and identify which sampling frequencies are lying above or below this value.

(iii) For sampling frequencies above foE extrapolate h' values from h'F, using Table 10.2 where appropriate, or assume h' to be equal to h'F if the low frequency end of the F-trace shows no height variation with frequency. Describe the relevant numerical values by A.

(iv) When h'F or h'E cannot be measured, adopt typical values from ionograms obtained when the traces of the normal layers were similar in height and frequency to those being reduced. These are also described by letter A and treated as in (ii).

(v) A particular difficulty arises when a second order Es trace lies on top of the 1 F trace and the 2 F trace is missing. Use extrapolation in time if possible. Otherwise use the height at the lowest frequency clearly giving an F trace and describe the missing lower sampling frequencies by A.

(b) Limitation by absorption - B.

(i) Strong absorption (as in SID cases) makes it impossible to obtain meaningful values. Replace numerical value of real height by letter B.

(ii) & (iii) When the number of missing virtual heights at sampling frequencies is five or less apply the procedure described for letter A, (ii) and (iii), but describe the adopted values of h' by B.

(iv) When fmin is above the lowest limit of the recorder and no normal E traces are present, use the procedure described in sections 10.22, 10.23; describe the extrapolated values of h' with letter B.

(v) When fmin is above the lowest limit of the recorder and normal E-layer traces are present, assume h' is equal to h'E for the lower missing values, describe with letter B.

(c) Limitation by lowest frequency of recorder when fmin is below this limit - E.

(i) Use the procedure described in sections 10.22, 10.23; describe the extrapolated values by letter E.

(ii) Whenever group retardation ascribable to E-layer ionization is evident at the lowest frequency of the F trace, sampling frequency below this frequency should be assumed to be reflected in the E layer. Care should be taken not to be misled by x-trace gyro-retardation; this gives a characteristic increase in height with decrease in frequency which is much slower than that shown by a true E-layer retardation. Confirmation can be obtained by examining the variation of foE with time. This test may fail at high latitudes when night E is present.

(d) fmin abnormally high because of instrumental fault - C, or broadcast band interference - S.

(i) Use the procedure described in (b) above, replacing the descriptive letter B by C or S, as appropriate. However, it is seldom worthwhile to analyze such data - it is essential to minimize C and S entries by suitably adjusting the ionosonde when real heights are likely to be needed.

A schedule of the main decisions referred to above is summarized in the following flow diagram, Figure 10.3.

10.25. Extrapolation of high frequency end of the trace may become necessary when the F trace disappears before reaching the critical frequency (R), when spread echoes are present (F), or when oblique reflections are present (N or Y). It is also necessary when the trace is distorted owing to the presence of layer tilt.

(a) When no trace can be distinctly seen and the uncertainty is too great to make a reasonable extrapolation, the numerical value of the real height is replaced, in tabulations, by the appropriate letter.

(b) For less extreme conditions compare the ionogram with others showing traces at similar heights and frequencies and extrapolate using the most probable shape of the end of the trace. See, for example, Figure 10.2 which has been computed for a parabolic model. The extrapolated values are, as usual, described by the appropriate letter R, F, Y or N.

(c) Great care is necessary when spread echoes are present as it is probable that real heights near the maximum will become seriously misleading before foF2 becomes doubtful as shown by the accuracy rules. The reliability of the result can be tested by estimating the highest and lowest sets of values of h', and hence of real height, which are consistent with the ionogram. Note that any traces which can be interpreted as due to oblique reflection should be ignored. If a main trace can be seen, this should always be used. When several main traces appear to be present, preference is always given to any well-defined continuous trace for which both components o and x may be observed, or to traces which are confirmed by the multiple order patterns. (See section 2.7).

Whenever part of an ionogram needs to be extrapolated, but others in the sequence show the probable value of the missing sampling virtual heights, interpolation in time should be used. This is particularly valuable for filling gaps due to Es blanketing or to sudden absorption.

10.26. Rules for interpolating missing values

Interpolation may be needed when gaps exist in the echo traces of the normal thick layers. The following cases are particularly important:

(i) Es blankets the lower frequency part of the F trace - A.
(ii) Part of the trace is obscured by spread - F.
(iii) The trace is interrupted at a critical frequency by deviative absorption - R.
(iv) Part of the trace is obscured by oblique traces - N, Y.
(v) Part of the trace is obscured by interference - S.

In all these cases an interpolated numerical value should be used to replace the missing value, taking account of the usual amount of group retardation that would be expected to be present. If the gap occurs in a part of the trace whose height is varying smoothly with frequency, so that the virtual height can be interpolated within the limits for an unqualified value of h' (Accuracy Rules, section 2.2), the value should be treated as if the trace were complete, i.e., as an accurate value not demanding a descriptive letter. Otherwise the most probable interpolated value may be estimated, in order of decreasing desirability, by the following methods:

(a) Interpolate on another ionogram obtained before or after, provided that the time difference is not too great and the traces of the stable layers are similar to those being measured.

(b) Interpolate on another ionogram obtained at the same time of day on a different occasion which is showing traces of the stable layers similar to those being measured.

(c) Interpolate the gap with a reasonable curve of the type usually found at the station, provided that the missing part is not wider than 1 MHz and no evidence exists for unusual complexity in the missing part. In these cases the numerical value is described by the appropriate letter describing the cause of the gap and is included in the index of missing values.

(d) Where the gap exceeds this limit or the virtual height is likely to be varying rapidly with frequency to an unknown extent, no numerical value of real height is possible. The numerical value is replaced by the appropriate descriptive letter.

10.27. Index of reliability

The index of reliability may be used to show the relative reliability of different values and is based on the principle that the average determination should be unqualified.

The reliability of the real height falls as the number of estimated values increases and is probably inadequate when half or more of the samples are estimated. Replace by the appropriate letter. Whenever the number of estimated values is greater than normal, the real height should be qualified U with the appropriate descriptive letter. This should also be done for a sequence to identify real height values where this count is larger than for an adjacent value. (Note: When the quality is improving with time the last value before the count of missing data decreases, is qualified).

Where it is desired to compare data from a number of stations a special index is necessary to show the differing reliability of each station.

This index is the sum of the numbers of extrapolated and interpolated virtual height measurements used in the real height determination. It can take any value from 0 to 9 but will usually be less than 5. The descriptive letter used is the one which applies to the largest number of estimated values.

Tabulation sheets should have separate columns for the qualifying letters or index and descriptive letters. The index is always entered in the qualifying column in this case.

10.28. Procedure when sampling frequency falls on a cusp

A particular difficulty arises when a sampling frequency falls on a cusp due to the critical frequency of a lower layer. The real height values vary in the way shown in Figure 10.4 as a sampling frequency moves from above to below the critical frequency and are clearly abnormally high when it is equal to the critical frequency. Of course, as shown in the Figure, the values found when the nearest sampling frequency is distant from the critical frequency are systematically too low.

The difficulty can be reduced, when desired, by smoothing the h'f pattern near the cusp so that the area under the smooth curve is approximately the same as the area under the cusp. The smoothing should be restricted to a frequency range, centered on the critical frequency, which is not greater

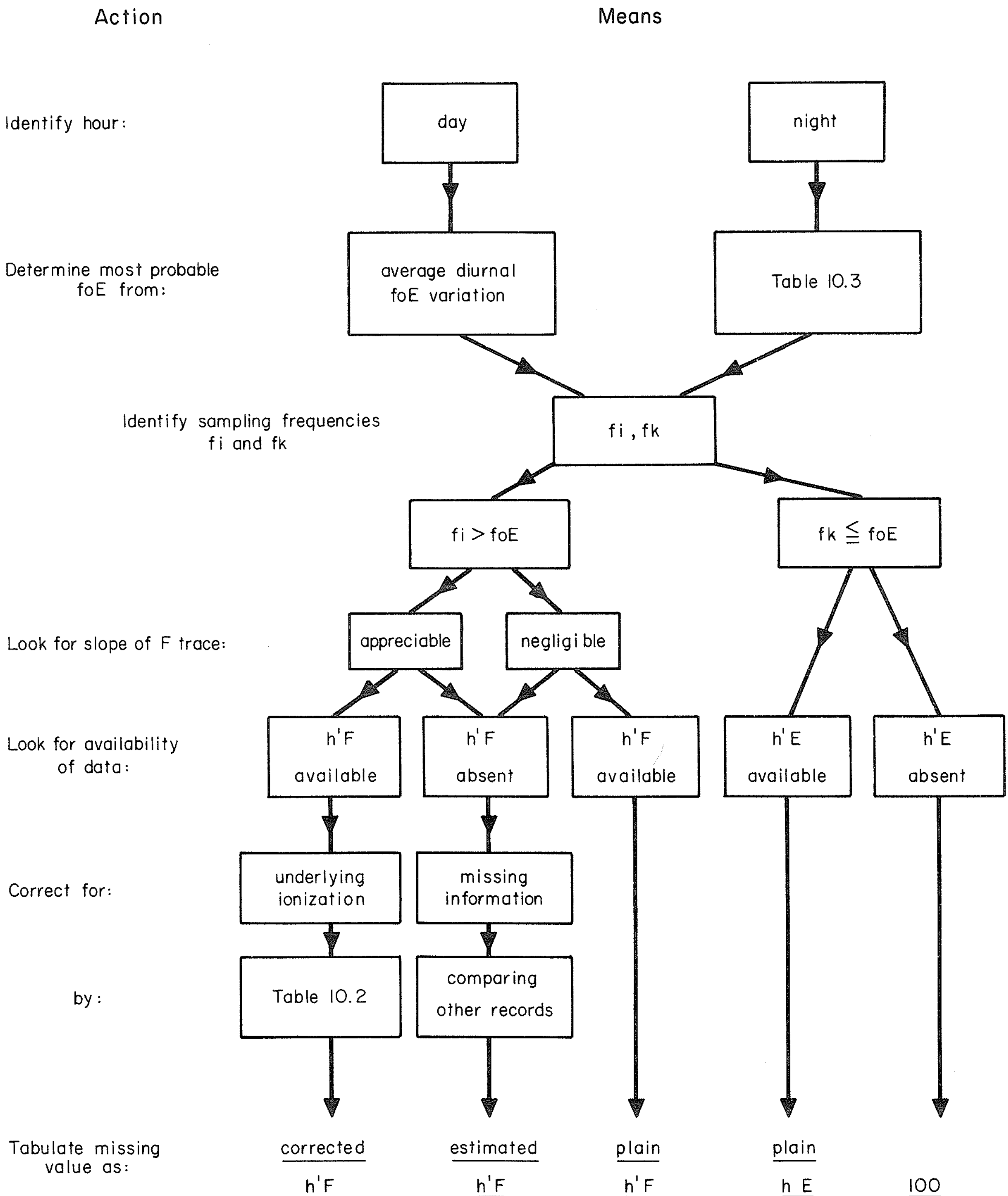
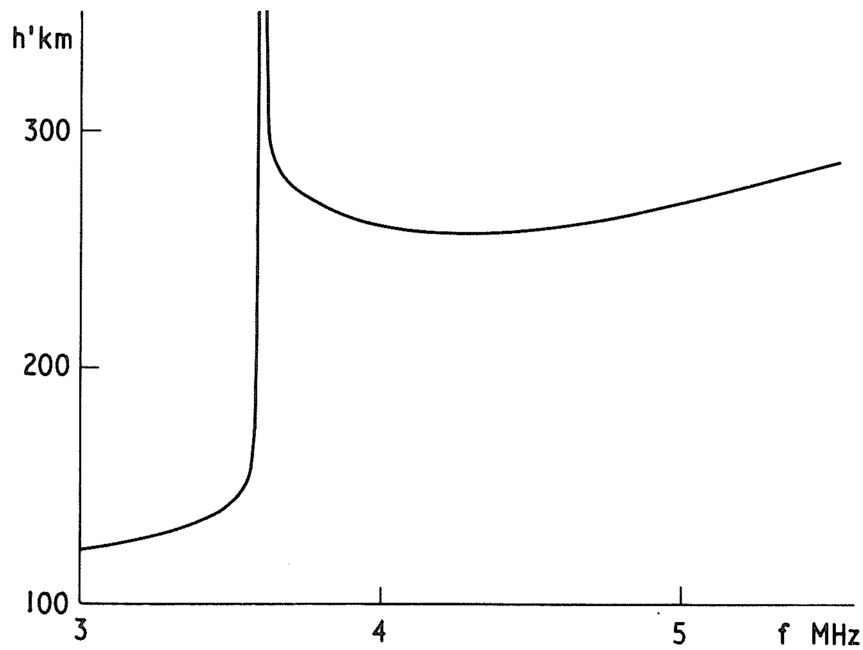


Fig. 10.3 Flow Diagram



Typical h'F pattern between E and F

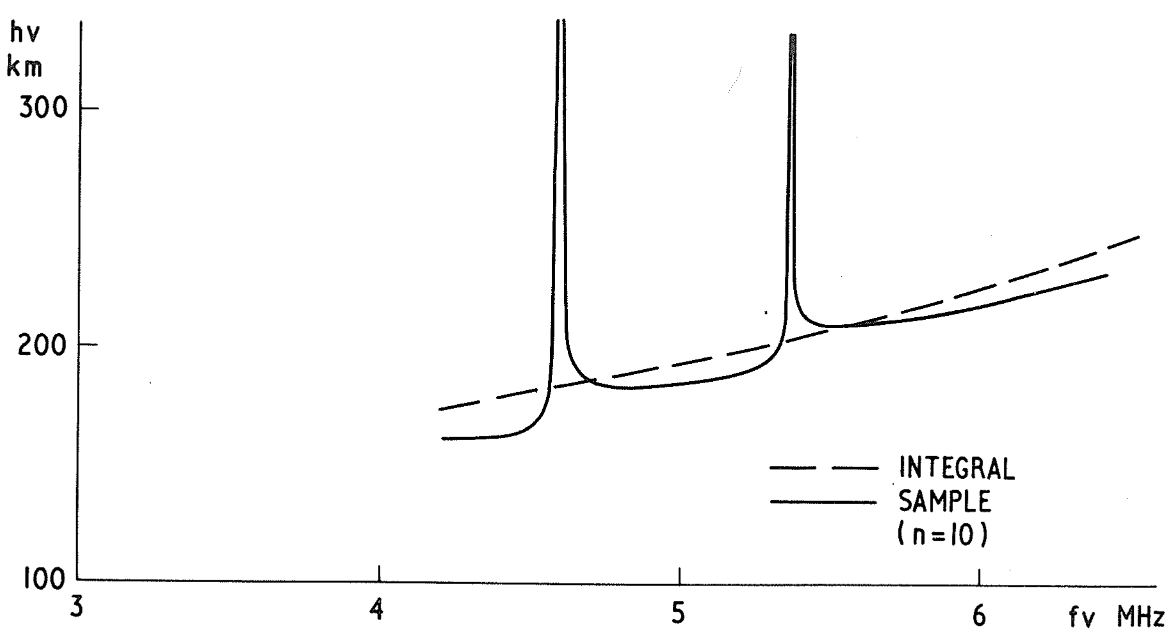


Fig. 10.4 Effect of sampling frequency near a cusp.
Profile calculated by integration — — — .
Profile calculated by ten-point method ——— .

Table 10.5

Schmerling Factors

Dip (0°-10°) fB(.600-.860), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.997	.997	.997	.997	.997	.997	.997	.997
.973	.973	.973	.973	.973	.973	.973	.973
.923	.923	.923	.923	.923	.924	.924	.925
.852	.852	.851	.851	.851	.851	.851	.851
.759	.759	.759	.759	.759	.758	.757	.756
.648	.648	.648	.648	.647	.647	.646	.643
.521	.521	.521	.521	.520	.520	.518	.518
.382	.381	.381	.381	.380	.380	.378	.383
.232	.232	.232	.232	.231	.231	.232	.237
.078	.077	.077	.077	.078	.078	.079	.082

Dip (0°-10°) fB(.860-1.12), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.997	.997	.997	.997	.997	.997	.997	.997
.973	.973	.973	.973	.973	.973	.973	.973
.923	.923	.923	.923	.923	.924	.924	.925
.852	.852	.851	.851	.851	.851	.851	.851
.759	.759	.759	.759	.758	.758	.757	.756
.648	.648	.648	.648	.647	.647	.646	.643
.521	.521	.521	.521	.520	.520	.518	.518
.381	.381	.381	.381	.380	.380	.378	.383
.232	.232	.232	.231	.231	.231	.232	.237
.077	.077	.077	.077	.078	.078	.079	.082

Dip (10°-20°) fB(.580-.855), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.997	.997	.997	.997	.997	.997	.997	.997
.972	.972	.972	.972	.972	.972	.972	.971
.921	.921	.920	.920	.920	.920	.921	.921
.849	.848	.848	.848	.847	.847	.846	.845
.757	.756	.756	.755	.754	.753	.752	.750
.646	.646	.645	.645	.644	.643	.641	.637
.520	.519	.519	.518	.518	.516	.514	.513
.381	.380	.380	.379	.379	.377	.376	.379
.232	.232	.231	.231	.230	.230	.230	.235
.077	.077	.077	.077	.077	.078	.078	.081

Dip (10°-20°) fB(.855-1.12), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.997	.997	.997	.997	.997	.997	.997	.997
.972	.972	.972	.972	.972	.972	.972	.971
.920	.920	.920	.920	.920	.920	.920	.921
.848	.848	.847	.847	.846	.846	.845	.845
.756	.755	.755	.754	.753	.752	.751	.749
.645	.645	.644	.644	.643	.642	.640	.637
.519	.519	.518	.518	.517	.515	.513	.512
.380	.380	.379	.379	.378	.377	.375	.378
.232	.231	.231	.230	.230	.229	.230	.234
.077	.077	.077	.077	.077	.077	.078	.080

Dip (20°-30°) fB(.580-.855), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.996	.996	.996	.996	.996	.996	.996	.995
.969	.969	.969	.969	.969	.969	.968	.967
.917	.917	.916	.916	.916	.915	.915	.915
.846	.845	.844	.843	.842	.841	.839	.837
.754	.753	.752	.751	.750	.748	.745	.741
.644	.643	.642	.641	.640	.638	.635	.630
.518	.518	.517	.516	.515	.513	.510	.507
.380	.379	.379	.378	.377	.375	.373	.374
.231	.231	.231	.230	.229	.229	.229	.232
.077	.077	.077	.077	.077	.077	.078	.080

Dip (20°-30°) fB(.855-1.15), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.996	.996	.996	.996	.996	.996	.996	.995
.969	.969	.969	.969	.969	.969	.968	.967
.916	.916	.915	.915	.914	.914	.914	.914
.844	.843	.842	.841	.840	.839	.837	.836
.752	.751	.750	.749	.747	.745	.743	.739
.642	.642	.641	.640	.638	.635	.632	.627
.517	.516	.516	.515	.513	.511	.508	.504
.379	.378	.378	.377	.376	.374	.371	.372
.231	.231	.230	.229	.229	.228	.228	.230
.077	.077	.077	.077	.077	.077	.077	.079

Dip (30°-40°) fB(.580-.900), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.996	.995	.995	.995	.995	.995	.994	.994
.966	.966	.966	.966	.965	.965	.964	.963
.914	.913	.912	.911	.910	.909	.908	.908
.842	.841	.840	.838	.837	.834	.831	.828
.751	.750	.749	.747	.745	.742	.738	.732
.642	.641	.640	.638	.636	.633	.629	.621
.517	.516	.515	.514	.512	.509	.505	.500
.379	.378	.378	.377	.375	.373	.370	.369
.231	.231	.230	.229	.228	.227	.227	.229
.077	.077	.077	.077	.077	.077	.077	.079

Dip (30°-40°) fB(.900-1.25), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.995	.995	.995	.995	.995	.995	.994	.993
.965	.965	.965	.965	.964	.964	.963	.962
.912	.911	.910	.909	.908	.906	.905	.906
.839	.838	.836	.835	.833	.830	.827	.824
.748	.747	.745	.743	.740	.737	.733	.727
.639	.638	.637	.635	.632	.629	.624	.616
.515	.514	.513	.511	.509	.506	.501	.496
.378	.377	.376	.375	.373	.370	.367	.366
.230	.230	.229	.228	.227	.226	.225	.226
.077	.077	.077	.077	.076	.076	.077	.078

Table 10.5 (continued)

Schmerling Factors

Dip (40°-50°) fB(.580-.965), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.995	.994	.994	.994	.994	.993	.993	.992
.963	.963	.962	.962	.962	.961	.960	.957
.911	.909	.098	.907	.905	.903	.901	.900
.839	.838	.836	.834	.831	.827	.823	.818
.748	.747	.745	.743	.740	.736	.730	.722
.640	.639	.637	.635	.632	.628	.622	.613
.515	.514	.513	.512	.509	.506	.500	.493
.378	.377	.376	.375	.373	.371	.366	.364
.231	.230	.229	.228	.227	.226	.225	.226
.077	.077	.077	.077	.076	.076	.077	.078

Dip (40°-50°) fB(.965-1.35), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.994	.994	.994	.994	.993	.993	.992	.991
.961	.960	.960	.960	.959	.959	.958	.955
.906	.905	.904	.902	.900	.898	.896	.895
.834	.832	.830	.828	.825	.821	.816	.811
.744	.742	.740	.737	.733	.728	.722	.714
.636	.634	.632	.630	.626	.621	.615	.604
.512	.511	.510	.507	.504	.500	.494	.486
.376	.375	.374	.372	.370	.367	.362	.358
.230	.229	.228	.227	.225	.224	.222	.222
.077	.076	.076	.076	.076	.076	.076	.076

Dip (50°-60°) fB(.70-1.10), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.993	.993	.993	.993	.992	.992	.991	.990
.960	.959	.958	.958	.957	.956	.954	.951
.906	.904	.903	.901	.898	.895	.892	.889
.834	.832	.830	.827	.824	.819	.813	.806
.744	.742	.740	.737	.733	.728	.720	.709
.636	.635	.633	.630	.626	.621	.613	.601
.513	.512	.510	.508	.505	.500	.493	.483
.376	.375	.374	.372	.370	.366	.361	.356
.230	.229	.228	.227	.225	.223	.221	.220
.076	.076	.076	.076	.076	.076	.076	.076

Dip (50°-60°) fB(1.10-1.50), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.993	.992	.992	.992	.991	.991	.990	.989
.956	.955	.955	.954	.953	.952	.951	.948
.900	.898	.897	.894	.892	.888	.885	.882
.828	.825	.822	.819	.815	.810	.804	.796
.738	.736	.733	.729	.724	.718	.710	.699
.631	.629	.626	.623	.618	.612	.604	.590
.509	.508	.505	.502	.499	.493	.485	.473
.374	.373	.371	.369	.366	.362	.355	.348
.228	.228	.227	.225	.223	.221	.218	.215
.076	.076	.076	.075	.075	.075	.074	.074

Dip (60 -70) fB(.780-1.20), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.992	.992	.992	.991	.991	.990	.989	.988
.956	.955	.954	.953	.952	.951	.949	.946
.901	.899	.897	.894	.891	.888	.883	.879
.829	.826	.823	.820	.816	.810	.803	.793
.739	.737	.734	.730	.725	.719	.710	.696
.632	.630	.627	.623	.619	.612	.603	.588
.509	.507	.505	.502	.498	.492	.484	.472
.373	.372	.370	.368	.365	.360	.353	.347
.227	.226	.225	.223	.221	.219	.217	.214
.075	.075	.075	.074	.074	.074	.074	.073

Dip (60 -70) fB(1.20-1.65), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.991	.991	.990	.990	.990	.989	.988	.986
.951	.950	.949	.948	.947	.946	.944	.941
.894	.892	.890	.887	.883	.879	.875	.870
.822	.819	.815	.811	.806	.800	.792	.782
.732	.729	.726	.721	.715	.708	.698	.683
.626	.624	.620	.616	.610	.603	.592	.576
.505	.503	.500	.497	.492	.485	.474	.461
.371	.369	.367	.365	.361	.355	.347	.338
.226	.225	.224	.222	.219	.216	.213	.208
.075	.075	.074	.074	.074	.073	.072	.071

Dip (70°-80°) fB(1.25-1.55), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.990	.990	.989	.989	.988	.988	.987	.985
.948	.947	.945	.944	.943	.941	.940	.937
.890	.888	.885	.882	.878	.874	.869	.864
.817	.814	.810	.806	.801	.794	.786	.776
.728	.725	.721	.716	.710	.702	.692	.678
.622	.619	.616	.611	.605	.598	.587	.573
.501	.499	.496	.492	.488	.481	.471	.459
.368	.367	.364	.361	.358	.352	.345	.336
.224	.223	.222	.220	.218	.216	.211	.207
.075	.075	.074	.074	.074	.073	.073	.071

Dip (70°-80°) fB(1.55-1.85), MHz fn, MHz

13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
.988	.988	.988	.987	.987	.986	.985	.983
.944	.943	.941	.940	.938	.937	.935	.932
.884	.881	.878	.874	.870	.866	.861	.856
.810	.806	.802	.797	.792	.784	.775	.765
.720	.716	.712	.707	.700	.692	.680	.666
.615	.612	.607	.602	.596	.587	.575	.559
.495	.492	.489	.484	.479	.471	.459	.445
.364	.361	.358	.355	.352	.344	.335	.326
.222	.220	.218	.216	.213	.210	.206	.201
.074	.073	.073	.073	.072	.071	.070	.069

Table 10.6

Band Limits for Schmerling Factors of Table 10.5

Lower plasma frequency limit, MHz	12.7	11.2	9.7	8.2	6.7	5.2	3.7	2.2
Designation on Table 11.7, MHz	13.5	12.0	10.5	9.0	7.5	6.0	4.5	3.0
Upper plasma frequency limit, MHz	00	12.7	11.2	9.7	8.2	6.7	5.2	3.7

than the frequency separation between the sampling frequency involved and the next higher sampling frequency. With logarithmic ionograms the boundaries are easily found by moving the slider so that the critical frequency lies between the two sampling frequencies.

Smoothing in this manner is unreliable when the plasma frequency is itself near the cusp and the most probable shape can only be found by sampling at additional plasma frequencies or by using a model.

10.3 The Ten-Point Method for Obtaining the Real Height - Corresponding to a Given Ionization Density (Plasma Frequency)

It is first necessary to deduce the appropriate sampling frequencies for the angle of dip and magnetic field at the station. This can be done conveniently using the Schmerling factors reproduced in Table 10.5. The band limits corresponding to the nominal values given in these tables are shown in Table 10.6. The section of the table which most nearly fits the magnetic field at the station is abstracted.

10.31. Basic procedure for ionograms with logarithmic frequency scales

Scales, according to Table 10.7 or transparent sliders similar to Figure 10.5, are provided for each band of plasma frequencies f_N. To find the real height for a particular plasma frequency:

(i) Select the scale which includes the required frequency.
(ii) Set the zero ordinate of the scale, marked on Figure 10.5 to the required frequency, Figure 10.6.
(iii) Read off and tabulate the virtual heights at the sampling frequencies 1, 2, 3 ..... 10.
(iv) Divide the sum by ten. This is the required 'real' height of reflection.

If the frequency scale of the ionogram is not stable, use the technique described in section 10.32 below.

10.32. Basic procedure for ionograms with non-logarithmic frequency scales

A table of sampling frequencies for all useful plasma frequencies, similar to Table 10.7 is provided. To find the real height for a particular plasma frequency:

(i) Find the sampling frequencies f_1, f_2, . . . f_{10} corresponding to the plasma frequency from the table.

(ii) Read off and tabulate the virtual heights at these sampling frequencies.

(iii) Divide the sum by ten. This is the required 'real' height of reflection $h(f_N)$.

10.33. Direct measurement of height of maximum, hm

For the part of Table 10.2 appropriate at the station deduce the frequency ratios f/fc for which h'/ym = 1 for the four bands. Select the band in which foF2 is found and measure the virtual height for the ratio f/fc which makes h'/ym = 1. This is equal to hm, the true height of maximum of the layer provided that the layer is parabolic to this value of f/fc. Thus this value is analogous to hp but with corrections for magnetic field.

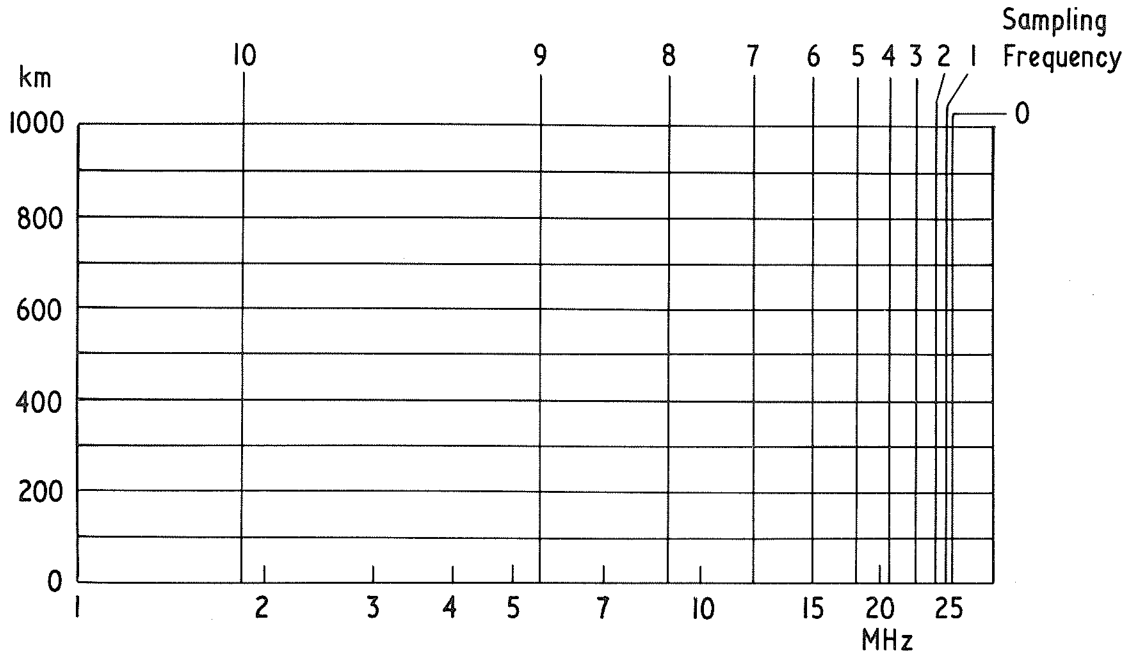


Fig. 10.5. Typical overlay for deducing true heights for ionograms with logarithmic frequency scales. The plasma frequency fN is defined by the line marked 0. The bottom scale is given to check that the ionogram law is correct. Samples are read at the frequencies given by the lines marked 1 to 10 when 0 is set to the desired plasma frequency.

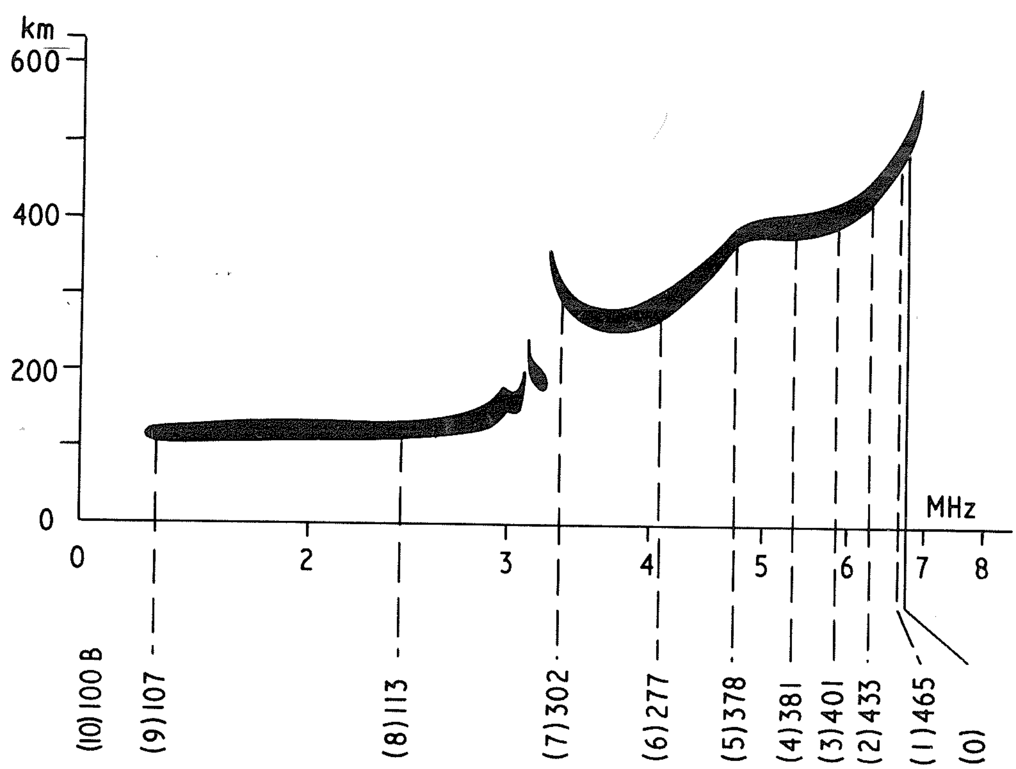


Fig. 10.6. Measurement of·h(0.95 foF2). The line 0 is set at 0.95 foF2 and the virtual heights at the sampling points measured and averaged. In this case h(0.45 foF2) = 296 km and the reliability index (if used) is 1B.

Table 10.7

Example of Table of Sampling Frequencies for use with Non-Logarithmic Frequency Scales

(Values applicable to Lat. 51.5 N, dip - 68°)

Plasma frequency	Sampling frequencies									
f_N	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
17.0	16.79	16.07	15.13	13.94	12.48	10.74	8.76	6.50	4.01	1.36
16.9	16.69	15.98	15.01	13.86	12.40	10.68	8.70	6.46	3.99	1.35
16.8	16.59	15.88	14.95	13.78	12.33	10.62	8.65	6.43	3.96	1.34
16.7	16.49	15.79	14.86	13.69	12.26	10.55	8.60	6.39	3.94	1.34
16.6	16.39	15.70	14.77	13.61	12.18	10.49	8.55	6.35	3.92	1.33
16.5	16.29	15.60	14.69	13.53	12.11	10.43	8.50	6.31	3.89	1.32
16.4	16.20	15.51	14.60	13.45	12.04	10.36	8.45	6.27	3.87	1.31
16.3	16.10	15.41	14.51	13.37	11.96	10.30	8.39	6.23	3.85	1.30
16.2	16.00	15.32	14.42	13.28	11.89	10.24	8.34	6.20	3.82	1.30
16.1	15.90	15.22	14.33	13.20	11.82	10.18	8.29	6.16	3.80	1.29
16.0	15.80	15.13	14.24	13.12	11.74	10.11	8.24	6.12	3.78	1.28
15.9	15.70	15.03	14.15	13.04	11.67	10.05	8.19	6.08	3.75	1.27
15.8	15.60	14.94	14.06	12.96	11.60	9.99	8.14	6.04	3.73	1.26
15.7	15.50	14.84	13.97	12.87	11.52	9.92	8.09	6.01	3.71	1.26
15.6	15.41	14.75	13.88	12.79	11.45	9.86	8.03	5.97	3.68	1.25
15.5	15.31	14.66	13.80	12.71	11.38	9.80	7.98	5.93	3.66	1.24
15.4	15.21	14.56	13.71	12.63	11.30	9.73	7.93	5.89	3.63	1.23
15.3	15.11	14.47	13.62	12.55	11.23	9.67	7.88	5.85	3.61	1.22
15.2	15.01	14.37	13.53	12.46	11.16	9.61	7.83	5.81	3.59	1.22
15.1	14.91	14.28	13.44	12.38	11.08	9.54	7.78	5.78	3.56	1.21
15.0	14.81	14.18	13.35	12.30	11.01	9.48	7.73	5.74	3.54	1.20
14.9	14.71	14.09	13.26	12.22	10.94	9.42	7.67	5.70	3.52	1.19
14.8	14.62	13.99	13.17	12.14	10.86	9.35	7.62	5.66	3.49	1.18
14.7	14.52	13.90	13.08	12.05	10.79	9.29	7.57	5.62	3.47	1.18
14.6	14.42	13.80	12.99	11.97	10.72	9.23	7.52	5.58	3.45	1.17
14.5	14.32	13.71	12.91	11.89	10.64	9.16	7.47	5.55	3.42	1.16
14.4	14.22	13.62	12.82	11.81	10.57	9.10	7.42	5.51	3.40	1.15
14.3	14.12	13.52	12.73	11.73	10.50	9.04	7.36	5.47	3.37	1.14
14.2	14.02	13.43	12.64	11.64	10.42	8.97	7.31	5.43	3.35	1.14
14.1	13.92	13.33	12.55	11.56	10.35	8.91	7.26	5.39	3.33	1.13
14.0	13.83	13.24	12.46	11.48	10.28	8.85	7.21	5.36	3.30	1.12
13.9	13.73	13.14	12.37	11.40	10.20	8.78	7.16	5.32	3.28	1.11
13.8	13.63	13.05	12.28	11.32	10.13	8.72	7.11	5.28	3.26	1.10
13.7	13.53	12.95	12.19	11.23	10.06	8.66	7.06	5.24	3.23	1.10
13.6	13.43	12.86	12.10	11.15	9.98	8.60	7.00	5.20	3.21	1.09
13.5	13.33	12.76	12.02	11.07	9.91	8.53	6.95	5.16	3.19	1.08
13.4	13.23	12.67	11.93	10.99	9.84	8.47	6.90	5.13	3.16	1.07
13.3	13.13	12.58	11.84	10.91	9.76	8.41	6.85	5.09	3.14	1.06
13.2	13.04	12.48	11.75	10.82	9.69	8.34	6.80	5.05	3.12	1.06
13.1	12.94	12.39	11.66	10.74	9.62	8.28	6.75	5.01	3.09	1.05
13.0	12.84	12.29	11.57	10.66	9.54	8.22	6.70	4.97	3.07	1.04
12.9	12.74	12.20	11.48	10.58	9.47	8.15	6.64	4.93	3.04	1.03
12.8	12.64	12.10	11.39	10.50	9.40	8.09	6.59	4.90	3.02	1.02
12.7	12.54	12.01	11.30	10.41	9.32	8.03	6.54	4.86	3.00	1.02
12.6	12.44	11.91	11.21	10.33	9.25	7.96	6.49	4.82	2.97	1.01
12.5	12.34	11.82	11.13	10.25	9.17	7.90	6.44	4.78	2.95	1.00

Table 10.7 (continued)

Example of Table of Sampling Frequencies for use with Non-Logarithmic Frequency Scales

(Values applicable to Lat. 51.5 N, dip - 68°)

Plasma frequency	Sampling frequencies									
f_N	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
12.4	12.25	11.72	11.04	10.17	9.10	7.84	6.39	4.74	2.93	0.99
12.3	12.15	11.63	10.95	10.08	9.03	7.77	6.33	4.70	2.90	0.98
12.2	12.05	11.54	10.86	10.00	8.95	7.71	6.28	4.67	2.88	0.98
12.1	11.95	11.44	10.77	9.92	8.88	7.65	6.23	4.63	2.86	0.97
12.0	11.85	11.35	10.68	9.84	8.81	7.58	6.18	4.59	2.83	0.96
11.9	11.75	11.25	10.59	9.76	8.73	7.52	6.13	4.55	2.81	0.95
11.8	11.65	11.16	10.50	9.68	8.66	7.46	6.07	4.51	2.78	0.94
11.7	11.55	11.06	10.41	9.59	8.59	7.39	6.03	4.48	2.76	0.94
11.6	11.46	10.97	10.32	9.51	8.51	7.33	5.97	4.44	2.74	0.93
11.5	11.36	10.87	10.24	9.43	8.44	7.27	5.92	4.40	2.71	0.92
11.4	11.26	10.78	10.15	9.35	8.37	7.20	5.87	4.36	2.69	0.91
11.3	11.16	10.68	10.06	9.27	8.29	7.14	5.83	4.32	2.67	0.90
11.2	11.06	10.59	9.97	9.18	8.22	7.08	5.77	4.28	2.64	0.90
11.1	10.96	10.50	9.88	9.10	8.15	7.02	5.72	4.25	2.62	0.89
11.0	10.86	10.40	9.79	9.02	8.07	6.95	5.66	4.21	2.60	0.88
10.9	10.76	10.31	9.70	8.94	8.00	6.89	5.61	4.17	2.57	0.87
10.8	10.67	10.21	9.61	8.96	7.92	6.83	5.56	4.13	2.55	0.86
10.7	10.57	10.12	9.52	8.77	7.85	6.76	5.51	4.09	2.53	0.86
10.6	10.47	10.02	9.43	8.69	7.78	6.70	5.46	4.05	2.50	0.85
10.5	10.37	9.93	9.35	8.61	7.71	6.64	5.41	4.02	2.48	0.84
10.4	10.27	9.83	9.26	8.53	7.63	6.57	5.36	3.98	2.45	0.83
10.3	10.17	9.74	9.17	8.45	7.56	6.51	5.30	3.94	2.43	0.82
10.2	10.07	9.64	9.08	8.36	7.49	6.45	5.25	3.90	2.41	0.82
10.1	9.98	9.55	8.99	8.28	7.41	6.38	5.20	3.86	2.38	0.81
10.0	9.88	9.46	8.90	8.20	7.34	6.32	5.15	3.82	2.36	0.80
9.9	9.78	9.36	8.81	8.12	7.27	6.26	5.10	3.79	2.34	0.79
9.8	9.68	9.27	8.72	8.04	7.20	6.19	5.05	3.75	2.31	0.78
9.7	9.58	9.17	8.63	7.95	7.12	6.13	5.00	3.71	2.29	0.77
9.6	9.47	9.02	8.47	7.78	6.96	6.00	4.90	3.65	2.27	0.77
9.5	9.37	8.93	8.38	7.70	6.88	5.93	4.85	3.61	2.24	0.76
9.4	9.27	8.84	8.29	7.61	6.81	5.87	4.79	3.58	2.22	0.76
9.3	9.17	8.74	8.20	7.53	6.74	5.81	4.74	3.54	2.19	0.75
9.2	9.08	8.65	8.11	7.45	6.67	5.75	4.69	3.50	2.17	0.74
9.1	8.98	8.55	8.03	7.37	6.59	5.68	4.64	3.40	2.15	0.73
9.0	8.88	8.46	7.94	7.29	6.52	5.62	4.59	3.42	2.12	0.72
8.9	8.78	8.37	7.85	7.21	6.45	5.56	4.54	3.39	2.10	0.72
8.8	8.68	8.27	7.76	7.13	6.38	5.50	4.49	3.34	2.08	0.71
8.7	8.58	8.18	7.67	7.05	6.30	5.43	4.44	3.31	2.05	0.70
8.6	8.48	8.08	7.59	6.97	6.23	5.37	4.39	3.27	2.03	0.69
8.5	8.39	7.99	7.50	6.89	6.16	5.31	4.34	3.23	2.01	0.68
8.4	8.29	7.90	7.41	6.80	6.09	5.25	4.28	3.20	1.98	0.68
8.3	8.19	7.80	7.32	6.72	6.01	5.18	4.23	3.16	1.96	0.67
8.2	8.09	7.71	7.23	6.64	5.94	5.12	4.18	3.12	1.94	0.66
8.1	7.99	7.61	7.14	6.56	5.87	5.06	4.13	3.08	1.91	0.65
8.0	7.90	7.52	7.06	6.48	5.80	4.97	4.08	3.04	1.88	0.64

Table 10.7 (continued)

Example of Table of Sampling Frequencies for use with Non-Logarithmic Frequency Scales

(Values applicable to Lat. 51.5 N, dip - 68°)

Plasma frequency	Sampling frequencies									
f_N	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
7.9	7.80	7.43	6.97	6.40	5.72	4.93	4.03	3.01	1.86	0.64
7.8	7.70	7.33	6.88	6.32	5.65	4.87	3.98	2.97	1.84	0.63
7.7	7.60	7.24	6.79	6.24	5.58	4.80	3.93	2.93	1.82	0.62
7.6	7.50	7.14	6.70	6.16	5.51	4.75	3.88	2.89	1.79	0.61
7.5	7.40	7.05	6.61	6.08	5.43	4.68	3.83	2.85	1.77	0.60
7.4	7.30	6.96	6.53	5.99	5.36	4.62	3.77	2.82	1.75	0.60
7.3	7.20	6.86	6.44	5.91	5.29	4.56	3.72	2.78	1.72	0.59
7.2	7.10	6.77	6.35	5.83	5.22	4.50	3.67	2.74	1.69	0.58
7.1	7.00	6.67	6.26	5.75	5.14	4.44	3.62	2.70	1.67	0.57
7.0	6.91	6.58	6.17	5.67	5.07	4.37	3.57	2.66	1.65	0.56
6.9	6.81	6.49	6.09	5.59	5.00	4.31	3.52	2.63	1.63	0.55
6.8	6.70	6.36	5.94	5.43	4.85	4.18	3.42	2.56	1.59	0.54
6.7	6.60	6.26	5.85	5.35	4.77	4.11	3.37	2.52	1.57	0.54
6.6	6.50	6.17	5.76	5.27	4.71	4.05	3.32	2.48	1.54	0.53
6.5	6.41	6.08	5.67	5.19	4.63	3.99	3.27	2.44	1.52	0.52
6.4	6.31	5.99	5.59	5.11	4.56	3.93	3.22	2.41	1.50	0.51
6.3	6.21	5.89	5.50	5.03	4.49	3.87	3.17	2.37	1.47	0.50
6.2	6.11	5.80	5.41	4.95	4.42	3.81	3.12	2.33	1.45	0.50
6.1	6.01	5.70	5.33	4.87	4.35	3.75	3.07	2.29	1.43	0.49
6.0	5.91	5.61	5.24	4.79	4.28	3.68	3.02	2.26	1.40	0.48
5.9	5.81	5.52	5.15	4.71	4.21	3.62	2.97	2.22	1.38	0.47
5.8	5.72	5.42	5.06	4.63	4.13	3.56	2.92	2.18	1.36	0.46
5.7	5.62	5.33	4.98	4.55	4.06	3.50	2.87	2.14	1.33	0.46
5.6	5.52	5.24	4.89	4.47	3.99	3.44	2.82	2.11	1.31	0.45
5.5	5.42	5.14	4.80	4.39	3.92	3.38	2.77	2.07	1.29	0.44
5.4	5.32	5.05	4.71	4.35	3.85	3.32	2.72	2.03	1.26	0.43
5.3	5.22	4.96	4.63	4.23	3.78	3.25	2.67	1.99	1.24	0.42
5.2	5.13	4.86	4.54	4.16	3.71	3.19	2.61	1.96	1.22	0.42
5.1	5.03	4.77	4.45	4.08	3.64	3.13	2.56	1.92	1.19	0.41
5.0	4.93	4.68	4.36	4.00	3.57	3.07	2.51	1.88	1.17	0.40
4.9	4.83	4.58	4.28	3.92	3.49	3.01	2.46	1.84	1.15	0.39
4.8	4.73	4.46	4.14	3.78	3.36	2.89	2.37	1.78	1.11	0.38
4.7	4.63	4.37	4.06	3.70	3.29	2.83	2.32	1.74	1.09	0.37
4.6	4.53	4.28	3.97	3.62	3.22	2.77	2.27	1.70	1.06	0.36
4.5	4.43	4.19	3.88	3.54	3.15	2.71	2.22	1.67	1.04	0.36
4.4	4.33	4.09	3.80	3.46	3.08	2.65	2.17	1.63	1.02	0.35
4.3	4.24	4.00	3.71	3.38	3.01	2.59	2.12	1.59	0.99	0.34
4.2	4.14	3.91	3.63	3.31	2.94	2.53	2.07	1.55	0.97	0.33
4.1	4.04	3.81	3.54	3.23	2.87	2.47	2.02	1.52	0.95	0.32
4.0	3.94	3.72	3.45	3.15	2.80	2.41	1.97	1.48	0.92	0.32
3.9	3.84	3.63	3.37	3.07	2.73	2.35	1.92	1.44	0.90	0.31
3.8	3.74	3.53	3.28	2.99	2.66	2.29	1.87	1.41	0.88	0.30
3.7	3.65	3.44	3.19	2.91	2.59	2.23	1.82	1.37	0.86	0.29
3.6	3.55	3.35	3.11	2.83	2.52	2.17	1.78	1.33	0.83	0.28
3.5	3.45	3.26	3.02	2.75	2.45	2.11	1.73	1.30	0.81	0.28

Table 10.7 (continued)

Example of Table of Sampling Frequencies for use with Non-Logarithmic Frequency Scales

(Values applicable to Lat. 51.5 N, dip - 68°)

Plasma frequency	Sampling frequencies									
f_N	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
3.4	3.35	3.14	2.90	2.63	2.33	2.00	1.64	1.23	0.77	0.26
3.3	3.25	3.05	2.82	2.55	2.26	1.94	1.59	1.19	0.75	0.25
3.2	3.15	2.96	2.73	2.48	2.20	1.88	1.54	1.16	0.72	0.25
3.1	3.05	2.86	2.65	2.40	2.13	1.83	1.49	1.12	0.70	0.24
3.0	2.95	2.77	2.56	2.32	2.06	1.77	1.44	1.08	0.68	0.23
2.9	2.85	2.68	2.48	2.24	1.99	1.71	1.39	1.05	0.66	0.22
2.8	2.76	2.59	2.39	2.17	1.92	1.65	1.35	1.01	0.63	0.22
2.7	2.66	2.49	2.31	2.09	1.85	1.59	1.30	0.97	0.61	0.21
2.6	2.56	2.40	2.22	2.01	1.78	1.53	1.25	0.94	0.59	0.20
2.5	2.46	2.31	2.14	1.94	1.72	1.47	1.20	0.90	0.57	0.19
2.4	2.36	2.21	2.03	1.83	1.61	1.38	1.12	0.84	0.52	0.18
2.3	2.26	2.11	1.94	1.75	1.55	1.32	1.08	0.81	0.50	0.17
2.2	2.16	2.02	1.86	1.68	1.48	1.26	1.03	0.77	0.48	0.17
2.1	2.06	1.93	1.77	1.60	1.41	1.21	0.98	0.74	0.46	0.16
2.0	1.97	1.84	1.69	1.52	1.34	1.15	0.94	0.70	0.44	0.15
1.9	1.87	1.75	1.60	1.45	1.28	1.09	0.89	0.67	0.41	0.14
1.8	1.77	1.65	1.52	1.37	1.21	1.03	0.84	0.63	0.39	0.14
1.7	1.67	1.56	1.42	1.28	1.12	0.95	0.77	0.57	0.36	0.12
1.6	1.57	1.46	1.34	1.20	1.05	0.90	0.73	0.54	0.33	0.11
1.5	1.47	1.37	1.25	1.13	0.99	0.84	0.68	0.51	0.31	0.10
1.4	1.38	1.28	1.17	1.05	0.92	0.78	0.64	0.47	0.29	0.09
1.3	1.28	1.19	1.10	0.98	0.86	0.73	0.59	0.44	0.27	0.09
1.2	1.18	1.10	1.00	0.90	0.79	0.67	0.54	0.41	0.25	0.08
1.1	1.08	1.01	0.92	0.83	0.72	0.62	0.50	0.37	0.23	0.08
1.0	0.98	0.92	0.84	0.75	0.66	0.56	0.45	0.34	0.21	0.07

10.4 Determination of hc and qc

10.41. General

The direct determination of the height of maximum density of a layer is subject to special difficulties of two types:

(a) It is difficult to avoid systematic experimental errors due to small errors in frequency determination when the virtual height varies rapidly with frequency.

(b) The convergency of the solutions of the integral equation is very poor near a critical frequency.

These errors can be minimized by using a two-step method of computing the height of maximum density. At the same time the extra information given by a two-step method can be used to provide a measure of the curvature of the ionization profile near its peak, i.e., the height of maximum electron density. In principle, we assume that the variation of ionization density with height sufficiently near the peak must be parabolic and use the characteristics of a parabolic variation to determine the constants of the parabola. Most computer methods of finding the height of maximum electron density use essentially the same principle.

As the curvature of the profile near the maximum is usually the parameter which mainly determines the total amount of ionization below the center of the layer, it is useful to determine a convenient parameter which measures this curvature. This parameter, in effect, gives the thickness of the densest part of the layer, at least when the distribution is simple; its value has important applications in the theory of the ionosphere.

10.42. It has been agreed internationally that the symbols hc, qc should be used for data obtained by the processes described below or by techniques compatible with this method.

10.43. Theory of method

Since we are only concerned with the shape of the ionization density near the maximum, it is convenient to express the variation of electron density N in terms of the maximum value N_m. If hc is the height of the maximum and qc is the quarter thickness of the parabola we may write

$$N = N_m \left\{ 1- \left[(h-h_c)/2q_c \right]^2 \right\} \qquad (10.13)$$

In plasma frequencies f_N we may write

$$f^2{}_N = f^2{}_{NM} \left\{ 1 - \left(\frac{h - hc}{2qc} \right)^2 \right\} \qquad (10.14)$$

and f_{NM} equals the critical frequency f_c of the layer for the ordinary ray.

$$\text{Thus} \quad hc = h + 2\,qc \sqrt{1 - f_N{}^2/fc^2} = h + d\,qc \qquad (10.15)$$

By measuring the true height at a convenient fraction of fc and qc by matching a theoretical set of h'f curves for different values of qc to the observed trace, hc and qc can be calculated with high accuracy. The correction for underlying ionization is given in section 10.45 and involves finding a true height for the standard frequency, f_3, discussed below.

If the true height h_3 is calculated for a plasma frequency f_3, the values of d for convenient values of f_3/fc are given in Table 10.8.

Table 10.8

f_3/fc	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90
d	0.40	0.486	0.560	0.625	0.681	0.735	0.783	0.829	0.872

In practice it is most convenient to measure h_3 when f_3/fc = 0.95 foF2. Table 10.9 gives the corrections to be added to h_3 to obtain hc for typical values of qc.

Table 10.9

$\Delta = hc - h_3 = d\ qc$ for $f_3 = 095$ foF2

q	20	25	30	35	40	45	50	55	60	65
$h_c - h_3$	12	16	19	22	25	28	31	34	37	41
q	70	75	80	85	90	95	100	105	110	115
$h_c - h_3$	44	47	50	53	56	59	62	66	69	72
q	120	125	130	135	140	145	150	155	160	165
$h_c - h_3$	75	78	81	84	87	91	94	97	100	103
q	170	175	180	185	190	195	200	205	210	215
$h_c - h_3$	106	109	112	116	119	122	125	128	131	134

10.44. Construction of qc overlays

The shape of the theoretical h'f traces depends on the magnetic field strength and dip at the station and on the ratio of the critical frequency to the gyrofrequency.

The necessary computations have been published by W. Becker for 11 standard values of dip and suitable values are reproduced in Table 10.10 for dip values 0°, 10°, 20°, 30°, 40°, 50°, 54°, 60°, 67.1°, 70° and 80°. For each dip angle, standard values of virtual height are calculated for five frequency bands defined by the ratio of the critical frequency, foF2, to the gyrofrequency, fB. It is convenient in practice to define the bands in terms of this ratio: foF2/fB ∞ - 22; 22 - 7.5; 7.5 - 3.8; 3.8 - 1.9; <1.9. It is possible to interpolate between the Tables 10.10 for intermediate dip values or frequency bands but this is seldom necessary. The procedure is, therefore:

(a) Select the Table in 10.10 whose dip angle most closely corresponds to the dip angle at the station, as given in the Ionospheric Stations Manual of URSI. Abstract from the appropriate Table in 10.10 the values of h'o/2q for frequencies above 0.88 of the critical frequency.

(b) Adopt a standard set of values of qc appropriate for the station. A convenient set is qc = 40, 60, 80, 100, 120, 140, 160 (200), but lower values may be more useful at certain high latitude stations. A quick test with ionograms showing abnormally large and abnormally small retardation near foF2 will give the desirable limits.

(c) For each frequency band multiply the tabulated virtual height values (Table 10.10) by twice the adopted value of qc for each of these.

(d) For a logarithmic frequency law these values, when plotted on suitable scales to match the height and frequency scale of the ionogram, give the final curves (e.g., Figure 10.7).

(e) For a non-logarithmic frequency law each band must be split up into sub-bands, since a fixed frequency ratio will occupy different horizontal distances in different points of the ionogram. When few ionograms are to be reduced it is sufficient to split into sub-bands with a variation range of that distance of ± 20% over each sub-band. In this case it is necessary to match borderline cases with two adjacent groups of patterns and take the average of the qc values found. Otherwise the permitted variation range is ± 10% (e.g., Figure 10.8). The actual number of sub-bands needed depends on the design of the ionosonde and varies with frequency, Figure 10.8.

10.45. Use of overlays

A set of standard overlays (Figures 10.7 or 10.8) are constructed and used as follows:

(a) Check that the frequency scale of the ionogram agrees with that of the overlays in the range 0.9 foF2 to foF2 approximately. If not, the trace must be replotted on a standard logarithmic scale or the ionogram abandoned (letter symbol C).

(b) Check that the height scales agree. If x km on the ionogram corresponds to 100 km on the overlay proceed as below but multiply all qc values by x/100.

(c) Select the set of curves which applies to the band in which foF2 falls. If foF2 is exactly at a boundary of a band use the patterns for the higher frequency group.

Table 10.10

Virtual Heights of Parabolic Layers

Ordinary ray

Magnetic dip	10°	20°	30°	40°	50°	54°	60°	67°	70°	80°	
f/foF2	h'o/2q	h'o/2q	h'o/2q	h'o/2q	h'o/2q	h'o/2q	h'o/2q	h'o/2q	h'o/2q	h'o/2q	Band
.995	2.006	2.074	2.176	2.313	2.489	2.572	2.709	2.896	2.980	3.294	
.990	1.642	1.695	1.772	1.870	1.991	2.045	2.133	2.245	2.293	2.458	
.980	1.268	1.308	1.363	1.430	1.507	1.541	1.593	1.656	1.682	1.765	$7.5<\frac{foF2}{fB}<22$
.950	.751	.776	.808	.844	.884	.900	.924	.952	.963	.995	
.880	.217	.231	.248	.267	.286	.293	.304	.316	.320	.333	
.995	2.008	2.088	2.214	2.389	2.623	2.736	2.931	3.210	3.340	3.870	
.990	1.644	1.708	1.806	1.939	2.108	2.187	2.319	2.497	2.577	2.872	
.980	1.271	1.320	1.393	1.488	1.604	1.656	1.739	1.846	1.891	2.046	$3.8<\frac{foF2}{fB}<7.5$
.950	.753	.786	.831	.887	.950	.977	1.018	1.068	1.088	1.150	
.880	.219	.238	.264	.293	.325	.338	.358	.380	.388	.414	
.995	2.010	2.098	2.244	2.454	2.745	2.890	3.146	3.526	3.710	4.520	
.990	1.645	1.718	1.835	2.000	2.220	2.326	2.509	2.766	2.886	3.364	
.980	1.272	1.329	1.420	1.543	1.701	1.775	1.897	2.060	2.133	2.398	$1.9<\frac{foF2}{fB}<3.8$
.950	.754	.793	.853	.930	1.022	1.063	1.128	1.210	1.244	1.356	
.880	.219	.243	.278	.322	.371	.392	.424	.462	.477	.524	
.995	2.010	2.104	2.264	2.503	2.842	3.015	3.326	3.801	4.039	5.152	
.990	1.646	1.723	1.854	2.046	2.311	2.443	2.674	3.012	3.174	3.867	
.980	1.272	1.334	1.438	1.585	1.783	1.878	2.041	2.267	2.371	2.774	$\frac{foF2}{fB}<1.9$
.950	.755	.798	.868	.964	1.087	1.143	1.235	1.356	1.407	1.588	
.880	.220	.246	.289	.345	.414	.444	.492	.551	.575	.653	

Note: h'o/2q tabulated so that h'o = o at h'o = hm (uncorrected height of meximum).

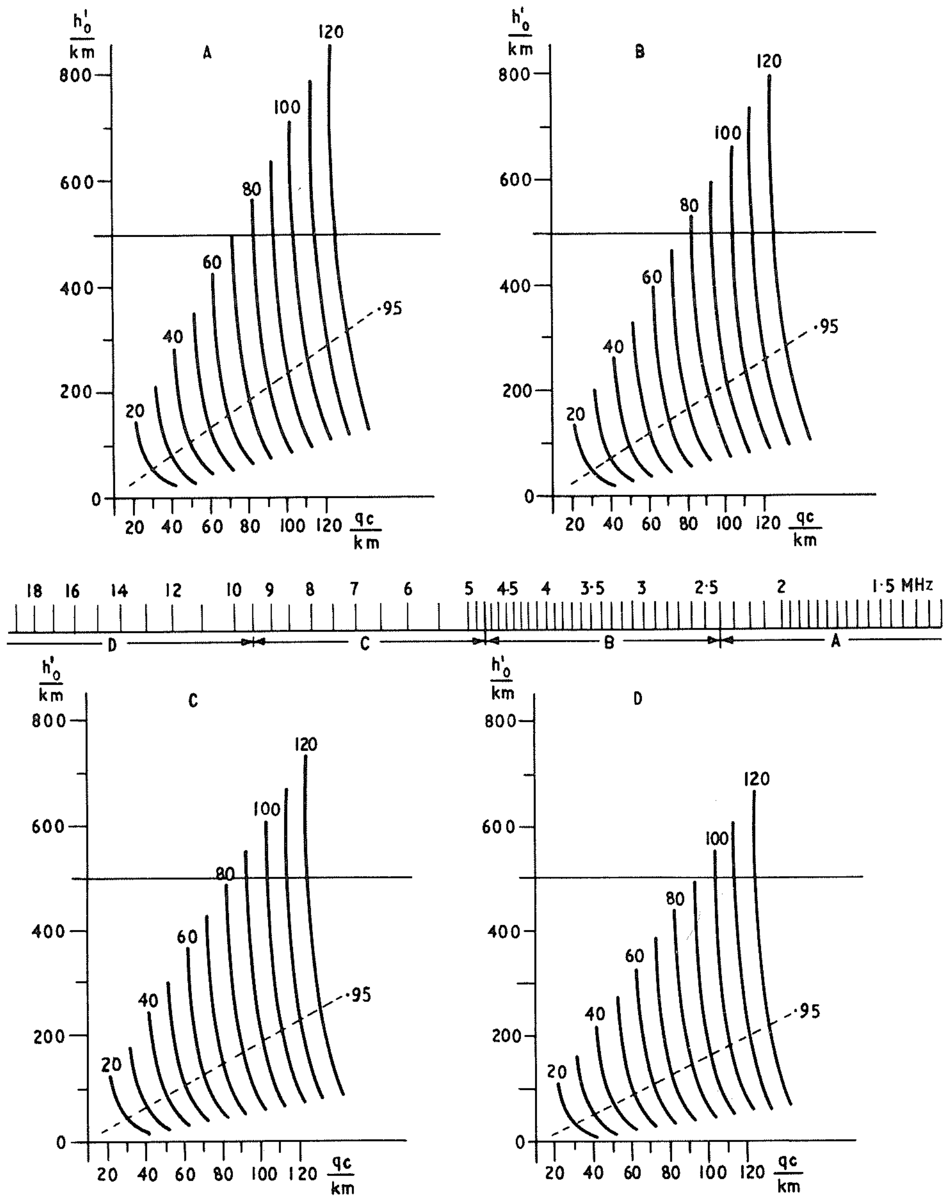


Fig. 10.7. Calculated virtual heights for the o-component for dip 63.5°, fB = 1.25 MHz. Use A, B, C, D according to range of frequency in which foF2 is found. (Note frequency scale from left to right). The appropriate value of qc is shown on the curves.

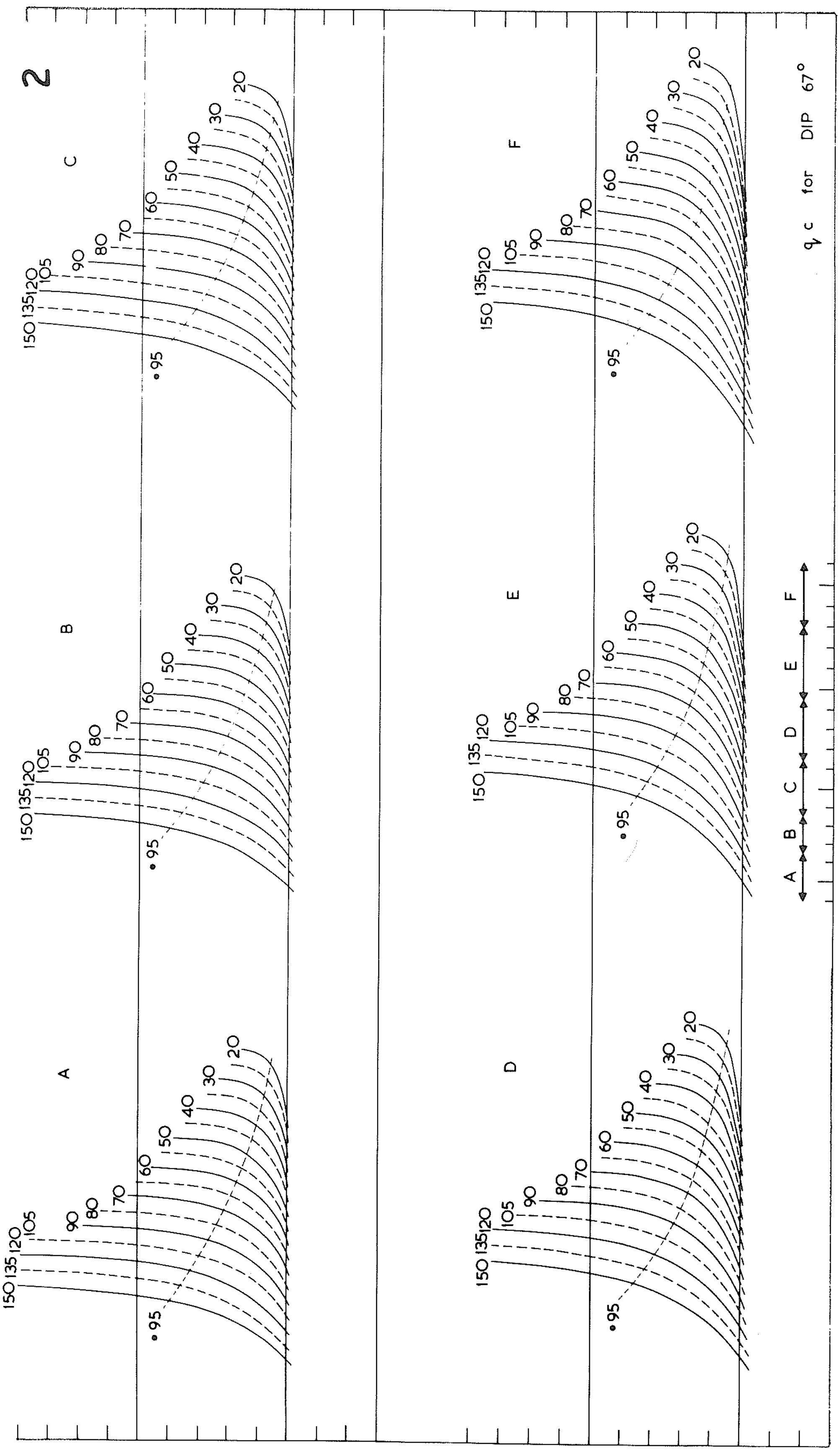


Fig. 10.8 Typical overlay when frequency law is not logarithmic. Dip 67°, fB = 1.3 MHz.
Use A, B, C, D, E, F according into which frequency range foF2 falls.

(d) Move the overlay horizontally and vertically, taking care that the horizontal (or vertical) lines on the overlay are kept parallel to the horizontal (or vertical) lines on the ionogram, until one curve fits the (ordinary) ionogram trace, in particular between 0.95 foF2 and foF2. The critical frequency shown on the overlay must fit with the critical frequency shown on the ionogram. If the trace is not very clear a good value of foF2 can be found by the curve fit itself.

(e) Note the value qc of that standard curve. (If one pattern fits best at frequencies above 0.95 foF2 and another one between 0.9 and 0.95 foF2, the former shall be used.)

(f) Where two standard curves fit equally well or the trace lies between two curves, take the average or interpolate as appropriate.

(g) From Table 10.9 find Δ = 0.6245 qc.

(h) Using the methods described in section 10.3, find the profile height h_3 (for f_3 = 0.95 foF2, where foF2 is eventually obtained by curve fit (d). (A typical example is given in Figure 10.8.) Note the index of missing values.

(i) Add h_3 to Δ . This is hc.

10.5 The Ten-Point Method for Producing Ionization Profiles and Relevant Parameters

10.51. General

It is very inefficient to deduce a profile using the ten-point method applied to selected plasma frequencies but the method is often used when a more efficient method is not available, particularly if only a few sample profiles are required. In this method the ionization profiles are obtained by measuring the real heights for a number of conveniently spaced plasma frequencies and plotting the resultant data as an ionization profile with height or its equivalent, the real height curve, as a function of plasma frequency. The data are usually expressed in tabular form as ionization densities at constant real heights. These are deduced from the smoothed profile or real height curves.

Special care is necessary to identify and smooth out irregularities in the profile due to sampling frequencies falling on a cusp (section 10.28) and to avoid smoothing out ledges and lower layers which are clearly evident on the ionogram. It is desirable to mark the critical frequencies of such ledges on the real height profile at an early stage so as to be able to make additional samples where necessary to define them adequately.

It is not worthwhile to continue the analysis at the low frequency end of the distribution when more than five of the sampling frequencies fall below fmin.

Detailed ionization profiles for the E layer demand special techniques (see section 2.12) and very accurate ionograms, and are not usually attempted using the ten-point method. For all methods it is essential to introduce data given by long wave and other special investigations [e.g., W. R. Piggott and E. V. Thrane, Journ. Atmos. Terr. Phys., 28, 467-479, 1966].

10.52. Selection of plasma frequencies

The effort available should normally be divided according to the following priorities:

(i) it is most important to define the ionization distribution near the height of maximum density of the layer;
(ii) it is next important to define any well-marked stratification, e.g., a well-defined F1 layer; and
(iii) finally the distribution near the bottom of the layer should be estimated.

A good practical rule when sampling, on the average, 10 plasma frequencies is to measure at the following fractions of the critical frequency of the F2 layer:

(1.0), 0.95, 0.90, 0.85, 0.80, 0.75, 0.65, 0.50, 0.40, 0.30.

These correspond to the following fractions of the maximum ionization density:

(1.0), 0.90, 0.81, 0.72, 0.64, 0.56, 0.42, 0.25, 0.16, 0.09.

In general, some of these frequencies will not be needed because they fall on the E trace or lie below fmin. It is preferable to measure hc (section 10.4) rather than f/fc = 1.0.

10.53. Procedure for ionograms with logarithmic frequency scales

(i) Read off critical frequencies of foF2, foF1 and foE, if present, and mark on profile diagram.
(ii) Select plasma frequencies to be measured (section 10.31), and compare Table 10.6.
(iii) Select overlay with a scale applicable to the F2 critical frequency value, foF2 (Table 10.5).
(iv) Set the zero ordinate of the scale to foF2 and measure the virtual heights at the sampling frequencies using the rules given in section 10.2.
(v) Repeat at the next lower plasma frequency (section 10.31) and continue repeating until the scale is no longer appropriate (Table 10.6).
(vi) Change to next lower frequency overlay (Table 10.5) and repeat until profile is complete.
(vii) Examine profile for irregularities at frequencies not showing cusps on ionograms and smooth out, remembering that the ionogram exaggerates any real changes in slope.
(viii) Add any extra points needed to define ledges shown on the ionogram.
(ix) If tabulation is needed, read off plasma frequencies at each 10 km interval of height and also tabulate exact value of hmF2.

When the frequency scale of the ionogram is slightly abnormal, it is usually possible to use the overlay provided that the zero frequency is applied to the correct value of f_N. Any errors are smoothed out. Otherwise either replot the main trace of the ionogram on a standard frequency scale and proceed as above.

10.54. Procedure for ionograms with non-logarithmic scales

Replot the o traces for the thick layers on a logarithmic scale and then proceed as in section 10.53.

10.6 Determination of the Height of the Peak, Sub-Peak Content and Scale Height of the Peak by the Titheridge Method

10.61. The principle of the polynominal method has been given by Titheridge [Radio Science, 2, 1169-1175 and 1237-1253, 1967] and is summarized in section 10.11.

The real height profile N(h) is expressed as a polynomial with a small number of terms, in practice five or six. If the virtual height is measured at a corresponding number of frequencies all the constants of the polynomial can be determined. The frequencies must be chosen so that

(a) these constants are well defined

(b) the resultant model is similar in form to the actual ionosphere.

Titheridge has selected families of sampling frequencies so as to be appropriate for three groups of conditions:

(i) A normal F layer (Table 10.11 below)
(ii) An F layer with marked F1 stratification (Table 10.12 below)
(iii) Night time (Table 10.13 below)

Table 10.12 in (ii) is used when a sample frequency given by Table 10.11 in (i) would fall close to an F1 or E cusp, in which cases the polynomial would be distorted by the abnormally low value of $\frac{dN}{dh}$ in these regions. Titheridge includes a parabolic function near the height of maximum and modifies the polynomial so that it gives dh/dN = 0 at f(N) = 0 and f(N) = fc so that the peak is approximately parabolic. In most cases, the average accuracy is equal to that obtained by carrying out a complete profile calculation using a lamination analysis with more than 20 points. The real heights of reflection at the measured frequencies can also be obtained if required, giving five or six points on the electron-density profile. However, the accuracy of the lowest sample is very poor as it is not possible to correct for underlying ionization. The relations between the true height and the virtual heights at the sampling frequencies depend on the strength and dip of the magnetic field. In practice, the coefficients depend only on the ratio of the critical frequency fc to the gyrofrequency f_B and the magnetic dip angle.

10.62. Sampling frequencies

Virtual heights are always measured at the following fractions of foF2:

Five point	0.150	0.440	0.680	0.870	0.980		(Table 10.11)
Six point	0.150	0.350	0.550	0.750	0.900	0.980	(Table 10.12)

Hence, for logarithmic frequency scales, it is convenient to make overlays similar to Figure 10.5 but with lines at these intervals and a starting line at f/foF2 = 1.000. For other frequency laws it is convenient to construct a table similar to Table 10.7 when numerous calculations must be made, or to make a special cursor at these intervals to fit a standard slide rule.

10.63. Parameters determined

The method gives the following parameters, all measured in km.

(i) The height of maximum electron density, HM.
(ii) A thickness parameter similar to qc which could be identified with the scale height, H, near HM when the layer is in diffusive equilibrium.
(iii) The slab thickness, T, corresponding to the sub-peak electron content. T is defined as the thickness of a rectangular layer with the same maximum electron density as the observed layer which would have the same electron content

$$Nm \cdot T = \int_{0}^{hm} N\, dh \qquad (10.15)$$

Note that the sub-peak slab thickness should not be confused with the total slab thickness as determined, for example, by Faraday observations of Beacon satellites.

(iv) An estimate of true height at the sampling frequencies.

It should be noted that HM should be identical with hc, H with qc when both methods represent the distribution equally accurately. In practice some differences are likely as the sample method is inherently less accurate than a curve fit method so the parameters are kept distinct.

In addition the true heights at the five or six sampling frequencies can be determined from the tables by using the bottom set of entries.

10.64. Basic Tables

Since the shape of the h'f curve for a given profile varies with both dip angle and the ratio of foF2/fB, different factors will be needed for different conditions. The minimum set needed to give the likely accuracy available with the method are reproduced in Tables 10.11, 10.12, 10.13.

The first line of each table gives the dip and center ratio foF2/fB.

The second line gives the sample frequencies for evaluating HM, H and T.

The third, fourth and fifth lines give the factors by which the observed values of h' must be multiplied to calculate HM, H and T, respectively.

Thus if the entries are

For HM,	$\alpha_1\ \alpha_2\ \alpha_3\ \alpha_4\ \alpha_5\ \alpha_6$	line 3
For H,	$\beta_1\ \beta_2\ \beta_3\ \beta_4\ \beta_5\ \beta_6$	line 4
For T,	$\gamma_1\ \gamma_2\ \gamma_3\ \gamma_4\ \gamma_5\ \gamma_6$	line 5

the parameters are given by the following equations:

$$\alpha_1 h'_1 + \alpha_2 h'_2 + \alpha_3 h'_3 + \alpha_4 h'_4 + \alpha_5 h'_5 + \alpha_6 h'_6 = HM \qquad (10.16)$$

$$\beta_1 h'_1 + \beta_2 h'_2 + \beta_3 h'_3 + \beta_4 h'_4 + \beta_5 h'_5 + \beta_6 h'_6 = H \qquad (10.17)$$

$$\gamma_1 h'_1 + \gamma_2 h'_2 + \gamma_3 h'_3 + \gamma_4 h'_4 + \gamma_5 h'_5 + \gamma_6 h'_6 = T \qquad (10.18)$$

For any station a set of accurate sample parameters can be obtained from J. E. Titheridge [Radio Research Centre, University of Auckland, Auckland, New Zealand].

Table 10.11

Five-point coefficients for calculating the height of the peak, the scale height at the peak, the slab thickness, and the real heights of reflection of ionospheric layers with critical frequencies between 1.6fB and 16fB.

DIP = 13° fc = 8.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1928	.1743	.2225	.0933	.3172
H	-.0081	-.0901	.1440	-.4880	.4422
T	-.1923	-.1217	.0078	.0055	.3007
.150	1.2211	-.4350	.3883	-.2267	.0522
.440	.5000	.5734	-.1121	.0487	-.0101
.680	.2886	.3626	.3902	-.0510	.0096
.870	.2276	.2145	.3027	.2679	-.0128
.980	.1970	.2074	.1741	.2768	.1447

DIP = 25° fc = 3.0 fB

f/fc	.150	.440	.680	.870	.980
HM	.1966	.1807	.2254	.0997	.2976
H	-.0100	-.0862	.1304	-.4503	.4160
T	-.1970	-.1154	.0131	.0174	.2819
.150	1.2277	-.4479	.4016	-.2354	.0541
.440	.5148	.5580	-.1112	.0483	-.0099
.680	.2972	.3700	.3730	-.0496	.0093
.870	.2328	.2228	.3033	.2532	-.0121
.980	.2016	.2125	.1818	.2687	.1354

DIP = 25° fc = 10.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1933	.1770	.2222	.1063	.3012
H	-.0095	-.0848	.1276	-.4553	.4220
T	-.1953	-.1188	.0068	.0219	.2854
.150	1.2290	-.4520	.4069	-.2386	.0547
.440	.5076	.5676	-.1150	.0502	-.0103
.680	.2909	.3690	.3821	-.0518	.0098
.870	.2287	.2172	.3082	.2584	-.0125
.980	.1981	.2082	.1800	.2771	.1366

DIP = 35° fc = 2.5 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2002	.1876	.2280	.1107	.2735
H	-.0122	-.0804	.1115	-.4030	.3841
T	-.2027	-.1084	.0177	.0348	.2587
.150	1.2368	-.4665	.4217	-.2488	.0568
.440	.5316	.5411	-.1112	.0484	-.0099
.680	.3061	.3793	.3540	-.0485	.0091
.870	.2379	.2315	.3061	.2359	-.0113
.980	.2060	.2174	.1913	.2615	.1238

DIP = 35° fc = 6.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1955	.1823	.2241	.1195	.2786
H	-.0114	-.0788	.1080	-.4103	.3925
T	-.2003	-.1135	.0094	.0408	.2636
.150	1.2389	-.4729	.4299	-.2536	.0577
.440	.5214	.5546	-.1167	.0512	-.0104
.680	.2971	.3783	.3665	-.0516	.0097
.870	.2319	.2239	.3130	.2432	-.0119
.980	.2010	.2114	.1891	.2729	.1256

DIP = 35° fc = 12.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1935	.1791	.2197	.1216	.2860
H	-.0106	-.0790	.1115	-.4252	.4033
T	-.1977	-.1159	.0027	.0399	.2709
.150	1.2380	-.4711	.4272	-.2511	.0570
.440	.5127	.5643	-.1183	.0517	-.0105
.680	.2920	.3737	.3778	-.0536	.0100
.870	.2293	.2178	.3142	.2512	-.0125
.980	.1987	.2082	.1837	.2806	.1288

DIP = 45° fc = 4.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1990	.1900	.2268	.1346	.2496
H	-.0138	-.0717	.0847	-.3536	.3544
T	-.2072	-.1054	.0133	.0636	.2357
.150	1.2517	-.4996	.4600	-.2738	.0617
.440	.5406	.5356	-.1174	.0516	-.0104
.680	.3065	.3896	.3454	-.0510	.0095
.870	.2370	.2334	.3175	.2232	-.0111
.980	.2054	.2166	.2004	.2661	.1115

DIP = 45° fc = 6.7 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1960	.1855	.2223	.1390	.2573
H	-.0129	-.0713	.0865	-.3682	.3659
T	-.2041	-.1092	.0054	.0647	.2432
.150	1.2518	-.5006	.4605	-.2730	.0613
.440	.5300	.5482	-.1206	.0531	-.0107
.680	.2994	.3855	.3587	-.0536	.0100
.870	.2330	.2258	.3209	.2320	-.0117
.980	.2020	.2119	.1954	.2759	.1148

DIP = 45° fc = 12.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1940	.1819	.2173	.1384	.2685
H	-.0118	-.0726	.0939	-.3909	.3814
T	-.2004	-.1122	-.0014	.0600	.2540
.150	1.2482	-.4928	.4506	-.2655	.0595
.440	.5191	.5598	-.1215	.0532	-.0107
.680	.2938	.3789	.3724	-.0554	.0103
.870	.2303	.2189	.3205	.2427	-.0123
.980	.1996	.2085	.1880	.2841	.1199

DIP = 55° fc = 2.3 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2070	.2029	.2313	.1462	.2126
H	-.0172	-.0641	.0607	-.2842	.3048
T	-.2169	-.0911	.0217	.0863	.2000
.150	1.2660	-.5278	.4924	-.2964	.0658
.440	.5702	.5032	-.1131	.0494	-.0097
.680	.3245	.4016	.3135	-.0486	.0090
.870	.2479	.2489	.3173	.1958	-.0098
.980	.2147	.2269	.2134	.2511	.0939

DIP = 55° fc = 3.5 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2019	.1971	.2281	.1535	.2194
H	-.0161	-.0635	.0596	-.2954	.3153
T	-.2140	-.0970	.0141	.0902	.2066
.150	1.2677	-.5335	.4993	-.2998	.0664
.440	.5586	.5182	-.1188	.0523	-.0103
.680	.3147	.4003	.3270	-.0515	.0095
.870	.2414	.2411	.3239	.2041	-.0104
.980	.2091	.2208	.2110	.2625	.0967

DIP = 55° fc = 5.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1987	.1924	.2243	.1575	.2270
H	-.0151	-.0633	.0614	-.3094	.3264
T	-.2109	-.1013	.0071	.0910	.2140
.150	1.2676	-.5341	.4993	-.2986	.0659
.440	.5482	.5309	-.1223	.0539	-.0106
.680	.3074	.3970	.3396	-.0539	.0099
.870	.2371	.2339	.3275	.2124	-.0109
.980	.2056	.2159	.2068	.2718	.0999

Table 10.11 (continued)

DIP = 45° fc = 2.4 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2035	.1950	.2300	.1271	.2445
H	-.0147	-.0728	.0870	-.3459	.3462
T	-.2095	-.1005	.0205	.0587	.2307
.150	1.2497	-.4936	.4524	-.2694	.0609
.440	.5502	.5229	-.1122	.0490	-.0099
.680	.3150	.3904	.3339	-.0483	.0090
.870	.2427	.2402	.3113	.2164	-.0106
.980	.2102	.2221	.2023	.2558	.1096

DIP = 55° fc = 12.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1944	.1845	.2148	.1556	.2507
H	-.0128	-.0662	.0768	-.3570	.3591
T	-.2031	-.1085	-.0059	.0804	.2370
.150	1.2588	-.5152	.4748	-.2803	.0619
.440	.5251	.5558	-.1248	.0547	-.0108
.680	.2953	.3839	.3675	-.0573	.0105
.870	.2312	.2197	.3268	.2346	-.0122
.980	.2004	.2088	.1920	.2880	.1108

DIP = 66° fc = 2.2 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2109	.2115	.2328	.1677	.1771
H	-.0195	-.0544	.0329	-.2176	.2586
T	-.2250	-.0800	.0219	.1175	.1657
.150	1.2866	-.5707	.5443	-.3317	.0715
.440	.5921	.4812	-.1132	.0493	-.0094
.680	.3350	.4131	.2924	-.0495	.0089
.870	.2535	.2578	.3241	.1736	-.0089
.980	.2194	.2321	.2252	.2468	.0765

DIP = 66° fc = 3.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2058	.2057	.2303	.1737	.1845
H	-.0183	-.0544	.0331	-.2299	.2695
T	-.2220	-.0862	.0154	.1200	.1728
.150	1.2875	-.5747	.5489	-.3333	.0716
.440	.5804	.4962	-.1188	.0521	-.0099
.680	.3252	.4120	.3054	-.0520	.0094
.870	.2470	.2504	.3302	.1819	-.0095
.980	.2139	.2262	.2230	.2573	.0796

DIP = 66° fc = 4.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2022	.2005	.2270	.1778	.1925
H	-.0172	-.0545	.0349	-.2445	.2813
T	-.2187	-.0914	.0088	.1205	.1807
.150	1.2869	-.5749	.5480	-.3311	.0711
.440	.5692	.5101	-.1231	.0543	-.0104
.680	.3170	.4092	.3185	-.0544	.0098
.870	.2421	.2430	.3344	.1906	-.0100
.980	.2099	.2209	.2193	.2669	.0831

DIP = 66° fc = 5.5 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1991	.1955	.2225	.1799	.2029
H	-.0161	-.0551	.0393	-.2642	.2960
T	-.2147	-.0963	.0017	.1185	.1908
.150	1.2843	-.5700	.5406	-.3246	.0697
.440	.5568	.5246	-.1265	.0558	-.0107
.680	.3093	.4043	.3330	-.0567	.0102
.870	.2379	.2350	.3368	.2009	-.0106
.980	.2064	.2159	.2135	.2765	.0877

DIP = 55° fc = 7.5 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1962	.1881	.2195	.1589	.2373
H	-.0140	-.0640	.0667	-.3297	.3409
T	-.2071	-.1051	-.0001	.0883	.2240
.150	1.2649	-.5287	.4916	-.2923	.0645
.440	.5368	.5438	-.1246	.0548	-.0108
.680	.3008	.3913	.3537	-.0561	.0103
.870	.2337	.2263	.3288	.2227	-.0116
.980	.2027	.2117	.2003	.2808	.1045

DIP = 80° fc = 2.2 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2141	.2195	.2353	.1924	.1387
H	-.0207	-.0437	.0054	-.1492	.2081
T	-.2331	-.0686	.0205	.1527	.1285
.150	1.3120	-.6232	.6123	-.3775	.0764
.440	.6132	.4603	-.1139	.0492	-.0087
.680	.3439	.4249	.2738	-.0515	.0088
.870	.2577	.2652	.3334	.1516	-.0079
.980	.2231	.2361	.2380	.2449	.0578

DIP = 80° fc = 3.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2082	.2124	.2326	.1982	.1486
H	-.0193	-.0442	.0071	-.1661	.2226
T	-.2287	-.0767	.0134	.1538	.1382
.150	1.3116	-.6251	.6116	-.3739	.0758
.440	.5975	.4800	-.1208	.0527	-.0094
.680	.3315	.4233	.2902	-.0543	.0093
.870	.2499	.2563	.3403	.1621	-.0086
.980	.2166	.2292	.2350	.2571	.0621

DIP = 80° fc = 3.9 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2045	.2070	.2289	.2014	.1582
H	-.0182	-.0448	.0099	-.1832	.2363
T	-.2245	-.0828	.0070	.1527	.1476
.150	1.3097	-.6215	.6038	-.3666	.0746
.440	.5842	.4961	-.1254	.0550	-.0099
.680	.3224	.4201	.3044	-.0566	.0097
.870	.2448	.2485	.3441	.1717	-.0091
.980	.2125	.2238	.2306	.2666	.0664

DIP = 80° fc = 5.0 fB

f/fc =	.150	.440	.680	.870	.980
HM	.2020	.2023	.2243	.2027	.1687
H	-.0173	-.0457	.0142	-.2024	.2512
T	-.2204	-.0878	.0008	.1496	.1579
.150	1.3057	-.6130	.5912	-.3569	.0731
.440	.5723	.5101	-.1287	.0566	-.0103
.680	.3154	.4156	.3174	-.0585	.0101
.870	.2413	.2413	.3456	.1815	-.0097
.980	.2096	.2193	.2247	.2752	.0711

DIP = 80° fc = 6.5 fB

f/fc =	.150	.440	.680	.870	.980
HM	.1998	.1977	.2185	.2022	.1818
H	-.0165	-.0471	.0207	-.2266	.2695
T	-.2165	-.0926	-.0056	.1441	.1707
.150	1.2990	-.5994	.5742	-.3453	.0714
.440	.5608	.5233	-.1315	.0581	-.0107
.680	.3095	.4095	.3307	-.0602	.0105
.870	.2385	.2340	.3449	.1930	-.0105
.980	.2072	.2151	.2167	.2840	.0771

Table 10.11 (continued)

DIP = 66°			fc = 8.0 fB		
f/fc =	.150	.440	.680	.870	.980
HM	.1966	.1907	.2169	.1790	.2168
H	-.0149	-.0567	.0478	-.2914	.3153
T	-.2102	-.1008	-.0056	.1123	.2043
.150	1.2786	-.5578	.5244	-.3125	.0673
.440	.5434	.5394	-.1285	.0566	-.0109
.680	.3022	.3970	.3489	-.0586	.0105
.870	.2345	.2268	.3365	.2137	-.0114
.980	.2034	.2116	.2050	.2859	.0941

DIP 80°			fc = 9.0 fB		
f/fc =	.150	.440	.680	.870	.980
HM	.1971	.1923	.2114	.1984	.2007
H	-.0155	-.0499	.0324	-.2624	.2954
T	-.2122	-.0978	-.0127	.1336	.1890
.150	1.2885	-.5792	.5515	-.3299	.0691
.440	.5479	.5378	-.1340	.0594	-.0111
.680	.3036	.4005	.3466	-.0614	.0108
.870	.2353	.2255	.3418	.2088	-.0114
.980	.2042	.2106	.2055	.2940	.0858

DIP = 66°			fc = 12.0 fB		
f/fc =	.150	.440	.680	.870	.980
HM	.1948	.1869	.2119	.1738	.2326
H	-.0137	-.0597	.0602	-.3233	.3365
T	-.2057	-.1047	-.0109	.1016	.2097
.150	1.2699	-.5390	.5012	-.2962	.0640
.440	.5309	.5521	-.1284	.0563	-.0109
.680	.2967	.3885	.3635	-.0594	.0107
.870	.2319	.2199	.3332	.2271	-.0121
.980	.2011	.2087	.1955	.2931	.1016

DIP 80°			fc = 12.5 fB		
f/fc =	.150	.440	.680	.870	.980
HM	.1945	.1874	.2064	.1907	.2210
H	-.0144	-.0541	.0479	-.3021	.3227
T	-.2083	-.1020	-.0179	.1195	.2087
.150	1.2782	-.5597	.5289	-.3139	.0665
.440	.5361	.5501	-.1341	.0591	-.0112
.680	.2981	.3906	.3622	-.0618	.0109
.870	.2321	.2180	.3375	.2246	-.0122
.980	.2011	.2071	.1949	.3015	.0955

Table 10.12

Six-point coefficients for calculations on the daytime F layer, for critical frequencies between 2fB and 20fB.

DIP = 13° fc = 8.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1761	.1129	.1409	.2294	.0137	.3271
H	-.0367	.0617	-.1770	.2471	-.6247	.5296
T	-.2072	.0095	-.1980	.1680	-.1012	.3288
.150	1.4073	-.8152	.7163	-.5399	.3100	-.0784
.350	.6242	.3390	.0829	-.0855	.0532	-.0138
.550	.3557	.2175	.5157	-.1470	.0772	-.0190
.750	.2619	.0941	.3792	.2721	-.0070	-.0003
.900	.2082	.1032	.2156	.2416	.2479	-.0165
.980	.1903	.0919	.2042	.1469	.2436	.1230

DIP = 45° fc = 5.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1850	.1038	.1739	.2116	.0719	.2539
H	-.0323	.0407	-.1376	.1655	-.4582	.4218
T	-.2197	.0131	-.1848	.1764	-.0461	.2611
.150	1.4601	-.9378	.8431	-.6508	.3798	-.0944
.350	.6779	.2725	.1070	-.1076	.0673	-.0171
.550	.3784	.2303	.4866	-.1609	.0867	-.0211
.750	.2733	.0998	.4080	.2203	.0006	-.0021
.900	.2171	.1010	.2436	.2408	.2140	-.0164
.980	.1977	.0904	.2235	.1583	.2385	.0916

DIP = 25° fc = 4.0 fB

f/fc	.150	.350	.550	.750	.900	.980
HM	.1799	.1116	.1515	.2254	.0256	.3060
H	-.0358	.0559	-.1669	.2272	-.5780	.4976
T	-.2114	.0106	-.1913	.1718	-.0888	.3091
.150	1.4191	-.8412	.7413	-.5610	.3234	-.0816
.350	.6422	.3167	.0905	-.0917	.0570	-.0147
.550	.3653	.2211	.5031	-.1488	.0787	-.0194
.750	.2672	.0982	.3852	.2547	-.0043	-.0009
.900	.2123	.1039	.2253	.2382	.2364	-.0162
.980	.1939	.0927	.2114	.1498	.2380	.1143

DIP = 45° fc = 9.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1822	.1026	.1676	.2098	.0739	.2639
H	-.0321	.0431	-.1397	.1697	-.4795	.4386
T	-.2160	.0117	-.1901	.1692	-.0453	.2705
.150	1.4584	-.9335	.8389	-.6460	.3753	-.0929
.350	.6633	.2920	.0988	-.1016	.0636	-.0162
.550	.3692	.2281	.4992	-.1623	.0868	-.0210
.750	.2688	.0938	.4071	.2339	-.0021	-.0015
.900	.2135	.0989	.2354	.2466	.2225	-.0170
.980	.1949	.0883	.2177	.1556	.2483	.0952

DIP = 25° fc = 14.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1773	.1099	.1473	.2242	.0308	.3105
H	-.0353	.0566	-.1667	.2252	-.5858	.5060
T	-.2092	.0097	-.1965	.1676	-.0852	.3136
.150	1.4209	-.8466	.7489	-.5680	.3271	-.0823
.350	.6333	.3285	.0859	-.0889	.0555	-.0143
.550	.3581	.2207	.5123	-.1513	.0798	-.0196
.750	.2631	.0933	.3871	.2630	-.0061	-.0005
.900	.2091	.1017	.2201	.2443	.2414	-.0166
.980	.1911	.0908	.2069	.1497	.2458	.1157

DIP = 45° fc = 16.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1803	.1034	.1612	.2095	.0693	.2763
H	-.0325	.0463	-.1443	.1805	-.5079	.4579
T	-.2126	.0105	-.1926	.1626	-.0496	.2819
.150	1.4501	-.9130	.8161	-.6250	.3611	-.0893
.350	.6496	.3100	.0913	-.0953	.0596	-.0151
.550	.3627	.2247	.5088	-.1609	.0853	-.0206
.750	.2659	.0904	.4019	.2473	-.0047	-.0009
.900	.2112	.0988	.2273	.2492	.2307	-.0172
.980	.1930	.0880	.2128	.1518	.2543	.1001

DIP = 35° fc = 3.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1845	.1097	.1646	.2199	.0418	.2795
H	-.0347	.0487	-.1539	.2015	-.5193	.4578
T	-.2167	.0125	-.1839	.1762	-.0727	.2845
.150	1.4347	-.8762	.7760	-.5909	.3425	-.0861
.350	.6646	.2886	.1007	-.1001	.0623	-.0160
.550	.3771	.2250	.4886	-.1519	.0811	-.0199
.750	.2736	.1025	.3931	.2333	-.0009	-.0017
.900	.2174	.1046	.2370	.2343	.2226	-.0160
.980	.1982	.0934	.2200	.1532	.2319	.1033

DIP = 55° fc = 3.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1927	.1018	.1948	.2023	.0942	.2142
H	-.0310	.0306	-.1190	.1302	-.3727	.3620
T	-.2288	.0181	-.1736	.1850	-.0252	.2245
.150	1.4846	-.9954	.9019	-.7039	.4149	-.1020
.350	.7148	.2236	.1281	-.1254	.0786	-.0197
.550	.3992	.2330	.4653	-.1668	.0914	-.0220
.750	.2847	.1069	.4188	.1863	.0068	-.0035
.900	.2257	.1027	.2622	.2319	.1937	-.0162
.980	.2051	.0919	.2381	.1612	.2287	.0751

DIP = 35° fc = 7.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1808	.1072	.1593	.2190	.0491	.2847
H	-.0339	.0493	-.1535	.1979	-.5273	.4675
T	-.2139	.0109	-.1909	.1718	-.0675	.2896
.150	1.4381	-.8864	.7898	-.6036	.3497	-.0876
.350	.6536	.3034	.0949	-.0968	.0605	-.0155
.550	.3672	.2258	.4998	-.1552	.0827	-.0202
.750	.2676	.0966	.3967	.2433	-.0030	-.0012
.900	.2127	.1014	.2310	.2428	.2286	-.0165
.980	.1941	.0906	.2145	.1542	.2419	.1047

DIP = 55° fc = 4.3 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1892	.0997	.1895	.2022	.0985	.2209
H	-.0304	.0319	-.1202	.1304	-.3852	.3735
T	-.2258	.0162	-.1797	.1808	-.0223	.2309
.150	1.4865	-1.0011	.9099	-.7108	.4180	-.1025
.350	.7031	.2395	.1214	-.1209	.0759	-.0190
.550	.3896	.2338	.4754	-.1687	.0920	-.0221
.750	.2790	.1018	.4209	.1967	.0046	-.0030
.900	.2213	.0998	.2565	.2390	.1999	-.0166
.980	.2014	.0893	.2331	.1615	.2374	.0773

Table 10.12 (continued)

DIP = 35° fc = 15.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1788	.1067	.1542	.2172	.0494	.2936
H	-.0340	.0514	-.1557	.2031	-.5470	.4822
T	-.2110	.0101	-.1946	.1656	-.0680	.2979
.150	1.4352	-.8793	.7822	-.5963	.3441	-.0860
.350	.6418	.3187	.0888	-.0923	.0577	-.0148
.550	.3606	.2229	.5101	-.1560	.0826	-.0201
.750	.2646	.0921	.3946	.2547	-.0052	-.0007
.900	.2102	.1003	.2240	.2466	.2358	-.0169
.980	.1921	.0894	.2100	.1510	.2495	.1080

DIP = 55° fc = 6.5 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1862	.0984	.1828	.2015	.1004	.2307
H	-.0302	.0342	-.1226	.1344	-.4056	.3898
T	-.2220	.0144	-.1852	.1741	-.0213	.2400
.150	1.4849	-.9968	.9057	-.7059	.4131	-.1010
.350	.6884	.2596	.1124	-.1141	.0716	-.0179
.550	.3798	.2328	.4873	-.1697	.0918	-.0220
.750	.2740	.0959	.4205	.2101	.0018	-.0024
.900	.2175	.0976	.2484	.2455	.2080	-.0170
.980	.1982	.0872	.2271	.1599	.2467	.0809

DIP = 45° fc = 3.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1886	.1062	.1789	.2122	.0659	.2482
H	-.0330	.0398	-.1372	.1673	-.4483	.4115
T	-.2225	.0147	-.1782	.1805	-.0502	.2556
.150	1.4570	-.9289	.8311	-.6400	.3739	-.0932
.350	.6889	.2576	.1129	-.1112	.0694	-.0177
.550	.3880	.2296	.4759	-.1581	.0855	-.0209
.750	.2791	.1054	.4050	.2104	.0027	-.0025
.900	.2216	.1041	.2403	.2331	.2080	-.0160
.980	.2016	.0931	.2286	.1577	.2292	.0898

DIP = 55° fc = 10.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1839	.0985	.1759	.2009	.0978	.2431
H	-.0304	.0373	-.1265	.1432	-.4329	.4093
T	-.2181	.0127	-.1887	.1666	-.0238	.2513
.150	1.4780	-.9790	.8856	-.6865	.3994	-.0975
.350	.6730	.2805	.1029	-.1064	.0667	-.0167
.550	.3716	.2300	.4983	-.1688	.0905	-.0216
.750	.2703	.0914	.4166	.2246	-.0011	-.0017
.900	.2146	.0967	.2396	.2498	.2165	-.0173
.980	.1959	.0863	.2212	.1566	.2542	.0857

DIP = 55° fc = 16.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1818	.1000	.1685	.2017	.0897	.2583
H	-.0310	.0412	-.1327	.1577	-.4677	.4326
T	-.2144	.0110	-.1906	.1598	-.0310	.2652
.150	1.4657	-.9484	.8518	-.6557	.3793	-.0927
.350	.6577	.3007	.0939	-.0987	.0618	-.0155
.550	.3651	.2266	.5072	-.1660	.0882	-.0211
.750	.2674	.0889	.4095	.2394	-.0040	-.0011
.900	.2123	.0973	.2309	.2516	.2255	-.0175
.980	.1940	.0865	.2159	.1524	.2592	.0920

DIP = 80° fc = 2.6 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.2038	.0915	.2349	.1777	.1600	.1320
H	-.0260	.0112	-.0772	.0498	-.1985	.2406
T	-.2449	.0310	-.1647	.2008	.0287	.1490
.150	1.5541	-1.1738	1.0938	-.8851	.5324	-.1215
.350	.7795	.1329	.1750	-.1702	.1077	-.0250
.550	.4291	.2346	.4442	-.1920	.1085	-.0244
.750	.2999	.1093	.4516	.1263	.0189	-.0059
.900	.2367	.0989	.2946	.2241	.1620	-.0163
.980	.2145	.0885	.2636	.1654	.2281	.0399

DIP = 66° fc = 2.7 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1985	.0973	.2142	.1904	.1248	.1748
H	-.0289	.0207	-.0988	.0907	-.2876	.3039
T	-.2369	.0239	-.1679	.1919	.0006	.1884
.150	1.5167	-1.0750	.9866	-.7825	.4662	-.1119
.350	.7470	.1794	.1498	-.1455	.0916	-.0224
.550	.4149	.2343	.4529	-.1776	.0989	-.0233
.750	.2929	.1092	.4336	.1566	.0125	-.0047
.900	.2318	.1016	.2780	.2275	.1775	-.0163
.980	.2102	.0910	.2505	.1633	.2269	.0581

DIP = 80° fc = 3.3 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1999	.0897	.2289	.1793	.1619	.1402
H	-.0256	.0130	-.0797	.0522	-.2139	.2540
T	-.2410	.0279	-.1702	.1961	.0308	.1565
.150	1.5550	-1.1742	1.0943	-.8826	.5280	-.1206
.350	.7654	.1531	.1650	-.1620	.1023	-.0238
.550	.4176	.2373	.4534	-.1915	.1073	-.0241
.750	.2932	.1048	.4531	.1384	.0159	-.0053
.900	.2318	.0964	.2886	.2318	.1680	-.0166
.980	.2104	.0862	.2583	.1666	.2356	.0429

DIP = 66° fc = 3.7 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1943	.0951	.2078	.1914	.1284	.1831
H	-.0283	.0224	-.1009	.0923	-.3033	.3179
T	-.2332	.0211	-.1746	.1873	.0032	.1962
.150	1.5180	-1.0786	.9925	-.7871	.4671	-.1118
.350	.7331	.1989	.1409	-.1391	.0876	-.0214
.550	.4033	.2363	.4636	-.1788	.0988	-.0232
.750	.2860	.1038	.4356	.1689	.0098	-.0041
.900	.2265	.0985	.2715	.2358	.1844	-.0167
.980	.2057	.0881	.2446	.1643	.2361	.0611

DIP = 80° fc = 4.2 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1969	.0886	.2222	.1801	.1626	.1496
H	-.0254	.0151	-.0825	.0560	-.2325	.2693
T	-.2370	.0249	-.1747	.1898	.0319	.1651
.150	1.5539	-1.1675	1.0851	-.8714	.5187	-.1188
.350	.7504	.1748	.1536	-.1526	.0962	-.0225
.550	.4070	.2389	.4625	-.1905	.1059	-.0238
.750	.2878	.1002	.4528	.1511	.0128	-.0047
.900	.2279	.0944	.2815	.2385	.1745	-.0168
.980	.2073	.0844	.2524	.1665	.2430	.0465

Table 10.12 (continued)

DIP = 66° fc = 5.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1912	.0937	.2012	.1915	.1298	.1926
H	-.0281	.0246	-.1035	.0961	-.3226	.3334
T	-.2294	.0188	-.1799	.1813	.0043	.2049
.150	1.5165	-1.0741	.9879	-.7814	.4615	-.1103
.350	.7186	.2192	.1312	-.1315	.0828	-.0202
.550	.3932	.2364	.4742	-.1791	.0983	-.0230
.750	.2807	.0985	.4356	.1818	.0070	-.0035
.900	.2225	.0962	.2642	.2425	.1917	-.0170
.980	.2024	.0860	.2388	.1635	.2446	.0646

DIP = 80° fc = 5.5 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1941	.0883	.2138	.1803	.1614	.1621
H	-.0256	.0177	-.0861	.0624	-.2578	.2893
T	-.2325	.0215	-.1786	.1816	.0315	.1765
.150	1.5482	-1.1488	1.0627	-.8499	.5037	-.1159
.350	.7332	.2000	.1398	-.1413	.0891	-.0209
.550	.3968	.2395	.4720	-.1889	.1042	-.0235
.750	.2831	.0957	.4499	.1659	.0094	-.0040
.900	.2245	.0931	.2723	.2446	.1827	-.0172
.980	.2044	.0832	.2451	.1649	.2511	.0513

DIP = 66° fc = 7.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1883	.0933	.1934	.1914	.1284	.2051
H	-.0282	.0276	-.1072	.1036	-.3491	.3533
T	-.2251	.0164	-.1843	.1736	.0030	.2164
.150	1.5107	-1.0582	.9700	-.7635	.4482	-.1072
.350	.7020	.2424	.1198	-.1223	.0769	-.0188
.550	.3835	.2351	.4855	-.1784	.0969	-.0227
.750	.2761	.0933	.4328	.1969	.0037	-.0028
.900	.2190	.0947	.2550	.2482	.2003	-.0173
.980	.1996	.0846	.2321	.1613	.2529	.0694

DIP = 80° fc = 7.5 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1910	.0890	.2032	.1805	.1568	.1795
H	-.0261	.0211	-.0914	.0736	-.2941	.3168
T	-.2277	.0177	-.1823	.1719	.0278	.1926
.150	1.5353	-1.1142	1.0267	-.8185	.4328	-.1120
.350	.7139	.2284	.1244	-.1287	.0813	-.0193
.550	.3871	.2385	.4824	-.1869	.1022	-.0232
.750	.2787	.0915	.4436	.1840	.0054	-.0032
.900	.2210	.0926	.2602	.2503	.1934	-.0176
.980	.2015	.0826	.2361	.1616	.2601	.0581

DIP = 66° fc = 10.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1859	.0941	.1853	.1917	.1232	.2198
H	-.0285	.0310	-.1123	.1153	-.3817	.3762
T	-.2209	.0141	-.1871	.1654	-.0013	.2297
.150	1.5000	-1.0306	.9394	-.7345	.4283	-.1025
.350	.6852	.2656	.1085	-.1128	.0708	-.0174
.550	.3753	.2324	.4959	-.1762	.0948	-.0222
.750	.2723	.0894	.4270	.2130	.0004	-.0021
.900	.2161	.0945	.2452	.2522	.2096	-.0176
.980	.1972	.0842	.2256	.1578	.2598	.0753

DIP = 80° fc = 10.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1879	.0901	.1931	.1815	.1492	.1982
H	-.0267	.0247	-.0979	.0884	-.3342	.3456
T	-.2238	.0149	-.1855	.1638	.0209	.2098
.150	1.5190	-1.0766	.9909	-.7870	.4615	-.1079
.350	.6972	.2522	.1123	-.1187	.0749	-.0179
.550	.3796	.2356	.4923	-.1847	.1001	-.0229
.750	.2749	.0882	.4358	.2017	.0019	-.0025
.900	.2178	.0927	.2489	.2543	.2043	-.0180
.980	.1986	.0825	.2281	.1577	.2674	.0656

DIP = 66° fc = 15.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1836	.0961	.1770	.1933	.1133	.2366
H	-.0293	.0354	-.1195	.1319	-.4200	.4015
T	-.2166	.0119	-.1886	.1577	-.0093	.2450
.150	1.4840	-.9915	.8966	-.6942	.4016	-.0964
.350	.6681	.2885	.0979	-.1032	.0646	-.0159
.550	.3680	.2287	.5053	-.1720	.0915	-.0215
.750	.2690	.0871	.4184	.2298	-.0030	-.0013
.900	.2135	.0955	.2354	.2544	.2190	-.0177
.980	.1952	.0847	.2196	.1538	.2644	.0824

DIP = 80° fc = 15.0 fB

f/fc =	.150	.350	.550	.750	.900	.980
HM	.1639	.0920	.1810	.1851	.1331	.2249
H	-.0278	.0310	-.1098	.1147	-.3942	.3861
T	-.2191	.0130	-.1902	.1557	.0061	.2345
.150	1.4976	-1.0294	.9449	-.7415	.4299	-.1014
.350	.6769	.2787	.1013	-.1085	.0681	-.0165
.550	.3707	.2285	.5070	-.1804	.0963	-.0222
.750	.2698	.0839	.4247	.2255	-.0024	-.0016
.900	.2134	.0929	.2357	.2575	.2189	-.0183
.980	.1950	.0821	.2199	.1523	.2740	.0767

Table 10.13

Coefficients including an extraordinary ray correction for underlying ionization, for critical frequencies between about 2fB and 10fB.

DIP = 5° fc= 2.5 fB, f1= 1.00 fB, fx= 1.62 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.5640	-.2724	.1706	.1837	.0229	.3313
H	-.0171	.0449	-.2445	.3424	-.6729	.5472
T	-.4706	.3041	-.3165	.2870	-.1485	.3445
f1	1.6906	-.8074	.2335	-.1784	.0806	-.0191
.600	1.0067	-.4961	.6686	-.2651	.1090	-.0251
.750	.7558	-.3936	.4789	.1272	.0424	-.0108
.900	.6303	-.3178	.2716	.1603	.2776	-.0219
.980	.5741	-.2903	.2579	.0673	.2704	.1206

DIP = 5° fc= 5.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.500	.700	.880	.980
HM	.3776	-.1267	.1233	.2416	.0560	.3282
H	-.0663	.1073	-.2209	.2831	-.5899	.4866
T	-.4123	.2270	-.1884	.1062	-.0513	.3189
f1	1.9556	-.9813	.0431	-.0263	.0113	-.0024
.500	.8545	-.3238	.5507	-.1152	.0425	-.0087
.700	.5874	-.2631	.3917	.2954	-.0131	.0017
.880	.4511	-.1741	.1911	.2797	.2657	-.0135
.980	.4038	-.1656	.2023	.1446	.2754	.1395

DIP = 15° fc= 2.5 fB, f1= 1.00 fB, fx= 1.62 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.5874	-.2817	.1545	.1966	.0198	.3234
H	-.0221	.0458	-.2346	.3294	-.6504	.5319
T	-.4921	.3131	-.2876	.2681	-.1348	.3334
f1	1.7490	-.8353	.1722	-.1311	.0591	-.0140
.600	1.0532	-.5137	.6209	-.2335	.0949	-.0218
.750	.7916	-.4070	.4477	.1437	.0323	-.0083
.900	.6583	-.3285	.2504	.1761	.2634	-.0197
.980	.5994	-.3000	.2382	.0848	.2588	.1187

DIP = 15° fc= 5.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.500	.700	.880	.980
HM	.3871	-.1343	.1265	.2416	.0599	.3192
H	-.0708	.1086	-.2138	.2723	-.5700	.4737
T	-.4266	.2376	-.1822	.1059	-.0448	.3101
f1	2.0138	-1.0336	.0333	-.0203	.0087	-.0019
.500	.8808	-.3417	.5410	-.1133	.0418	-.0085
.700	.6061	-.2757	.3915	.2895	-.0132	.0018
.880	.4636	-.1833	.1937	.2799	.2594	-.0132
.980	.4150	-.1738	.2030	.1485	.2718	.1355

DIP = 25° fc= 2.5 fB, f1= 1.00 fB, fx= 1.62 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.6277	-.2953	.1192	.2260	.0140	.3084
H	-.0316	.0469	-.2149	.3023	-.6052	.5024
T	-.5340	.3282	-.2298	.2301	-.1059	.3114
f1	1.8596	-.8817	.0424	-.0305	.0133	-.0031
.600	1.1357	-.5414	.5228	-.1677	.0653	-.0147
.750	.8558	-.4272	.3837	.1800	.0108	-.0032
.900	.7074	-.3443	.2055	.2120	.2345	-.0150
.980	.6435	-.3140	.1958	.1238	.2360	.1150

DIP = 25° fc= 4.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.540	.720	.890	.980
HM	.5290	-.2445	.1268	.2354	.0497	.3036
H	-.0537	.0743	-.1931	.2528	-.5513	.4710
T	-.5301	.3196	-.1747	.1368	-.0500	.2983
f1	2.1200	-1.1325	.0222	-.0146	.0064	-.0015
.540	1.0914	-.5215	.5215	-.1298	.0492	-.0108
.720	.7751	-.3983	.3838	.2448	-.0058	.0004
.890	.6141	-.2990	.1968	.2579	.2446	-.0144
.980	.5519	-.2725	.1957	.1501	.2534	.1215

DIP = 35° fc= 2.5 fB, f1= 1.00 fB, fx= 1.62 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.6795	-.3100	.0657	.2701	.0073	.2874
H	-.0438	.0476	-.1866	.2613	-.5397	.4611
T	-.5914	.3461	-.1474	.1739	-.0614	.2802
f1	2.0120	-.9370	-.1541	.1228	-.0573	.0136
.600	1.2457	-.5726	.3806	-.0707	.0212	-.0043
.750	.9391	-.4493	.2918	.2355	-.0216	.0045
.900	.7705	-.3614	.1382	.2681	.1927	-.0082
.980	.7000	-.3291	.1319	.1826	.2045	.1101

DIP = 35° fc= 4.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.540	.720	.890	.980
HM	.5591	-.2644	.1203	.2422	.0623	.2805
H	-.0615	.0734	-.1712	.2182	-.4949	.4361
T	-.5721	.3446	-.1448	.1215	-.0229	.2737
f1	2.2653	-1.2353	-.0551	.0387	-.0176	.0040
.540	1.1678	-.5643	.4728	-.1071	.0392	-.0084
.720	.8274	-.4277	.3648	.2463	-.0129	.0021
.890	.6513	-.3215	.1848	.2728	.2252	-.0127
.980	.5850	-.2922	.1814	.1694	.2444	.1120

DIP = 35° fc= 7.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.450	.680	.870	.980
HM	.2267	-.0095	.1487	.2432	.1079	.2829
H	-.1732	.2107	-.1822	.2059	-.4683	.4071
T	-.3706	.1931	-.1686	.0649	.0088	.2723
f1	2.2727	-1.2670	-.0089	.0048	-.0021	.0004
.450	.6414	-.0969	.5178	-.0893	.0334	-.0064
.680	.4735	-.1835	.4141	.3171	-.0249	.0038
.870	.3023	-.0551	.2053	.3173	.2414	-.0112
.980	.2896	-.0840	.2141	.1739	.2817	.1247

DIP = 45° fc= 2.4 fB, f1= 1.00 fB, fx= 1.62 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.7796	-.3396	-.0449	.3514	-.0110	.2644
H	-.0554	.0485	-.1568	.2133	-.4610	.4114
T	-.6780	.3772	-.0350	.0963	-.0018	.2413
f1	2.2278	-.9867	-.4720	.3557	-.1628	.0380
.600	1.4492	-.6322	.1242	.1010	-.0557	.0136
.750	1.0882	-.4921	.1232	.3405	-.0772	.0174
.900	.8876	-.3952	.0067	.3688	.1292	.0030
.980	.8052	-.3593	.0099	.2816	.1562	.1064

DIP = 45° fc= 3.5 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc=	(f1)	(fx)	.540	.720	.890	.980
HM	.6929	-.3453	.0495	.2851	.0625	.2553
H	-.0607	.0707	-.1588	.1853	-.4301	.3937
T	-.6843	.4194	-.0815	.0884	.0158	.2422
f1	2.4609	-1.3130	-.2495	.1534	-.0667	.0149
.540	1.4621	-.7356	.2821	-.0061	-.0037	.0012
.720	1.0185	-.5417	.2637	.2909	-.0394	.0080
.890	.8037	-.4126	.1024	.3279	.1857	-.0071
.980	.7197	-.3728	.1056	.2245	.2198	.1033

DIP = 45° fc= 6.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc=	(f1)	(fx)	.470	.690	.880	.980
HM	.3353	-.1017	.1506	.2422	.1177	.2560
H	-.1159	.1337	-.1433	.1512	-.4111	.3854
T	-.4487	.2503	-.1501	.0718	.0283	.2484
f1	2.4531	-1.4257	-.0434	.0247	-.0111	.0024
.470	.8586	-.2868	.4935	-.0933	.0354	-.0074
.690	.5933	-.2728	.4082	.2909	-.0235	.0040
.880	.4136	-.1473	.2016	.3150	.2304	-.0132
.980	.3785	-.1493	.2018	.1933	.2692	.1065

Table 10.13 (continued)

DIP = 25° fc= 7.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.450	.680	.870	.980
HM	.2170	.0018	.1402	.2482	.0897	.3031
H	-.1708	.2177	-.2036	.2372	-.5139	.4334
T	-.3517	.1806	-.1770	.0690	-.0123	.2914
f1	2.1173	-1.1199	.0039	-.0020	.0009	-.0002
.450	.6195	-.0851	.5265	-.0871	.0323	-.0062
.680	.4515	-.1658	.4075	.3275	-.0245	.0037
.870	.2922	-.0462	.2008	.3124	.2521	-.0113
.980	.2792	-.0755	.2133	.1671	.2812	.1346

DIP = 55° fc= 8.0 fB, f1= 1.00 fB, fx= 1.62 fB

f/fc =	(f1)	(fx)	.540	.720	.890	.980
HM	.6312	-.2724	.0484	.2900	.0800	.2227
H	-.0566	.0517	-.1245	.1379	-.3531	.3446
T	-.6246	.3346	-.0355	.0644	.0535	.2077
f1	2.2976	-1.0923	-.3539	.2271	-.1009	.0223
.540	1.3509	-.5841	.2236	.0223	-.0169	.0041
.720	.9350	-.4276	.2397	.2918	-.0490	.0100
.890	.7340	-.3246	.0918	.3440	.1598	-.0051
.980	.6561	-.2926	.0923	.2465	.2079	.0898

DIP = 55° fc= 4.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.540	.720	.890	.980
HM	.6287	-.3073	.0968	.2607	.0957	.2254
H	-.0743	.0670	-.1186	.1338	-.3608	.3529
T	-.6709	.3987	-.0650	.0725	.0510	.2137
f1	2.6198	-1.4656	-.2831	.2004	-.0920	.0205
.540	1.3435	-.6554	.3459	-.0420	.0097	-.0016
.720	.9449	-.4891	.3095	.2629	-.0351	.0070
.890	.7353	-.3681	.1444	.3184	.1781	-.0082
.980	.6597	-.3332	.1389	.2188	.2265	.0893

DIP = 55° fc= 6.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.470	.690	.880	.980
HM	.3564	-.1225	.1573	.2377	.1403	.2307
H	-.1137	.1229	-.1210	.1173	-.3568	.3514
T	-.4800	.2725	-.1367	.0645	.0558	.2240
f1	2.6618	-1.6107	-.0812	.0467	-.0211	.0046
.470	.9081	-.3211	.4779	-.0929	.0352	-.0072
.690	.6296	-.3016	.4111	.2820	-.0255	.0043
.880	.4355	-.1659	.2028	.3228	.2178	-.0129
.980	.3987	-.1660	.2004	.2014	.2709	.0945

DIP = 66° fc= 2.2 fB, f1= .90 fB, fx= 1.53 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.8413	-.3069	-.1841	.4684	-.0223	.2036
H	-.0766	.0394	-.0749	.0935	-.2765	.2951
T	-.7604	.3480	.1986	-.0764	.1386	.1516
f1	2.4618	-.9412	-1.0423	.8216	-.3875	.0876
.600	1.6071	-.5812	-.2579	.3769	-.1880	.0431
.750	1.2024	-.4472	-.1230	.5044	-.1758	.0393
.900	.9674	-.3566	-.1755	.5314	.0119	.0214
.980	.8751	-.3232	-.1595	.4424	.0747	.0905

DIP = 66° fc= 2.7 fB, f1= 1.00 fB, fx= 1.62 fB

f/fc =	(f1)	(fx)	.570	.740	.900	.980
HM	.7714	-.3219	-.0546	.3692	.0402	.1958
H	-.0728	.0448	-.0766	.0788	-.2754	.3011
T	-.7496	.3800	.1035	-.0100	.1148	.1614
f1	2.5368	-1.1298	-.7418	.5332	-.2603	.0619
.570	1.5706	-.6483	-.0368	.1923	-.1026	.0249
.740	1.1190	-.4803	.0635	.3853	-.1139	.0263
.900	.8874	-.3749	-.0321	.4308	.0810	.0077
.980	.8032	-.3402	-.0285	.3477	.1375	.0803

DIP = 55° fc= 2.3 fB, f1= .90 fB, fx= 1.53 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.7250	-.2833	-.0357	.3587	.0041	.2312
H	-.0626	.0398	-.1154	.1540	-.3719	.3561
T	-.6555	.3227	.0406	.0360	.0554	.2006
f1	2.1979	-.9080	-.6058	.4974	-.2367	.0551
.600	1.3661	-.5318	.0858	.1394	-.0785	.0190
.750	1.0266	-.4126	.1070	.3532	-.0960	.0218
.900	.8309	-.3300	.0038	.3923	.0963	.0068
.980	.7528	-.2995	.0045	.3101	.1377	.0945

DIP = 66° fc= 7.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.450	.680	.870	.980
HM	.2780	-.0653	.1753	.2233	.1762	.2125
H	-.1562	.1652	-.1115	.1017	-.3146	.3154
T	-.4397	.2404	-.1369	.0435	.0873	.2053
f1	2.9569	-1.9017	-.0854	.0472	-.0210	.0040
.450	.7263	-.1498	.4905	-.0973	.0369	-.0067
.680	.5628	-.2593	.4318	.2890	-.0285	.0042
.870	.3446	-.0933	.2147	.3369	.2080	-.0108
.980	.3338	-.1223	.2148	.1930	.2906	.0901

DIP = 80° fc= 2.2 fB, f1= .90 fB, fx= 1.53 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.9099	-.3148	-.2799	.5504	-.0347	.1691
H	-.0861	.0368	-.0341	.0312	-.1770	.2293
T	-.8418	.3611	.3400	-.1863	.2266	.1005
f1	2.6898	-.9825	-1.4164	1.1346	-.5419	.1164
.600	1.7615	-.6012	-.5048	.5634	-.2796	.0606
.750	1.3129	-.4594	-.2823	.6203	-.2434	.0518
.900	1.0488	-.3648	-.2964	.6417	-.0612	.0319
.980	.9476	-.3302	-.2707	.5475	.0242	.0815

DIP = 80° fc= 2.6 fB, f1= 1.00 fB, fx= 1.62 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.8668	-.3460	-.1685	.4827	-.0033	.1682
H	-.0842	.0410	-.0437	.0370	-.1883	.2382
T	-.8448	.4066	.2696	-.1548	.2157	.1078
f1	2.7563	-1.1780	-1.2284	1.0543	-.5159	.1117
.600	1.6752	-.6578	-.2665	.4202	-.2193	.0482
.750	1.2508	-.5042	-.1141	.5264	-.2023	.0434
.900	.9989	-.4006	-.1672	.5675	-.0233	.0248
.980	.9034	-.3630	-.1548	.4773	.0599	.0772

DIP = 80° fc= 3.2 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.600	.750	.900	.980
HM	.9370	-.4336	-.1570	.4778	.0011	.1748
H	-.0928	.0517	-.0464	.0393	-.2015	.2497
T	-.9517	.5153	.2679	-.1664	.2218	.1131
f1	3.1072	-1.5300	-1.2517	1.0964	-.5389	.1171
.600	1.8009	-.8184	-.2157	.3970	-.2103	.0465
.750	1.3490	-.6298	-.0862	.5234	-.1994	.0429
.900	1.0786	-.5014	-.1526	.5662	-.0149	.0240
.980	.9770	-.4550	-.1423	.4719	.0691	.0793

DIP = 80° fc= 4.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.540	.720	.890	.980
HM	.7024	-.3465	.0608	.2900	.1320	.1613
H	-.0776	.0545	-.0650	.0462	-.2133	.2552
T	-.7731	.4471	.0351	.0059	.1420	.1431
f1	3.0105	-1.6865	-.5969	.4325	-.2015	.0419
.540	1.5235	-.7348	.1890	.0474	-.0324	.0073
.720	1.0620	-.5408	.2362	.2963	-.0668	.0131
.890	.8193	-.4073	.0880	.3800	.1227	-.0026
.980	.7350	-.3680	.0832	.2805	.2061	.0631

Table 10.13 (continued)

DIP = 66° fc= 3.5 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.540	.720	.890	.980
HM	.7868	-.3804	-.0224	.3310	.0886	.1963
H	-.0792	.0620	-.0910	.0895	-.2823	.3010
T	-.8141	.4653	.0611	.0046	.1097	.1733
f1	2.8679	-1.4856	-.6474	.4064	-.1798	.0386
.540	1.7060	-.8170	.0324	.1278	-.0631	.0139
.720	1.1788	-.5924	.1267	.3521	-.0820	.0168
.890	.9178	-.4498	.0011	.4093	.1213	.0003
.980	.8209	-.4050	.0088	.3058	.1891	.0804

DIP = 80° fc= 5.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.500	.700	.880	.980
HM	.5343	-.2568	.1422	.2350	.1776	.1677
H	-.0814	.0693	-.0762	.0552	-.2295	.2626
T	-.6401	.3780	-.0628	.0416	.1235	.1597
f1	3.0553	-1.8712	-.3156	.2065	-.0930	.0180
.500	1.2538	-.5808	.3738	-.0637	.0200	-.0034
.700	.8533	-.4439	.3660	.2531	-.0342	.0057
.880	.6325	-.3073	.1763	.3402	.1670	-.0087
.980	.5665	-.2823	.1690	.2221	.2585	.0662

DIP = 66° fc= 4.5 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.500	.700	.880	.980
HM	.5764	-.2814	.1075	.2554	.1444	.1978
H	-.0814	.0771	-.1027	.0950	-.2905	.3025
T	-.6569	.3907	-.0603	.0457	.0935	.1872
f1	2.8215	-1.6380	-.3009	.1805	-.0789	.0158
.500	1.3650	-.6588	.3171	-.0282	.0057	-.0008
.700	.9096	-.4809	.3248	.2786	-.0390	.0069
.880	.6850	-.3414	.1444	.3468	.1730	-.0078
.980	.6093	-.3103	.1436	.2278	.2488	.0808

DIP = 80° fc= 7.0 fB, f1= 1.20 fB, fx= 1.80 fB

f/fc =	(f1)	(fx)	.450	.680	.870	.980
HM	.3033	-.0904	.1837	.2162	.2012	.1860
H	-.1397	.1405	-.0881	.0669	-.2600	.2804
T	-.4633	.2565	-.1246	.0351	.1164	.1800
f1	3.2396	-2.1581	-.1265	.0708	-.0317	.0058
.450	.7573	-.1691	.4800	-.0997	.0380	-.0066
.680	.5987	-.2890	.4365	.2797	-.0303	.0044
.870	.3630	-.1090	.2170	.3434	.1961	-.0106
.980	.3527	-.1380	.2146	.1990	.2945	.0773

Table 10.14

Frequency ratios fc/fB for Tables 10.11, 10.12 and 10.13

For Table 10.11

Band

Dip	1		2		3		4		5		6		7	
	From	To	From	To	From	To	From	To	From	To	From	To	From	To
13°	1.0	20.0												
25°	1.2	5.5	5.5	20.0										
35°	1.5	3.9	3.9	8.5	8.5	20.0								
45°	1.8	3.1	3.1	5.2	5.2	9.0	9.0	20.0						
55°	1.8	2.8	2.8	4.2	4.2	6.1	6.1	9.5	9.5	20.0				
66°	1.8	2.6	2.6	3.5	3.5	4.7	4.7	6.6	6.6	9.8	9.8	20.0		
80°	1.8	2.6	2.6	3.4	3.4	4.4	4.4	5.7	5.7	7.6	7.6	10.4	10.4	20.0

For Table 10.12

Dip	From	To	From	To	From	To	From	To	From	To	From	To	From	To
13°	1.0	20.0												
25°	1.2	7.5	7.5	20.0										
35°	1.5	4.6	4.6	10.2	10.2	20.0								
45°	2.2	3.9	3.9	6.7	6.7	12.0	12.0	20.0						
55°	2.7	3.8	3.8	5.3	5.3	8.1	8.1	12.6	12.6	20.0				
66°	2.3	3.2	3.2	4.3	4.3	5.9	5.9	8.4	8.4	12.2	12.2	20.0		
80°	2.2	2.9	2.9	3.7	3.7	4.8	4.8	6.4	6.4	8.7	8.7	12.2	12.2	20.0

For Table 10.13

Dip	From	To	From	To	From	To	From	To	From	To	From	To
5°	1.5	3.5	3.5	10.0								
15°	1.5	3.5	3.5	10.0								
25°	1.8	3.2	3.2	5.3	5.3	12.0						
35°	1.8	3.2	3.2	5.3	5.3	12.0						
45°	1.9	2.9	2.9	4.6	4.6	10.0						
55°	1.9	2.6	2.6	3.5	3.5	4.9	4.9	10.0				
66°	1.9	2.4	2.4	3.1	3.1	3.7	3.7	5.6	5.6	12.0		
80°	1.9	2.4	2.4	2.9	2.9	3.6	3.6	4.5	4.5	5.9	5.9	12.0

10.65. Selection of Table

Table 10.11 is similar to a five-point Schmerling method and is suitable when the ionogram does not show the presence of lower thick layers.

Table 10.12 is designed primarily for analysis of daytime ionograms with critical frequencies between about 2fB and 20fB. Table 10.11 should be used if one of the Table 10.12 sampling frequencies falls on a cusp.

Table 10.13 is designed for night time conditions when both o-and x-mode traces are present and measurable. It is a basic 5-point system plus an additional measurement on the x trace. It differs from Table 10.11 in that f1 is always measured at f1 = fB using the o-mode trace; and fx is always measured at fx = 1.62 fB using the x-mode trace. The 4 remaining sample points vary with foF2.

The bands of the ratios fo/fB for Tables 10.11, 10.12, 10.13 are collected in Table 10.14. The error increases rapidly when critical frequency approaches fB and the tables are inaccurate below the limits shown.

Note: Tables 10.11, 10.12, 10.13 are often complementary, if there is difficulty in measuring a sampling frequency for one, try the other set.

10.66. General procedure

(a) Select the section of the table with the nearest magnetic dip to that at the station or request a special set of parameters from Titheridge.

(b) Note the gyrofrequency fB for the station. Evaluate the central frequencies for the tables from Table 10.14 by multiplying the entries by fB. It is convenient to note band limits which can be calculated from the square root of the product of the adjacent central values, e.g., for Table 10.11 at 55°, fc/fB central values 2.3, 3.5, 5.0, 7.5, 12.0 the band limits are 1.8-2.8, 2.8-4.2; 4.2-6.1, 6.1-9.0, 9.0-20.

(c) The procedure for logarithmic frequency law will be described, the modification for arbitrary law is essentially similar to that described above for hc, qc. Construct a frequency overlay to match scale of ionogram with vertical lines at the critical frequency f/fc = 1 and sample frequencies (like Figure 10.2). For Table 10.13 mark f = fB and fx = 1.62fB and a convenient frequency marker near these.

(d) Move the overlay so that the line fc/fB = 1 is at the o-mode critical frequency.

(e) Note the value of the critical frequency.

(f) Read and tabulate the vertical heights at the sample frequencies. If Table 10.13 is being used, set the overlay so that the frequency marker agrees with the corresponding frequency marker on the ionogram before reading fi or fx_0. If any are missing use the techniques of section 10.1 to evaluate the missing values.

(g) Identify the sub-table to be used from (b).
The parameters HM, H, T and the profile can now be evaluated.

10.67. Evaluation

(a) For HM: read the coefficients in the third line of the sub-table designated HM and multiply each coefficient by the corresponding value of h'. The sum is HM.

(b) For H: as (a) using the fourth line designated H.

(c) For T: as (a) using the fifth line designated T.

10.7 Profile Analysis Using Monthly Median Virtual Height Curves

10.71. It is often desirable to have a relatively fast method of finding an average or representative height structure for a month or for a group of quiet days. Such average profiles (for example, averages of all the quiet days in a month at a particular hour) need not show all the fine detail of an accurate individual profile. Also it is not necessary to employ scaling or calculation methods which require extreme precision in preparing the input data, since we need only assure that the errors of data preparation are neither systematic nor significant compared with the day-to-day variation.

10.72. It is first necessary to construct a median h'f curve which is representative of all the data available. Clearly this should be consistent with the median values of all thick layer height and frequency parameters. A unique curve can be produced by drawing straight lines across the family of observed h'f curves and finding the median points on this curve. The lines must be arranged so that all characteristic features are properly sampled. The appropriate rules are as follows:

(a) Trace or plot the first order o-mode traces reflected from thick layers for the required hour on the desired days on a virtual height vs. sounding frequency sheet.

(b) To define cusps and critical frequencies correctly, the observed curves should be extrapolated when necessary to show which is the true median curve, e.g., at foF2 the traces should be made vertical.

(c) Across this set of curves draw straight lines which are approximately orthogonal to the curves (see Figure 10.9). Each line should cross each of the curves once and only once (except where it crosses missing parts in individual ionograms).

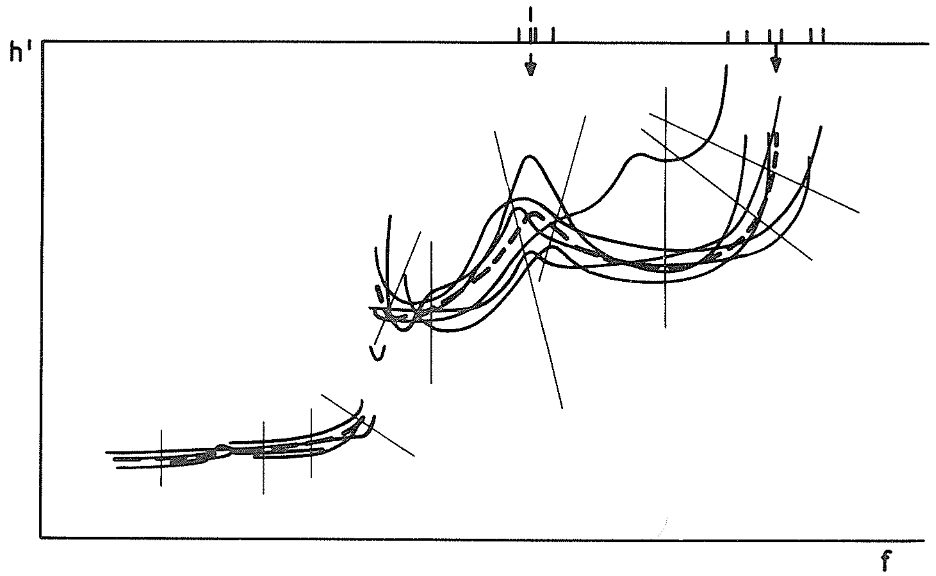


Fig. 10.9. Showing use of straight lines to determine median h'f curve. --- deduced median curve.

(d) For each of these lines count the intersections with curves and determine the median intersection point. This is the median intersection for an odd number of intersections. In case the number is even put the mean on the line between the two central points.

(e) Where the curves are so closely packed as to make counting impossible, the median may easily be drawn through the middle of the pack, without counting.

(f) Where only partial curves are present and it is likely that the missing trace would be above or below the median it should be counted as a high or low value as appropriate when evaluating the median.

(g) Draw a smooth curve through the median points obtained, if necessary adding additional lines until the median h'f curve is well defined at all frequencies. This is then the composite ionogram trace.

The final median virtual height curve should resemble the majority of individual curves.

If there is an F1 cusp on most of the curves, the median curve should show an approximately average shape and height at this cusp. Make the foE cusp (if any) and the surrounding virtual heights of about average shape and height. Similarly, when there is stratification in the E layer and lower F layer, it is useful to note any pattern formed by the stratifications. The median should follow the predominant pattern.

It is convenient to use tick marks to show the daily values of critical frequencies and then find the median values for these marks. This prevents errors in marking the median values of the critical frequencies on the composite ionogram.

Where an advanced computer program is available the technique can be extended to include the x-mode trace. The procedure should be adapted to the needs of the program and is beyond the scope of this section.

10.73. Evaluation of monthly median profile

Any of the methods described above can be used to deduce monthly median profile characteristics from the median ionogram.

At WDC-A a computer program of the advanced (lamination) type is used for the last step while the preceding steps (a) through (g) are executed at the station. The result is quoted as providing a rather representative profile for month and hour which had been selected. Full details will be found in the NOAA publication on electron density profile evaluation.

It should be noted that travelling disturbances generally distort the h'f pattern systematically - making the layer look fatter than it really is. No method available can correct for this, it is essential to omit ionograms affected by the phenomenon. However, in practice day-to-day changes in height and shape are usually larger than the systematic distortion.

10.74. Application of Titheridge method

At stations where a computer is not available, the manual version of Titheridge's polynomial method can be used. In this case it is desirable to calculate the median value of foF2 first and then find the sampling frequencies corresponding to this value. It is then only necessary to evaluate the median virtual heights at these frequencies. The rules given earlier should be strictly observed.

Where it is desired to use the scale height parameter H, much care is necessary to define the shape near foF2 accurately and it is, in general, better to use a qc overlay than the sample values.

10.8 Presentation and Use of Real Height Data

10.81. Presentation of individual data

If a complete reduction of ionograms is made, i.e., if heights are determined for at least ten different electron densities, it is advantageous to use an iso-ionic chart (e.g., Figure 10.10) or to interpolate for fixed real height values and give the resulting time variations (e.g., Figure 10.11 - this example gives monthly median values, but the same presentation is applicable to individual days).

10.82. Monthly median data

Monthly medians are intended to give a representative picture of the ionosphere and its diurnal variations for a particular month (see section 10.7 and Figure 10.11).

The most valuable of the possible median calculations is that given in section 10.7. It is always essential to confirm that the behavior of the ionosphere at the station is such that the median curve is not misleading. Some sample individual profiles should be taken using quiet day data from time-to-time for this purpose. Most monthly median profiles available at WDCs have been obtained using this method. For many purposes the most valuable single parameters are hc and qc or their equivalents.

There are several types of median which are particularly important and may be applied to particular sections of the profile:

(a) The median height at a fixed plasma frequency. This is useful when the gradient of ionization with height is large, e.g., near the bottom of the layer, and the changes in the shape of the distribution are most naturally ascribed to changes in the height of the layer.

(b) The median plasma frequency (ionization density) at constant real height. This is useful when the gradient of ionization with height is small but large variations occur from day-to-day, e.g., near the height of maximum of the layer.

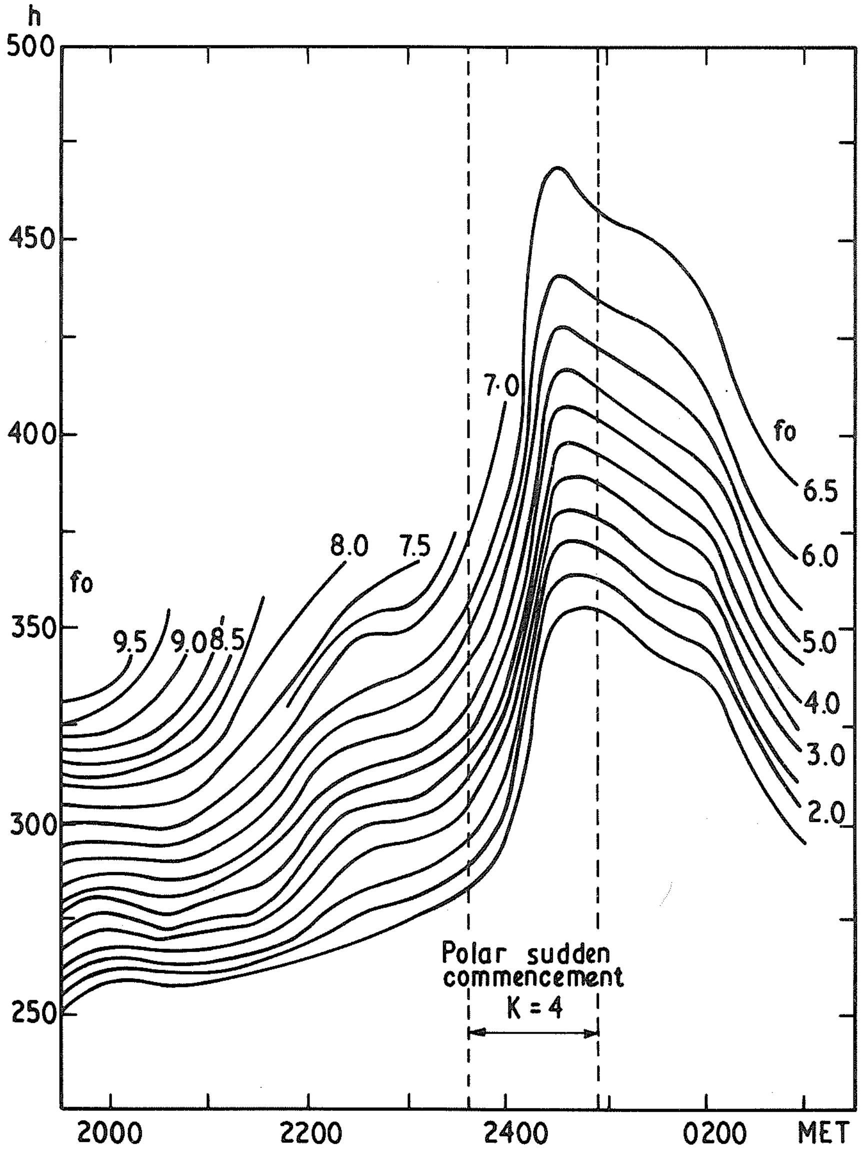


Fig. 10.10 An iso-ionic chart showing the variation of real height for constant ionization density during a magnetic movement. Electron densities are expressed as plasma frequencies, f_N, in MHz [Lindau/Harz, September 16, 17, 1956].

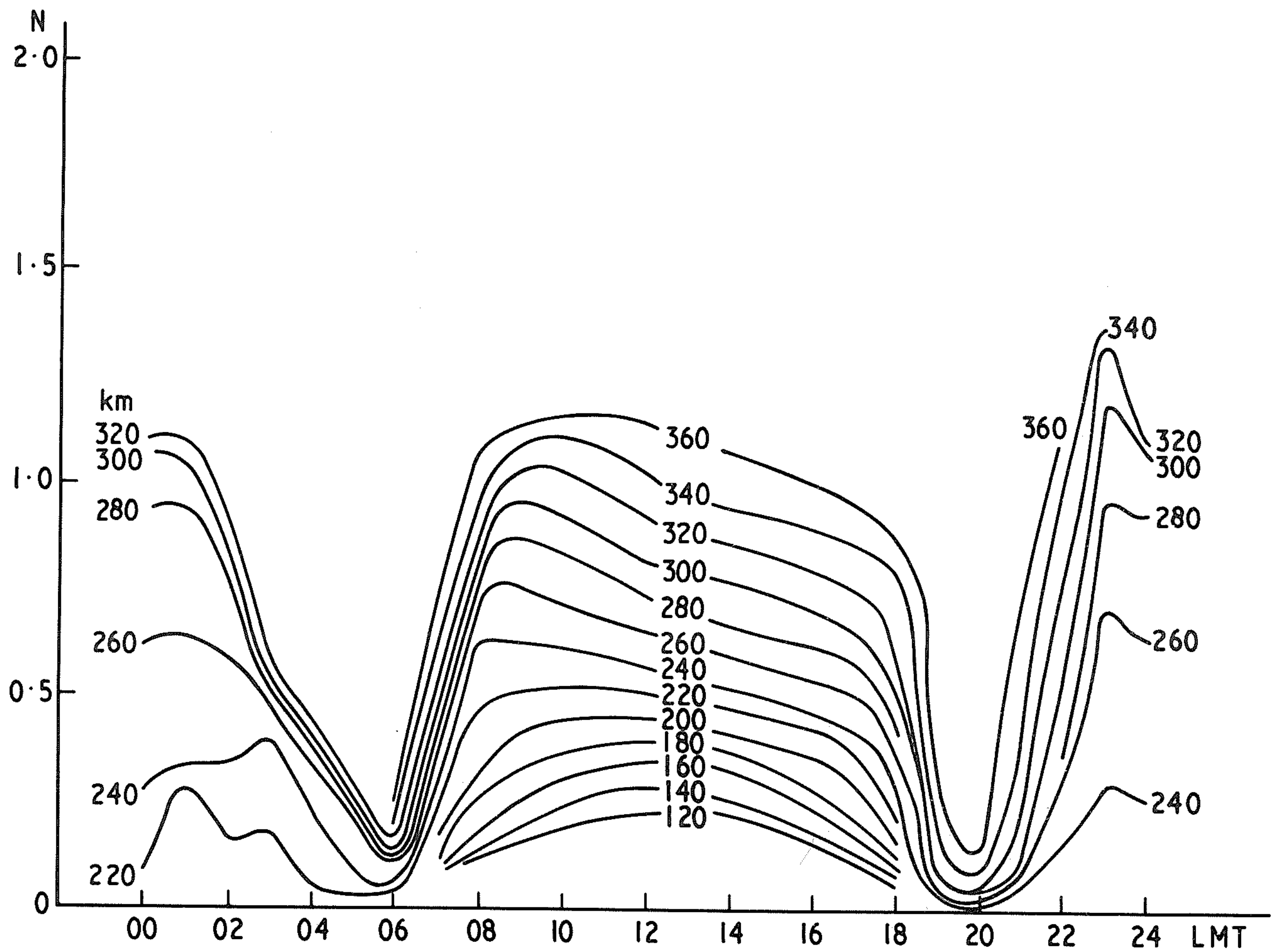


Fig. 10.11 Variations of electron density at constant real height. The curves show monthly mean electron densities for Talara, August, 1957, as a function of LMT. Electron densities expressed in units of 10^6 cm^{-3} equivalent to 10^{12} m^{-3}.

(c) The 'median shape' of the layer. This is given by the model with the median critical frequency, the median height at maximum and the median shape parameter, e.g., for parabolic models $f_c = \bar{f}_c$, ($N_m = \bar{N}_m$), $h_m = \bar{h}_m$ and $y_m = \bar{y}_m$, the bar representing the median of all countable values. This has been systematically developed by W. Becker.

10.9 Calculation of Electron Content

10.91. The electron content below a given height in the ionosphere can be found by integrating the electron density profile with respect to height. When the height of maximum density forms the upper limit, this is called the sub-peak electron content and is often useful for theoretical work on layer equilibrium problems. For most purposes the F1 and F2 layers can be treated together. In this case, the phrase 'F region' is used to show that both are included.

10.92. Practical Procedure

When it is desired to find the sub-peak electron content manually from a given profile the procedure is as follows:

(a) Identify the top and bottom heights of the layer and hence the limits of the integration.

(b) Divide the height range into n equal intervals of widths Δ where n is a convenient number (e.g., between 5 and 10) and Δ is in km units.

(c) Tabulate the (n + 1) values of plasma frequency at the boundaries of the intervals (in MHz units).

(d) Square the plasma frequencies in order to obtain values proportional to the electron densities.

(e) Add the average of the first and last values in (d) to the sum of the intermediate values, giving Σ.

The sub-peak electron density is then

$$g \cdot \Delta \cdot \Sigma$$

where $g = 1.24 \cdot 10^{13}\ m^{-2}\ /(km\ MHz^2) = 1.24 \cdot 10^{9}\ cm^{-2}\ /(km\ MHz^2)$ (10.10)

The factor $1.24 \cdot 10^{13}$ gives the electron content in units of m^{-2}, $1.24 \cdot 10^{9}$ gives in units of cm^{-2}.

With a numerical factor $g = 1.24 \cdot 10^{-3}$ the sub-peak electron density is obtained in units of $10^{16}\ m^{-2}$, the unit most widely used for comparison with satellite measurements of total electron contents, i.e., including the topside ionization up to the satellite height.

In the case when the profile is described by an analytical model it is better to use the analytical integral to give the sub-peak electron content, e.g., for a parabolic model with critical frequency, fo MHz, and half thickness, ym km, the sub-peak content is

$$\frac{2}{3} N_m y_m = \frac{2}{3} g\ fo^2\ y_m \qquad (10.11)$$

fo is measured in MHz, ym in km.

10.93. Limitations

The sub-peak electron content is very sensitive to the ionization distribution near the height of maximum electron density and small errors in determining this have much greater effects on the content found in the daytime than have major errors in determining the shape of the lower edge of the layer. For this reason curve-matching techniques have considerable advantages when the detail of the profile is not needed for other purposes. They are, of course, also much quicker to apply than is the process of obtaining and integrating a profile.

Since the ionization density varies very slowly with height near the maximum of the F2 layer small irregularities near the maximum can cause the sub-peak electron content to vary considerably. In practice, apparent sub-peak electron densities can be very variable when gravity waves and similar transient phenomena are present.

NOTES

11.0 General

Although the ionosonde has proved to be the most powerful tool of ionospheric research, the present conventional techniques for using ionograms have some disadvantages. One is the large amount of simplification necessary in scaling and reducing work, due to the need to present the data in a form which is quite different from the original record. Another is that certain dynamic phenomena may be overlooked when ionograms are taken and considered one by one. The first section describes methods of overcoming some of these difficulties and of expressing additional conventional characteristics which do not appear on the standard presentation in a useful form, viz. the f plot (Chapter 6). Then some new techniques are described, all of which are basically ionosondes with special recording systems. It is felt that the importance of such techniques may increase in the near future.

11.1 Special Plots

11.10. Height plots: This is a convenient form for a daily presentation of (virtual or true) height data, especially if special studies are to be made.

(a) It is desirable to have a format with the same horizontal time scale as that for the f plot. The height scale may depend on the type of research. The most convenient form, when suitable graph paper is available, is one in which the height scale is logarithmic and runs from 60 km to 800 km (Fig. 11.1). Two linear height scale systems are often used, one for survey purposes with about 15 mm per 100 km, mostly reproducing a height range from 0 to 800 km; the other for detailed studies, with about 40 mm per 100 km reproducing a narrower range (e.g. 0 - 600 km). An example is given in Fig. 11.2.

(b) Characteristics that may be plotted on an h' plot include h'F2, h'F, h'E and h'Es as well as other more transient phenomena such as h'F1.5 and h'E2. All conventions used should be explained on the sheet itself. The following system is used at many stations (see Fig. 11.1):

(i) The minimum virtual heights for the ordinary-wave trace of all thick layers are plotted as open circles.

(ii) The minimum heights of all thin layers - including all types of Es - are plotted as filled circles. Consecutive values from the same stratum are connected by lines.

(iii) In cases where the trace does not become horizontal, e.g. when stratification is incomplete, the possible range of the minimum virtual height is plotted as a vertical line.

(iv) When the minimum virtual height itself is not observed (i.e. for reasons described by the letters A, B, C, E, F, L, N, R, S, W), an appropriate limiting value is indicated by the symbols Λ or V.

(v) Es types are indicated at the bottom of the h' plot in a manner similar to that on the f plot, if desired.

(c) It frequently happens that more than one trace in the E region, and occasionally other regions, have the same minimum height. The interpretation of the h' plot is greatly aided if a special symbol is used whenever this occurs. A convenient convention is to use the symbol + in place of the symbols for the two traces (Fig. 11.1).

(d) Other height characteristics which may be introduced are "true height" parameters described in Chapter 10, in particular hc and qc (see section 10.4) or HM (section 10.6). It is important to make certain that such parameters are clearly defined and designated in accordance with the rules.

A plot containing only "true height" parameters is called an h plot, while one with h' and h values is an h, h' plot. The latter form is most desirable when studying the behavior and significance of new true height parameters (section 10.16).

11.11. E plots: Because of the complexity of the E-region reflections shown on many ionograms, it is often impossible to treat the data adequately using the usual f or h' plot.

A convenient method for studying the complex stratifications in the E region combines the concept of the f plot and h' plot with extended scales for the ranges in which E phenomena are observed.

There is a common (horizontal) time scale, identical with that of the f plot, and two vertical scales: one scale, for recording all characteristic frequencies, might range from 0.2 to 10 MHz; the other scale, for recording corresponding virtual heights, might range from 70 to 300. Provision for indicating Es type or other identification of echoes may be made along the same time scale. The points of measurement should be marked on the height and frequency graphs so that each phenomenon is clearly identified. The conventions employed are usually similar to those used in f plots and h' plots and again a key is essential. The same symbol must, of course, be used to denote both the critical or top frequency and the height of any particular trace. It is useful to use conventions which clearly differentiate between thick and thin layers. It is usually convenient to adopt a

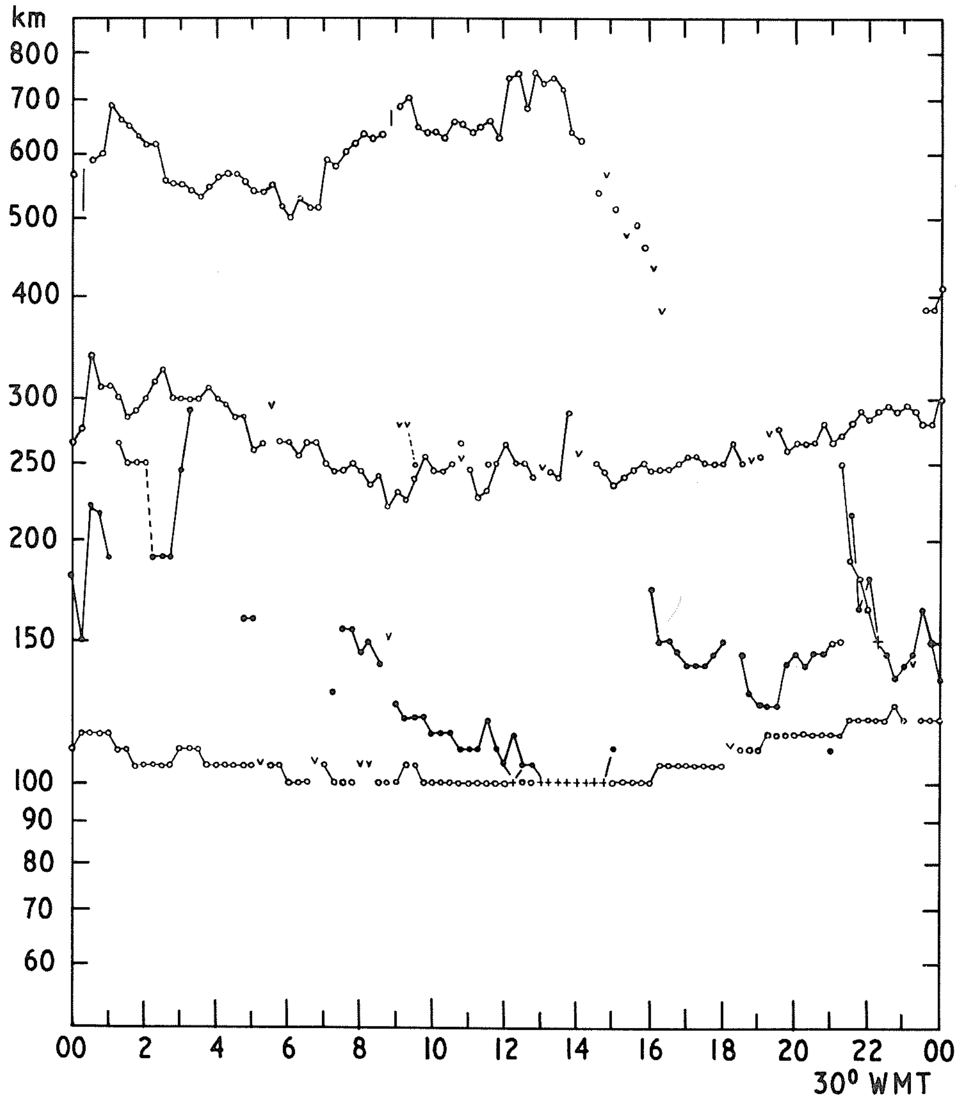


Fig. 11.1 Example of height plot using a logarithmic height scale (Halley Bay, December 3, 1958).

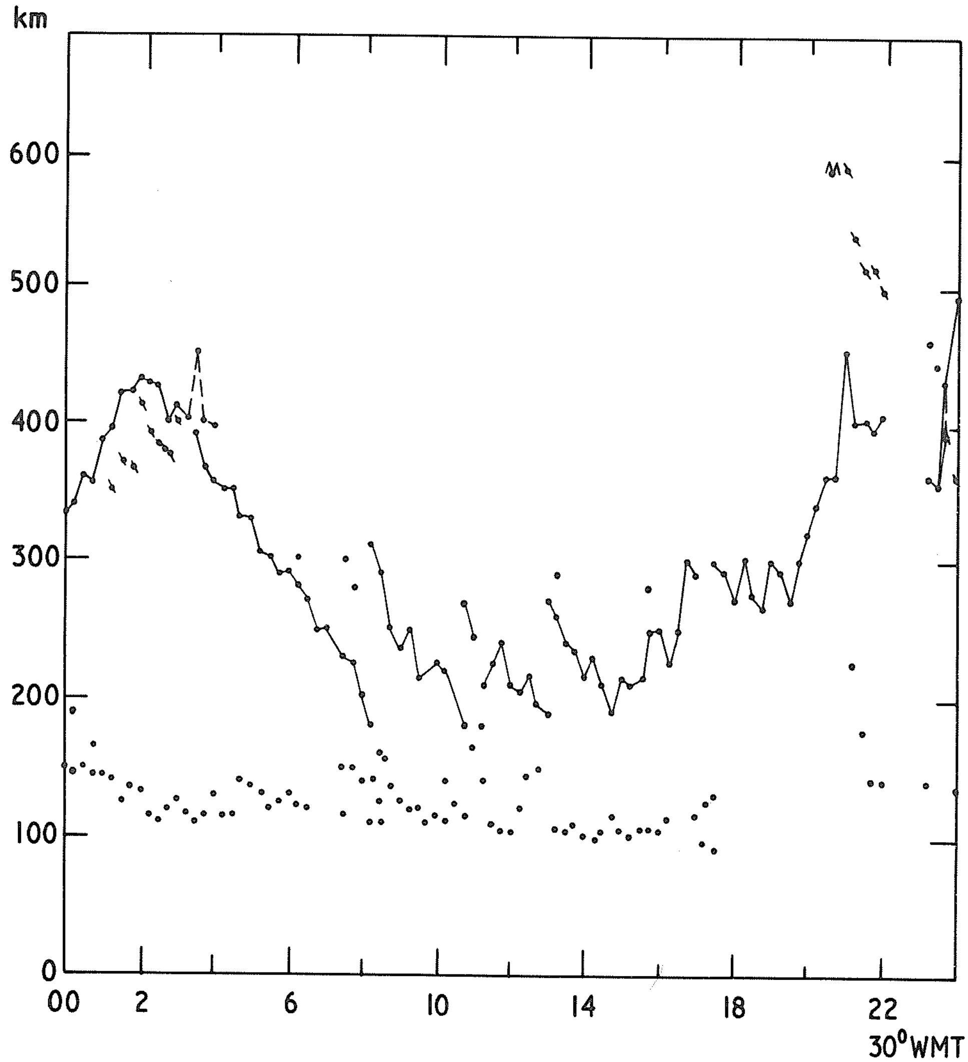


Fig. 11.2 A typical height plot (Halley Bay, June 19, 1958). Local rule: ↘ = oblique traces: ripples in F and sequential Es are shown clearly.

standard set of symbols for the E2, E or Es phenomena which recur most frequently at the station, and to distinguish between accurate and doubtful values. The following are readily distinguishable on an f plot, h' plot or E plot:

Accurate	Doubtful
△	▲
▽	▼
□	■
•	•U

Normal conventions should be used for fbEs -•- or -o-.

Most doubtful values can be regarded as either definitely greater than or less than a certain limit, so that the corresponding signs may be used.

11.12. Other data presentation methods: Contours of constant frequency or virtual height drawn on monthly (day-by-hour) tabulation sheets permit the easy determination of periods of unusual ionosphere behavior, which then may be associated with periods of high solar or magnetic activity.

Special graphs of frequency and height characteristics as functions of solar position (e.g. cos χ) are useful in studies of solar-controlled phenomena (sections 13.1, 13.2). Tables of hourly values of cos χ are available to stations in the URSI Ionospheric Stations Manual.

11.2 Moving Picture Technique

As ionograms are mostly recorded on cinema film it is not too difficult to apply a suitable speeded-up motion picture technique to a sequence of ionograms. This technique intensifies the impression of variation and movement and allows changes to be seen as coherent phenomena which, otherwise, do not appear as such or are completely overlooked.

The speeding-up should be of the order of 1 : 300, the best choice depending largely on the phenomena which are studied. All sorts of transient phenomena and perturbations are much more clearly visible with this projection. Stability of the picture frame and good adjustment of luminosity are important conditions for this type of work.

Stations using this technique regularly should give lists of their times of operation to their WDC.

11.3 Direct Recording of Ionospheric Characteristics

11.30. Continuous direct recording of certain ionospheric characteristics is very desirable both from the geophysical and from the propagation viewpoint. Essentially it only requires a special recording unit which produces curves of the required parameters, normally on 35 mm film. This technique, first developed by Nakata in Japan,* gives continuous records of certain parameters which can be directly compared with other geophysical parameters. In practice it is often difficult to record fxF2 or foF2 owing to interference but the direct recording of MUF(3000)F2 is usually both effective and convenient.**

The normal recording speed can be so low that a whole day is seen at one glance; this requires a recording speed of the order of 10 min/hour. Higher speeds may be useful for the investigation of quick changes. However, with the low speed, the daily variations appear clearly, as well as the more rapid perturbations. Precise timing is important for these records as the precise moment of rapid changes may often be required.

Figs. 11.3, 11.4 show typical examples of the three main types of recording, described in more detail below. The lower pattern shows ftE (section 11.32), the middle trace, h' (section 11.31) and the upper MUF (section 11.34). Where MUF is not recorded ftF should be substituted.

11.31. h' records: These are obtained if the frequency sweep of the usual panoramic display (h' versus frequency on the cathode ray tube) is suppressed and the pattern on the screen is recorded on continuously moving film (movement perpendicular to h' axis). With this very simple change we have changes of luminosity with height proportional to the incidence of different h' values. The record is not seriously perturbed by interference.

As minimum virtual heights appear very clearly on the records, these are especially useful for comparison with solar and magnetic changes (example: Fig. 11.3 shows a strong SID perturbation between 1039 and about 1400).

11.32. ftE records (top frequency of all layers in the E region): These are obtained by suppressing the height sweep of a panoramic display and gating (by luminosity) the height range between about 80 and 160 km. The pattern on the screen is recorded on continuously moving film (movement perpendicular to the frequency axis of the display). This requires only a supplementary gating unit. The trace gives a bright line which ends at the top frequency.

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* Rep. on Ion. Res., Japan, 7, 129-135, 1953, Nakata, Y., M. Kan and H. Uyeda.

** J. Atmosph. Terr. Phys., 8, 295, 1956, Bibl, K.

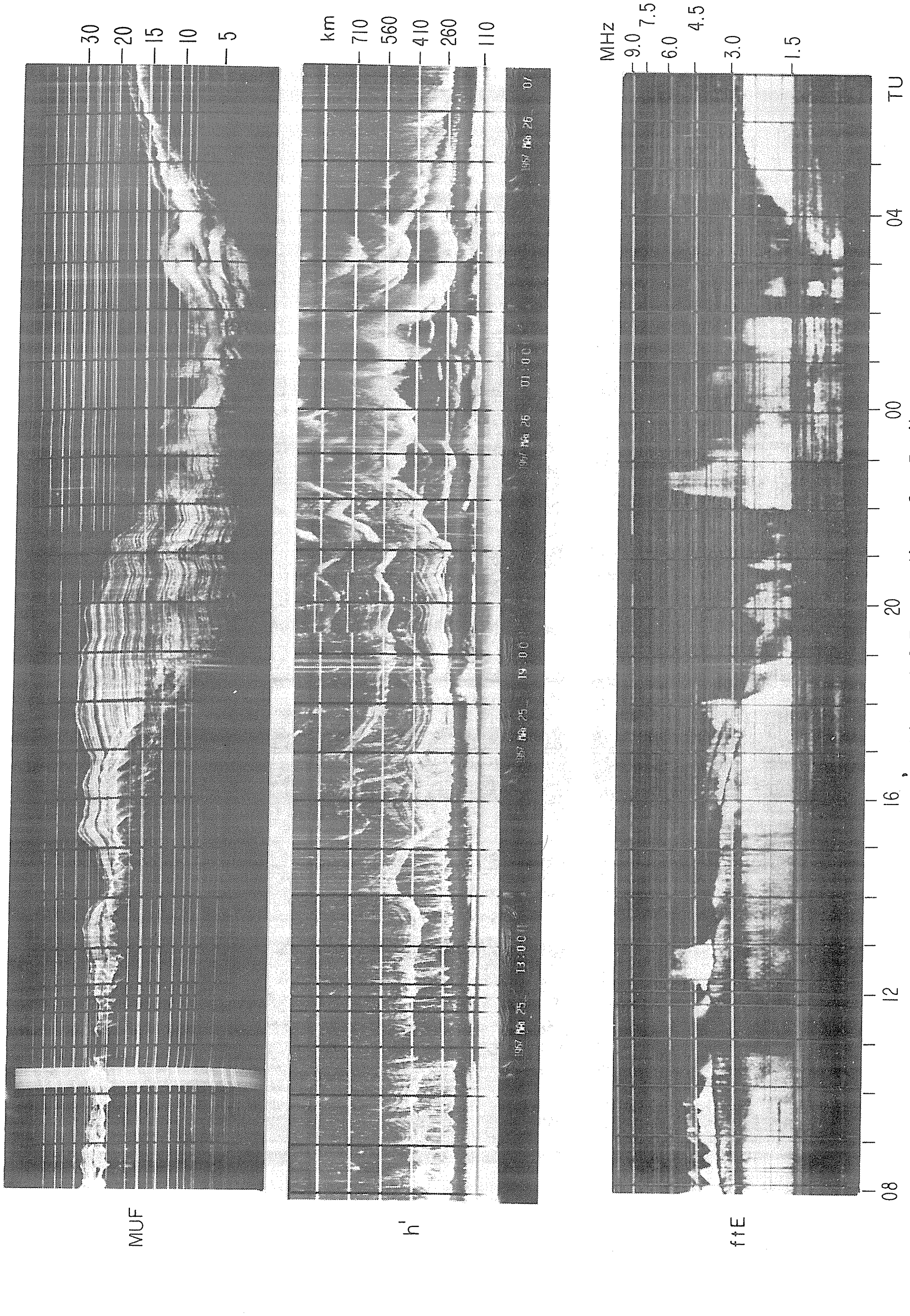


Fig. 11.3 MUF, h', and ftE recordings for Freiburg, May 25-26, 1967, showing an SID starting 1039 UT.

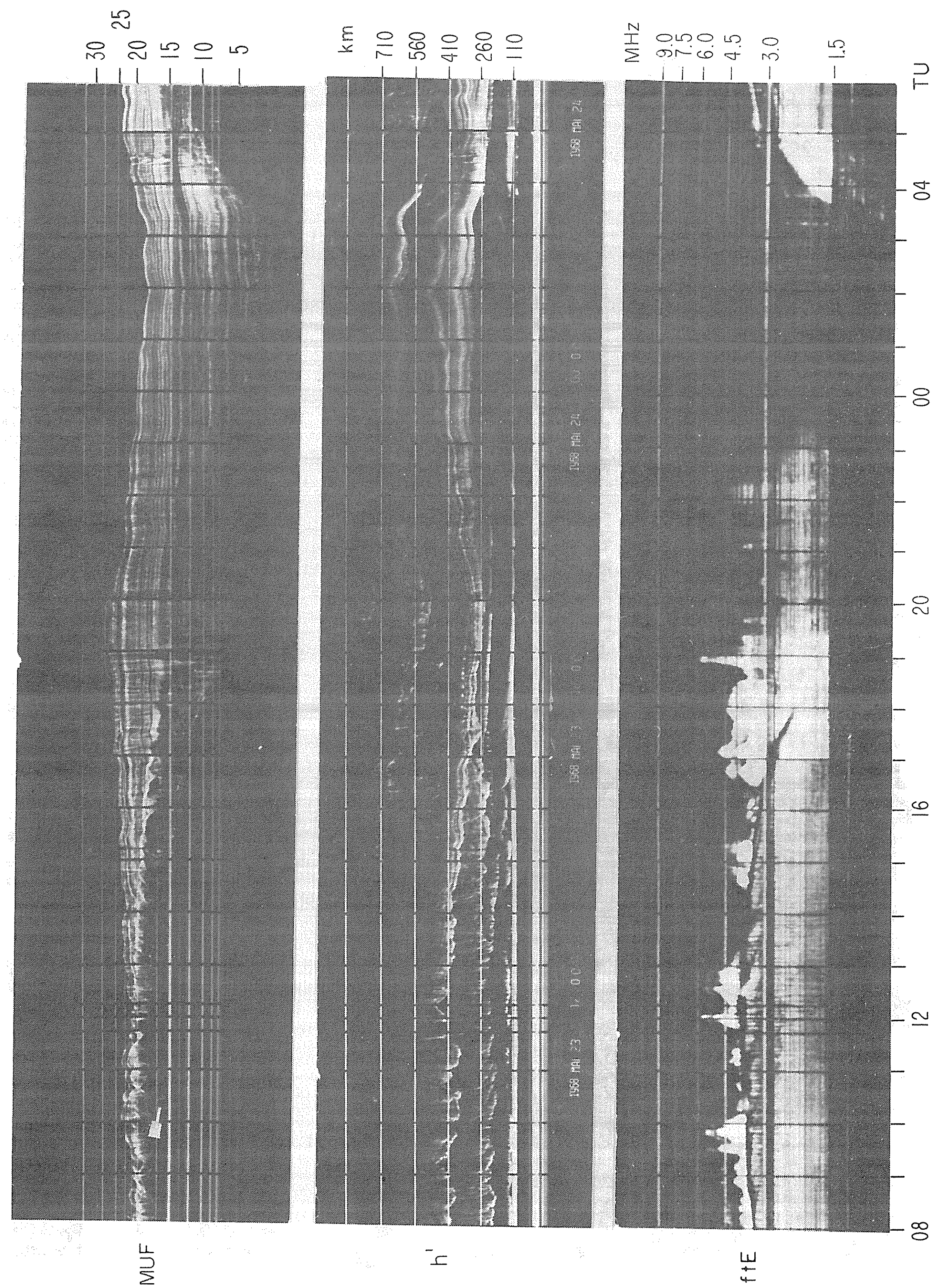


Fig. 11.4 MUF, h', and ftE recordings for Freiburg May 23-24, 1968. Note foE shows as a dark curve on the ftE pattern.

The records clearly show foE, sometimes fxE and the Es top frequency. Provided that the receiver is sensitive over a rather large range of input amplitudes, something like 40 dB, foEs and fxEs will usually appear distinctly. Rapid changes of Es are seen very nicely.

The cusp absorption near foE can be clearly seen as dark curves in the E-Es pattern during the day (Fig. 11.4).

11.33. ftF records (top frequency of all layers in the F region): Obtained in an analogous manner, by gating the height range between about 200 and 500 km. A polarimeter enables one of the magneto-ionic components to be selected as preferred.

The records suffer much more from interference as the effective signal to background ratio becomes worse, and the amplitude of interference is mostly larger on the higher frequencies where ftF occurs. Usually ftF = fxF2, but occasionally (e.g., after a SID) the x component does not appear and one has ftF = foF2.

11.34. MUF records: MUF records can be obtained directly using a similar technique to that just described if an 'oblique incidence ionogram' is artificially produced. This can be done by applying a suitable electronic analog device to an ionosonde recorder. Essentially one adds to the usual frequency sweep another one whose shape corresponds to the application of a transmission curve. Of course, if a polarimeter is not used, this record contains both components, the x component giving the higher value; these records are much less influenced by interference than are ftF records. MUF records are especially useful for propagational applications but they are also interesting for the geophysicist. As a combination of critical frequency and an M factor (which roughly varies in opposite sense with the layer height) MUF(3000)F2 is very sensitive to perturbations.

11.4 Digital Ionosondes

11.40. In a digital ionosonde, the transmitted frequency, the sampled delay ranges (virtual heights) and the signal amplitudes are obtained directly in digital form. With attachments, or implemented in their basic design, these sounders also give phase height, absorption and drift data. The ionogram data is normally primarily recorded on magnetic tape but can be presented in many different ways (Fig. 11.5). Several different types have been developed, mainly for specialized research purposes but at least one type is being used for synoptic measurements at a few stations. Such ionosondes are usually operated in conjunction with a small or large computer so that the data can be studied in a number of forms (Figs. 11.5 - 11.10).

11.41. Several modern types of ionosondes use frequency synthesizing techniques in which the transmitted frequency is synthesized from a standard frequency source and changes in steps. In these ionosondes, the frequency is known exactly for each step and can be measured by the programmed state of the synthesizer. Frequency progression in steps is advantageous for bistatic, oblique incidence, soundings and for coherent integration.

It is advantageous to count the number of intervals before the reflected signal is recorded, again in digital form. The scaling resolution in either direction is determined by the frequency and height increments adopted, though, of course, the reading accuracy also depends on the signal-to-noise ratio available. The ionosonde then produces a digital output of frequency and virtual height which is usually recorded on magnetic tape instead of an ionogram. A conventional ionogram can be obtained using a built-in computing device or with the aid of a computer. In practice it is necessary also to digitalize the amplitude of the signal present in each frequency-height unit box so that the signal-to-noise ratio can be adjusted as desired, before or after the recording has been made. The length of magnetic tape needed to store the recording increases with decrease in the box size, with the height range, with the frequency range and with the number of amplitude levels in use.

It is possible to use a print out in which the size of the symbol in each box is increased with the amplitude of the signal. By this method, the echo traces form the usual analog pattern, very useful for identification and physical understanding, while the accuracy of the digital measurements is maintained (Fig. 11.7).

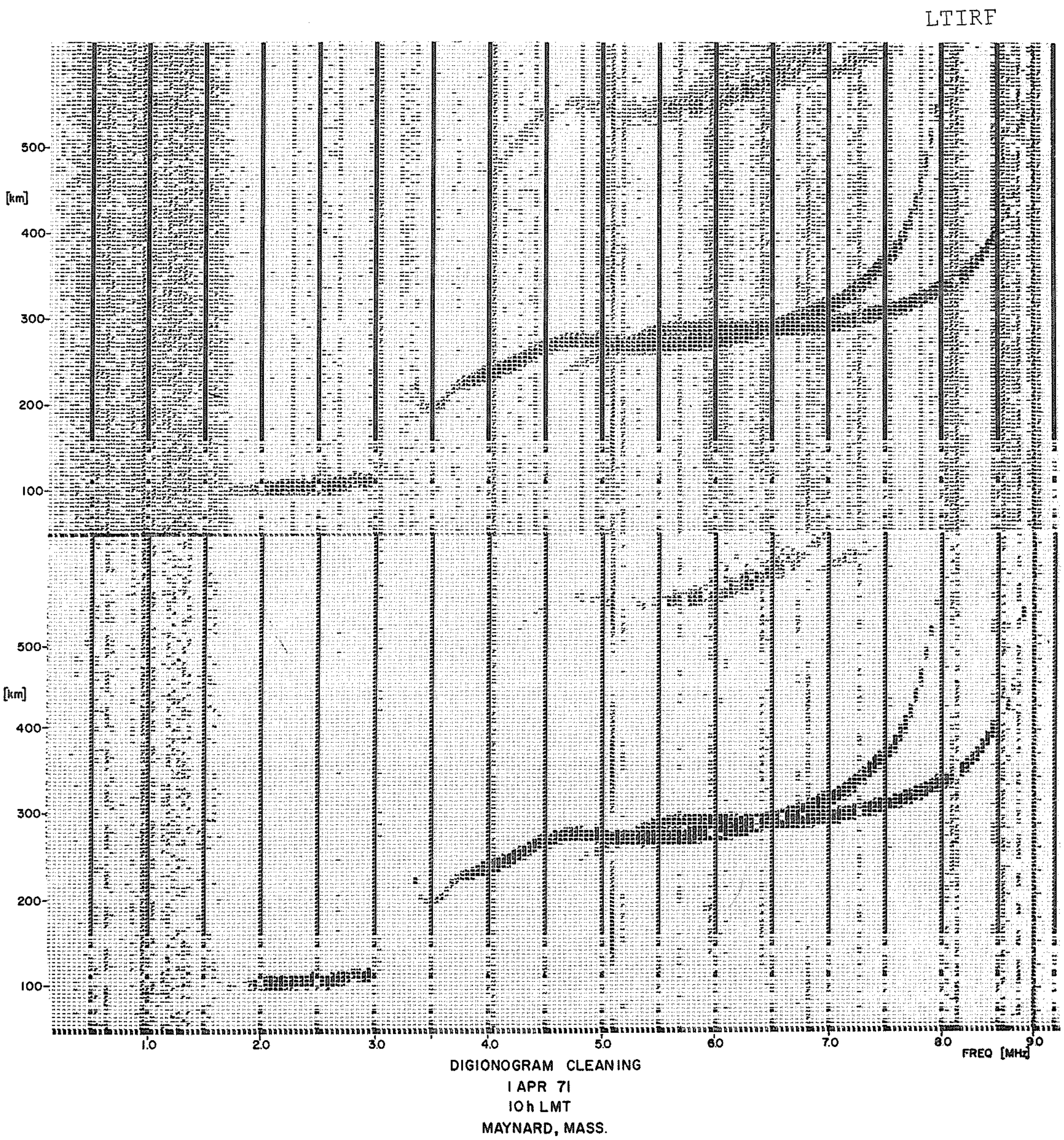


Fig. 11.5 Example of digitized ionogram as recorded and after processing to clean traces.

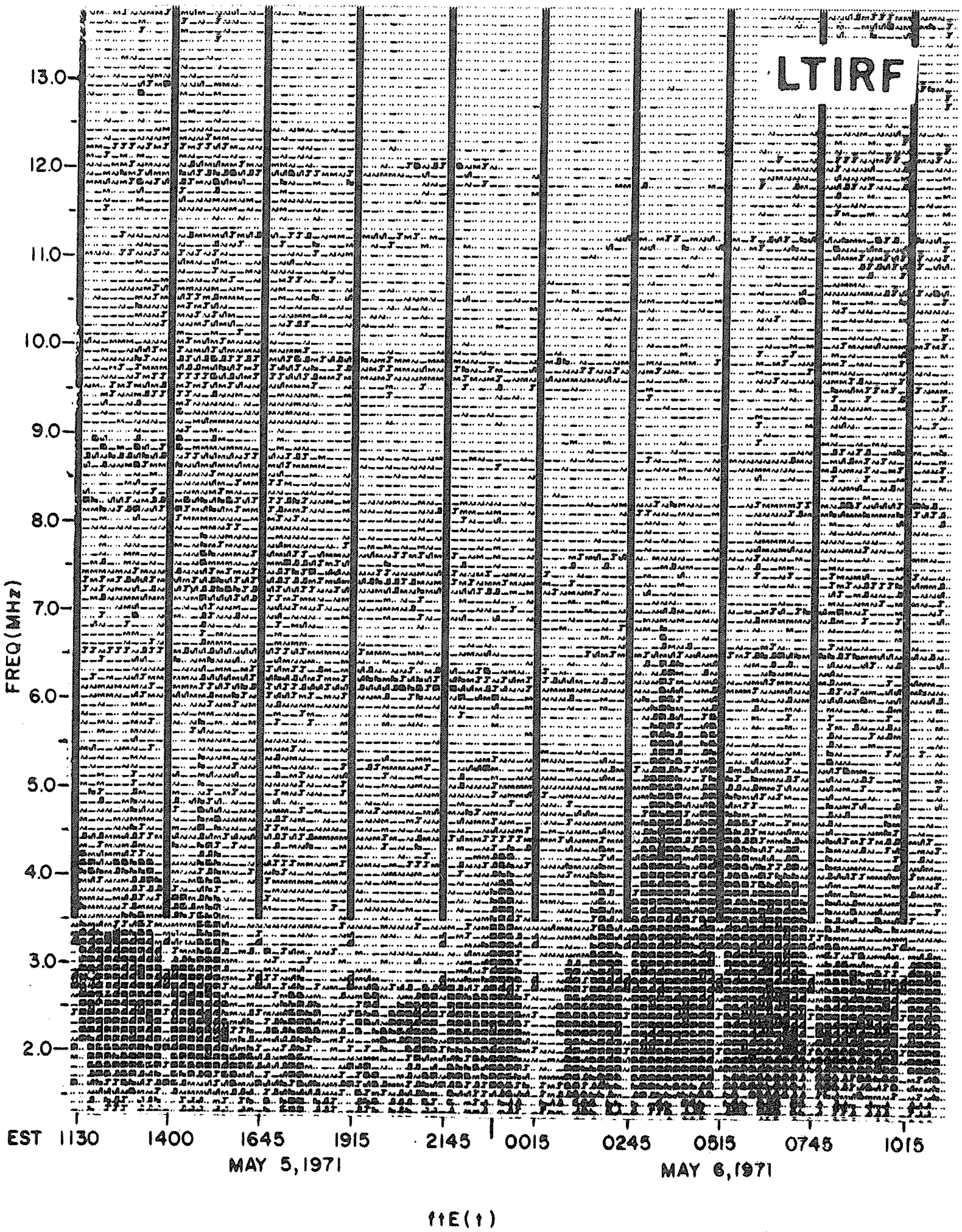


Fig. 11.6 Example of continuous recording of a characteristic (section 11.3) using digionogram methods.

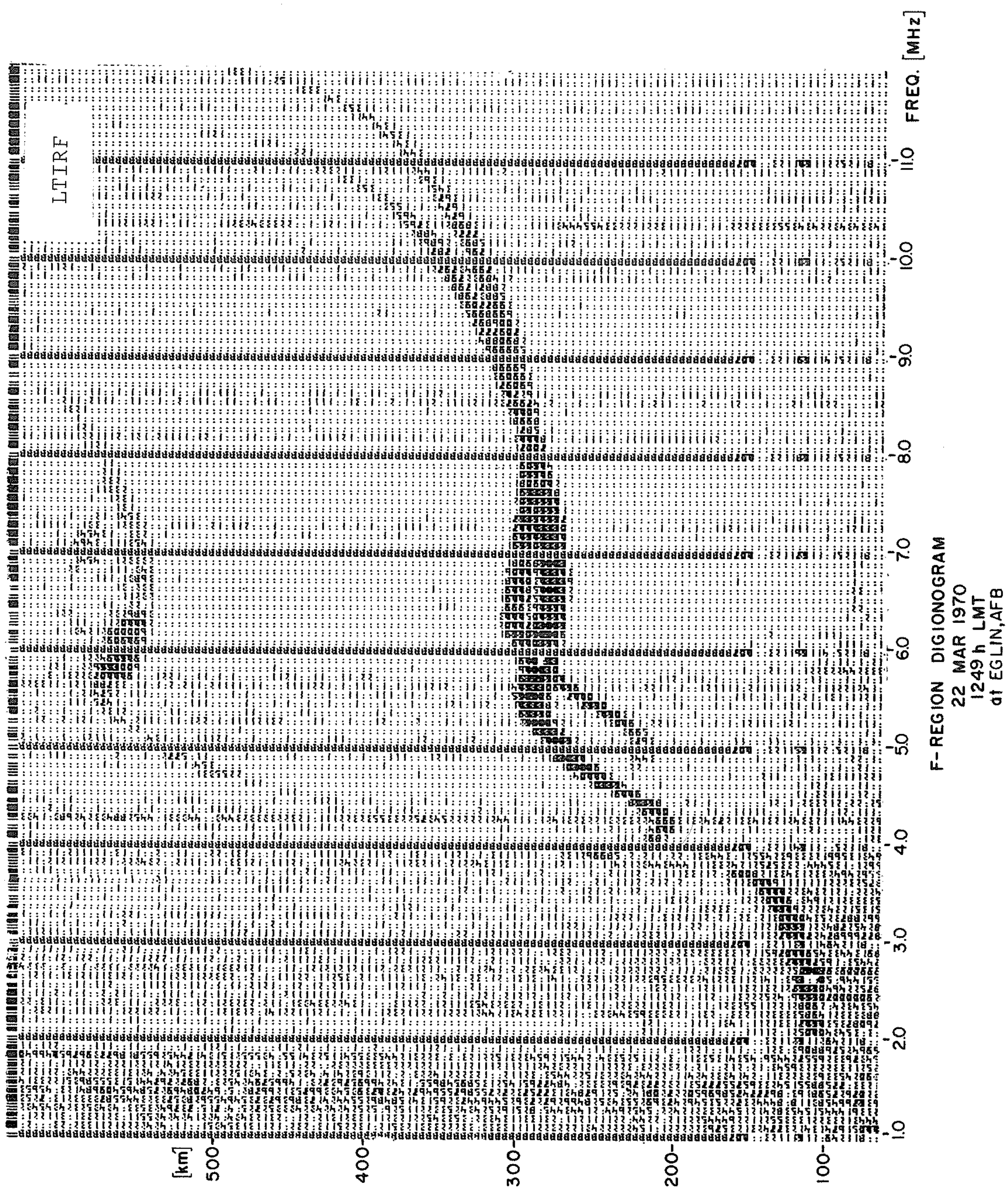


Fig. 11.7 Ionogram produced using symbols whose blackness is proportional to signal strength.

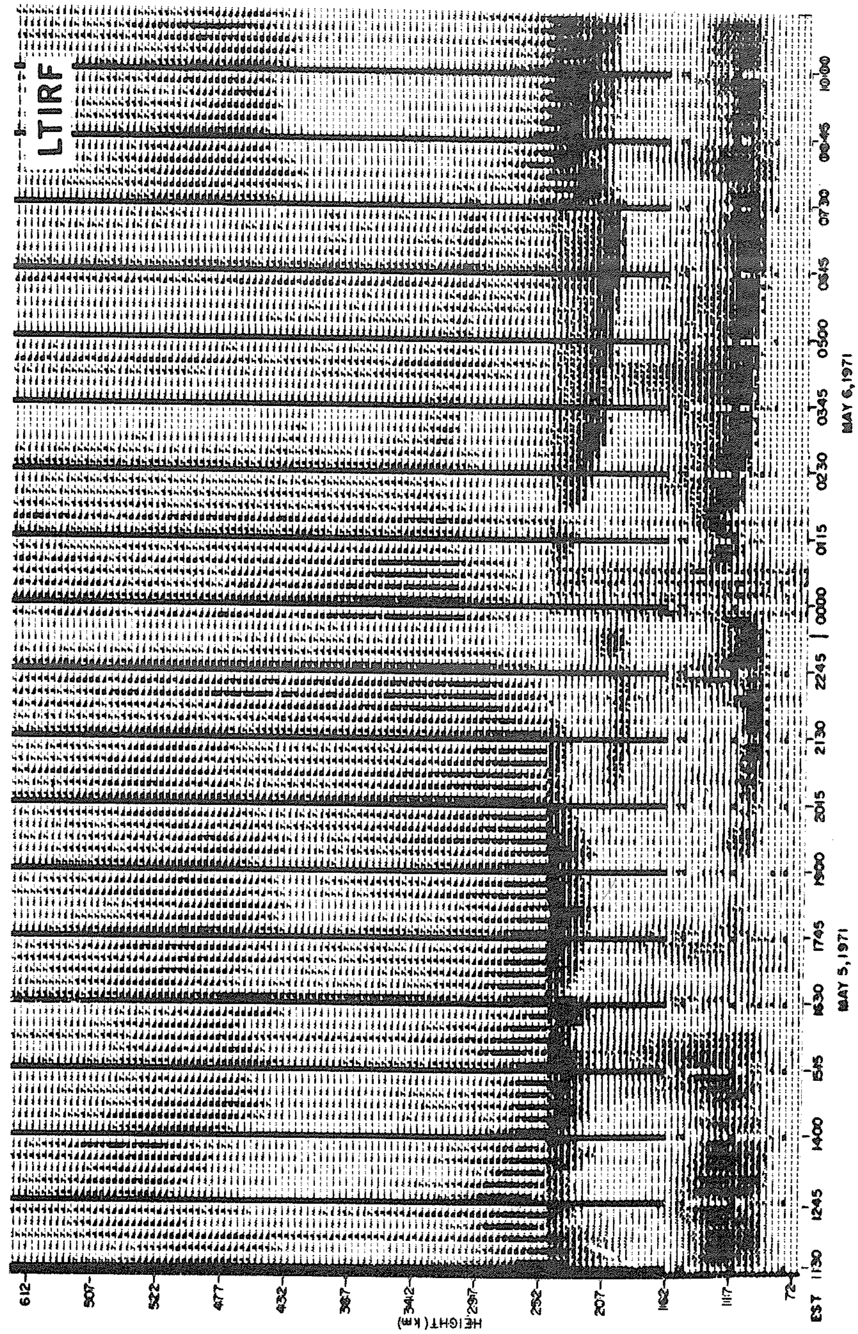


Fig. 11.8 Continuous recording of height using digionogram technique.

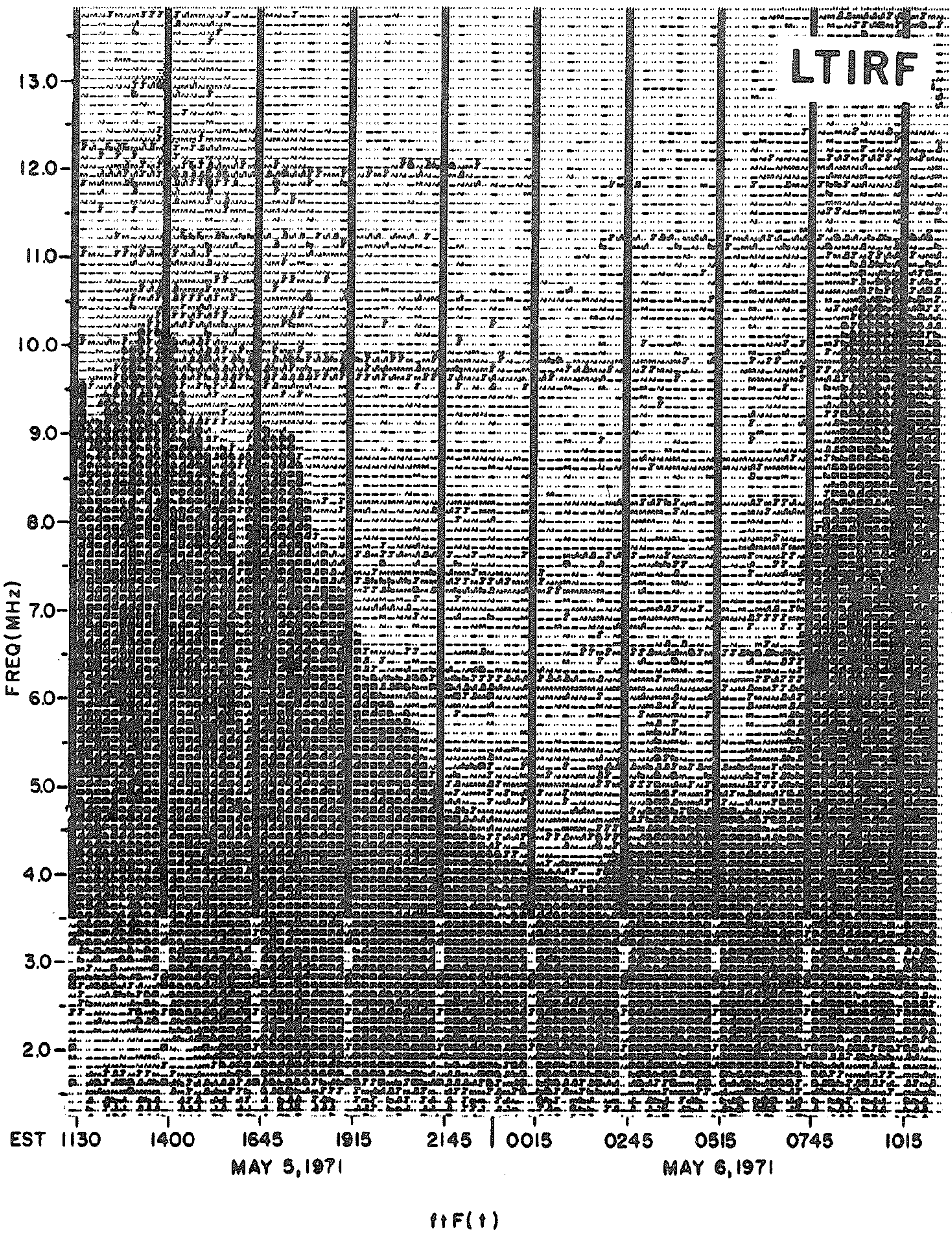


Fig. 11.9 Continuous recording of amplitude with frequency using digionogram technique.

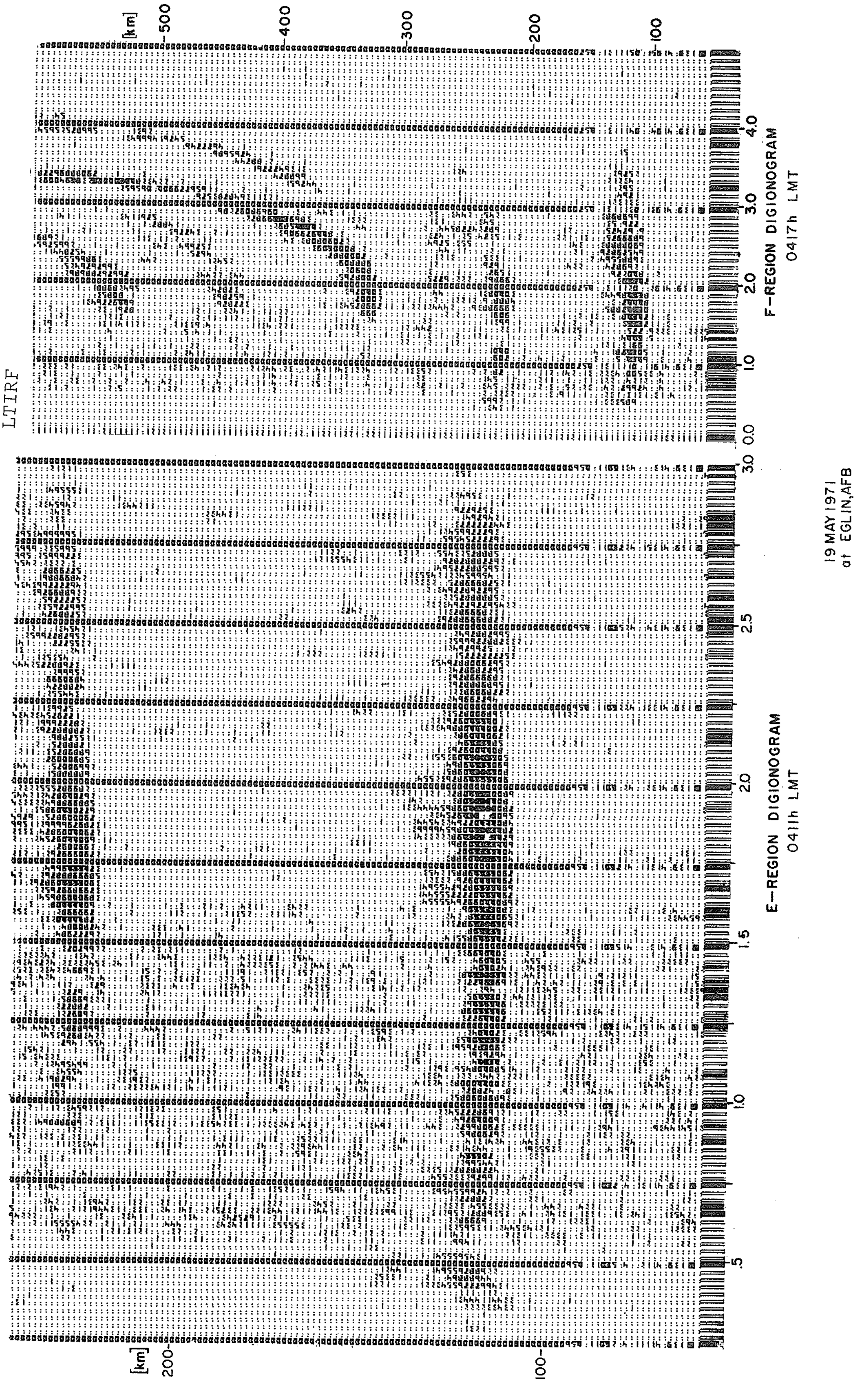


Fig. 11.10 Example of presentation with expanded height scale for E traces and normal for F traces, taken from same master data.

11.42. For complicated ionospheric conditions, a digital ionosonde cannot by itself distinguish between a desired and unwanted signal, although the signal-to-noise ratio can be improved relative to a normal ionosonde by digital integration. As with conventional ionograms a controlling person is needed to identify the significant traces and interpret the pattern. Once identified the measurement of h' and f is most accurately made using the automatic electronics though some averaging in time or frequency is usually desirable. Programs are being developed which aim at giving an automatic determination of ionospheric parameters but there are many difficulties. The digital ionosonde has considerable advantages when it is desired to compute electron density profiles with sophisticated methods since the data are already in digital form and are easily fed to the computer. As an intermediate step, digital characteristics recordings can be used for study of dynamic properties of the ionosphere (Fig. 11.8) and for absorption measurements as function of frequency (Fig. 11.9).

11.43. In general it is only possible to increase accuracy conveniently by factors of two. Thus, it is most convenient to record with different height or frequency scales for different purposes. A typical series might be:

(i) For E region, maximum height 375 km, minimum frequency shift 25 kHz

(ii) For F region, maximum height 750 km, minimum frequency shift 50 kHz

(iii) For interpretation, maximum height 1500 km, minimum frequency shift 100 kHz

The exact numbers depend on the design of the ionosonde, in particular, on the basic frequency used in the synthesizer. Fig. 11.10 shows examples of different height and frequency scales taken by the same Digisonde with 128 complex-amplitude virtual-height samples.

11.5 Amplitude Measurements with Ionosondes

It is possible to make useful amplitude measurements using an ionosonde provided:

(a) The output signal is a unique function of the input signal, preferably quasi-logarithmic (output proportional to log (input)).

(b) The receiver and display are stable in sensitivity.

(c) The transmitter and receiver cannot get out of tune with each other.

This means, in particular, that differentiating devices cannot be used when amplitude is to be measured.

For these types of ionosonde, the amplitude information can be added to the ionogram by switching every second pulse so that it deflects the spot downwards by an amount proportional to the output* (Fig. 11.11, 11.12).

For ionosondes in which the width of the trace varies with echo amplitude, a crude indication of amplitude can be obtained from this width provided only one echo is present. This is usually not sufficiently accurate for quantitative data.

11.6 Use of Aircraft and Ships for Sounding

Aircraft, satellites and ships can be used effectively for sounding in two ways:

(a) Synoptically by comparing data from the mobile ionosonde with that from fixed ionosondes so as to establish variations with position.

(b) For detailed analysis of phenomena which can move in time, in particular, phenomena across the auroral oval and phenomena at low latitudes.

In case (a) it is necessary to obtain a sufficient sample to show whether the changes seen are peculiar to the particular days on which the data were collected or whether they represent regular

* Paul, A. K., Electron Density Distribution in Ionosphere and Exosphere. E. Thrane (Ed) North Holland, Amsterdam, 1964 p. 17-20.

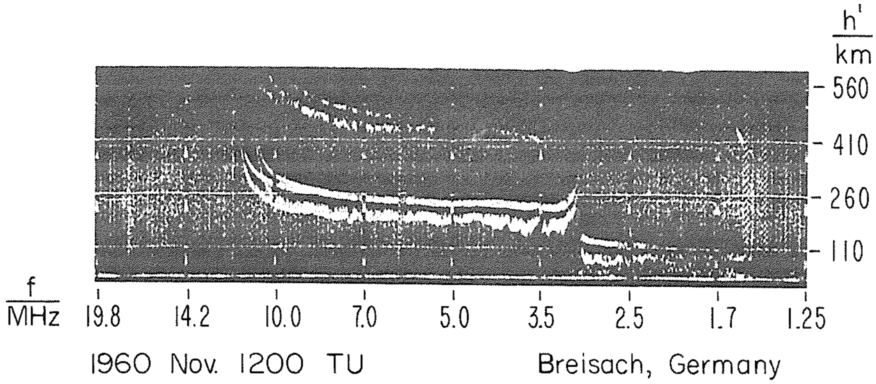


Fig. 11.11 Ionogram with amplitude registration.

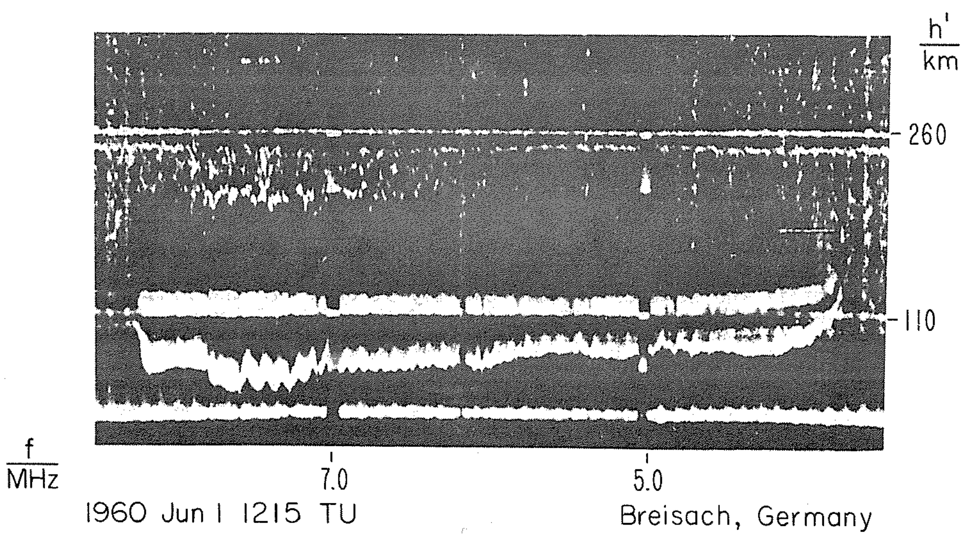


Fig. 11.12 Ionogram with amplitude registration showing beat between o- and x-mode reflections from Es.

features of the morphology. This generally demands some four or five samples for each time of day together with control from sufficient fixed stations to identify day-to-day changes in solar or magnetic activity.

In case (b) it is possible to traverse structures and study their variations with position. Aircraft are particularly useful, as typical structures can be scanned in a few hours flying time. The data are valuable both scientifically and for interpretation purposes. Thus a combination of ground based and mobile observations often provides a unique interpretation of phenomena which are difficult to interpret uniquely from time variations at a fixed station.

The following sequences and comments are provided by G. J. Gassmann, USAF, Cambridge Laboratories.

Fig. 11.13 shows some ionograms and all-sky camera photos from an aircraft flying towards an auroral arc. The changes in Es as the plane approaches the arc are clearly seen showing that the Es traces in (a), (b), (c) are oblique, and (d) is overhead. Aircraft flights show that Es type a or type r are usually oblique and may sometimes hide night E which is present when discrete aurora are overhead.

Figs. 11.14 and 11.15 show sequences of ionograms taken from North to South when flying across the auroral oval in winter and in summer. Figs. 11.16, 11.17 and 11.18 show a corresponding set of ionograms at Goose Bay and their interpretation.

Fig. 11.19 shows a sequence across the auroral zone in which normal E, night E and Es types r or a can be seen. Normal E is changing from foE = 2.9 MHz on frame (a) to foE = 2.5 MHz on frame (g) both approximately. Thus the values of foE for frame (c) to (f) are above the normal value, (foE) = K. Frame (d) is intermediate Es type a or type r and more like type r than type a, (e) is again r, (f) again intermediate, the o trace is unquestionably a typical type a but the x trace shows that it is really more like type r.

(Ed. Note: The values of h'Es quoted in these figures are consistent with the second order traces where seen but appear incorrect on this series of reproductions due to instrumental causes).

Discussing these auroral associated traces seen by aircraft, Gassman comments:

Night E occurs at geomagnetic latitudes starting at the location of the discrete aurora, where auroral types of Es occur, and stretch southward by several hundred kilometers.

Due to its limited north-south extent the night E layer shows large tilts against the horizontal; therefore it might be seen obliquely in which case no F-layer retardation will occur. The designation for Es r fits this situation and the Es r occurrence in the Arctic is nothing else than oblique night E.

In addition, the irregular structure of the night E traces suggests that this layer is interspersed with irregularities. This causes, at each sounding frequency, oblique scatter echoes maximizing from slant ranges of about half the skip distance. Consequently, a slanting trace may appear on the ionograms if the scatter is sufficiently strong. In the Arctic the ionospheric traces defined as Es s appear to be special manifestations of the night E layer, when the scatter process is dominant.

The ray geometry and the resulting ionogram is sketched in Fig. 11.20. In the left corner the ray path geometry for 3 MHz is indicated by a vertical cross-section. The figure shows a synthetic ionogram for a given vertical trace assuming that those rays which are reflected by the ionosphere are scattered at the apex of their path by a process which enables part of the energy to return to the origin. The multitude of resulting oblique traces results in a slanting envelope trace. The thicker the layer and the closer it is to the ground, the less steep is the slanting trace. The scatter process maximizes at the apex of the ray paths because at that point the plasma frequency W_N is closest to the operational frequency W and the relative change $\Delta\mu/\mu$ of the refraction index is then a maximum.

Es type a occurs definitely in aurora. The layer, however, can be seen by an ionosonde obliquely (see Fig. 11.13). The echo from Es a is caused by a scatter mechanism. The associated irregularities are suspected to be caused by the auroral electrojet. The occurrence of Es a often obscures the identification of night E which occurs near discrete aurora simultaneously.

The Arctic F layer shows the phenomena of the trough, Fig. 11.17, the ring-like irregularity zone and sometimes the polar cavity. The irregularity zone, which in the Arctic has maximum latitudinal extension near 1800 UT marks the northern edge of the trough. Figs. 11.14 and 11.15 show the change of ionograms along a geomagnetic meridian for winter and summer respectively. Oblique traces are common (due to reflections on ionospheric tilts). Since the latter usually run east-west the oblique ray paths take place mostly in the meridional plane. How the slant ranges of an oblique F-layer trace, after identification as such, can be used in locating the northern edge of the trough (southern edge of the irregularity zone) is shown in Figures 11.16, 11.17 and 11.18.

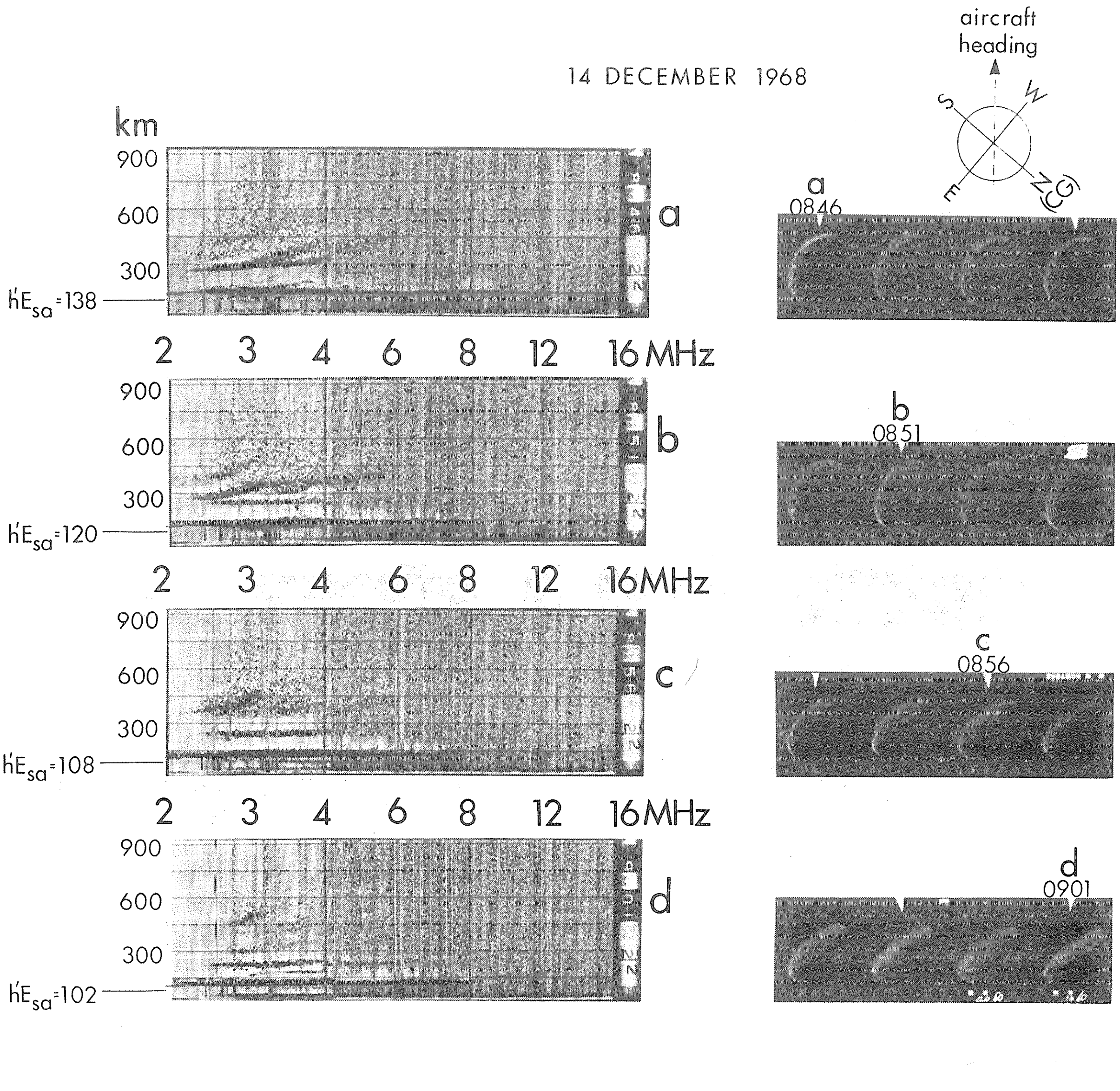
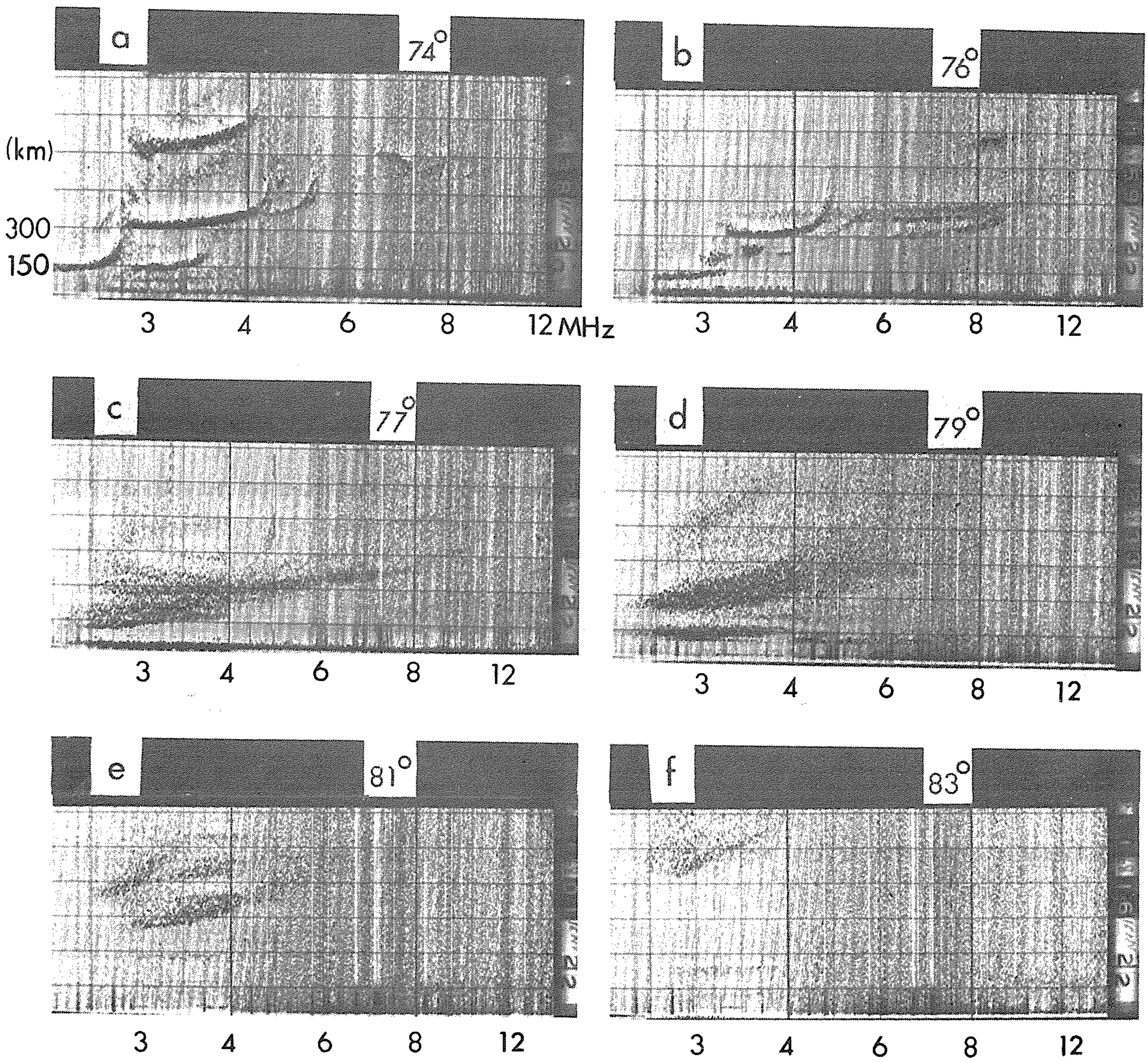


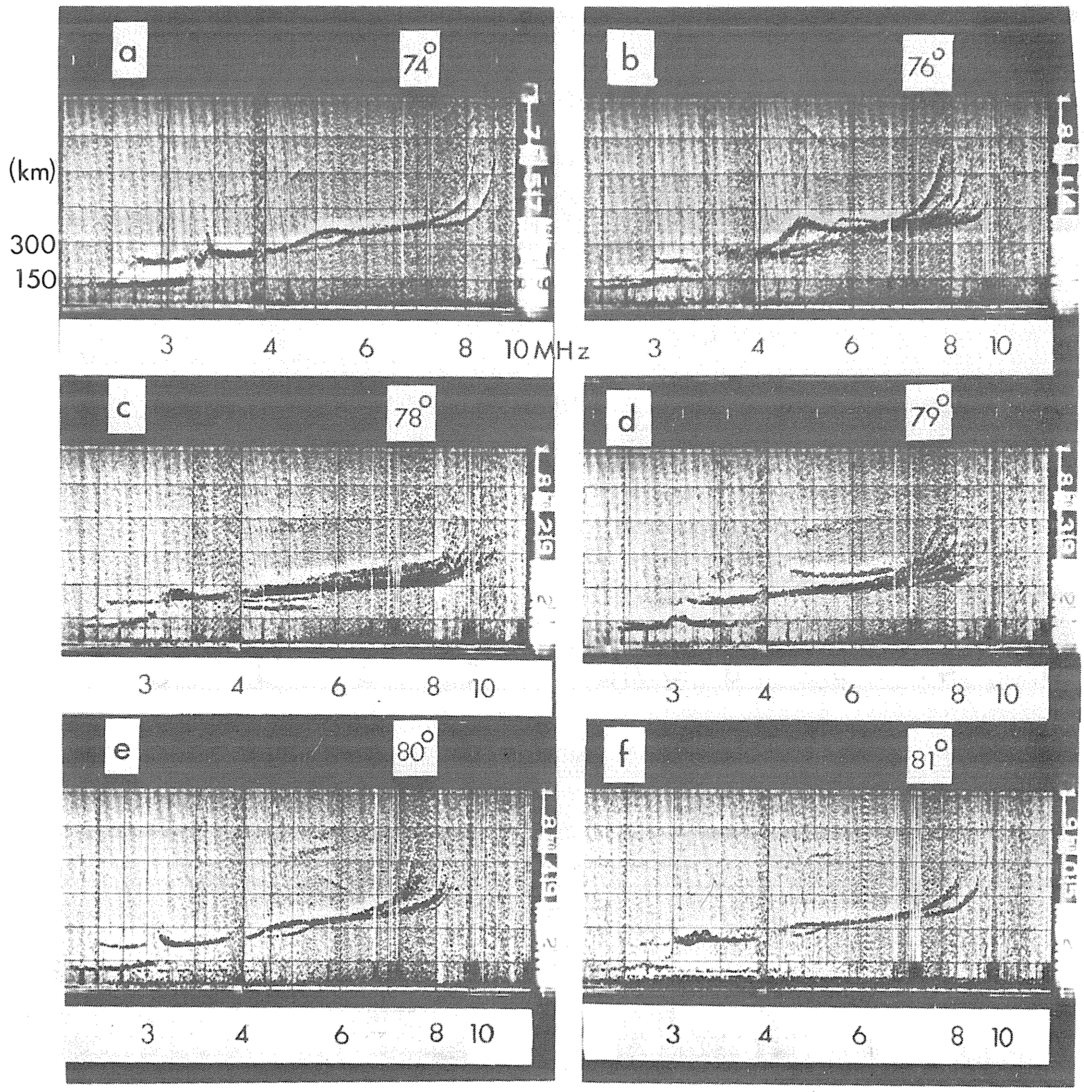
Fig. 11.13 Variation of Es across the auroral zone.

Sequence of airborne ionograms and all-sky photographs. h'Es a is smallest in frame (d) when discrete aurora is overhead. The Es a trace in frame (a) results from an echo about 40° off vertical. (From Wagner, R. A. and C. P. Pike, AGARDOGRAPH, CP97, Nov. 1971, J. Frihagen, Editor).



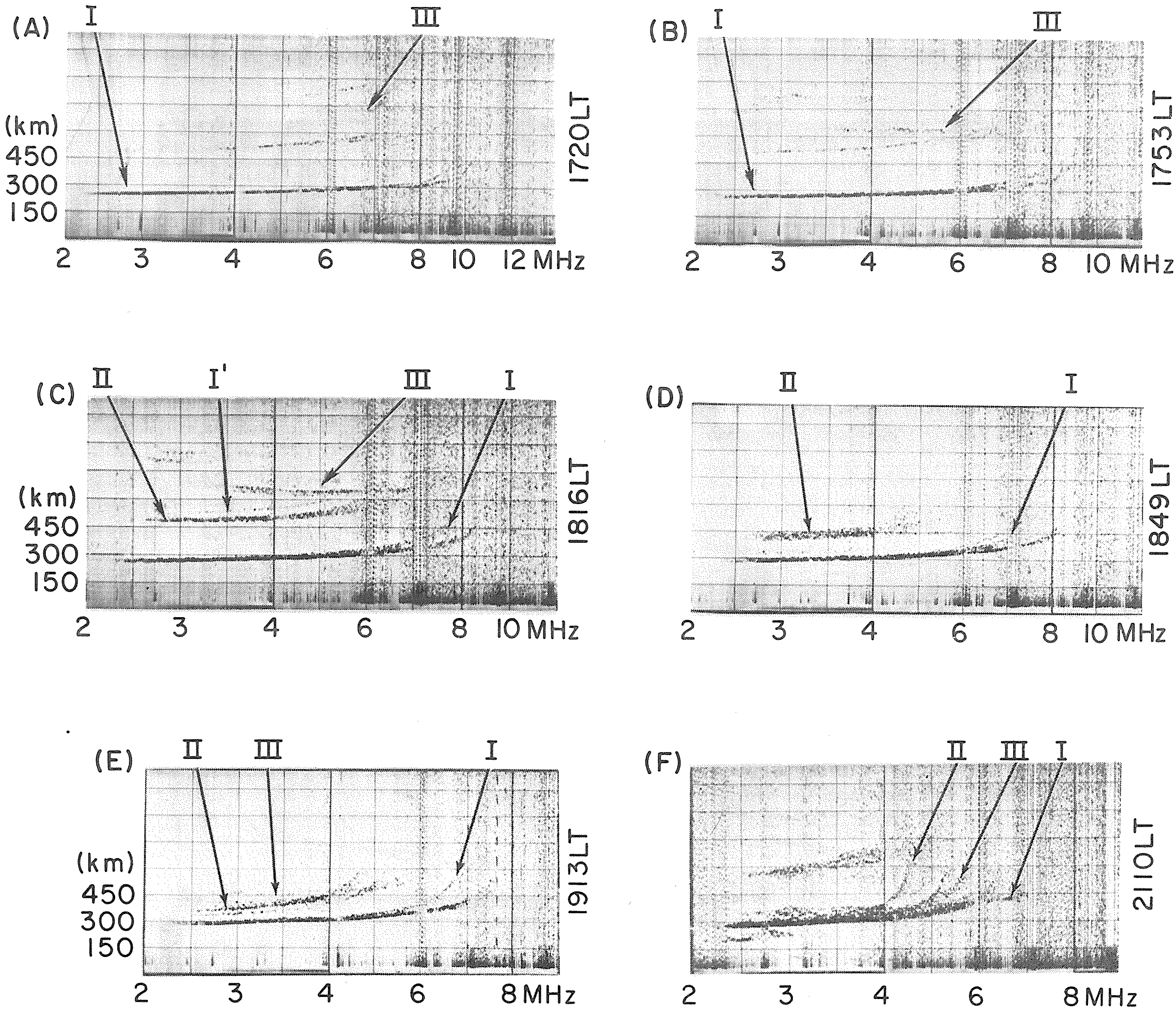
11.14 F layer structure across auroral oval in Winter.

Sequence of airborne ionograms in arctic winter (16 Nov. 1968, 1138-1316 UT) from south to north (geomagnetic latitudes are indicated) taken in the noon sector of the auroral oval. The F-layer irregularity zone is overhead in frame (c). All other frames show oblique traces from this layer. (From C. P. Pike, J.G.R., 1971, 76, p. 7745-53.



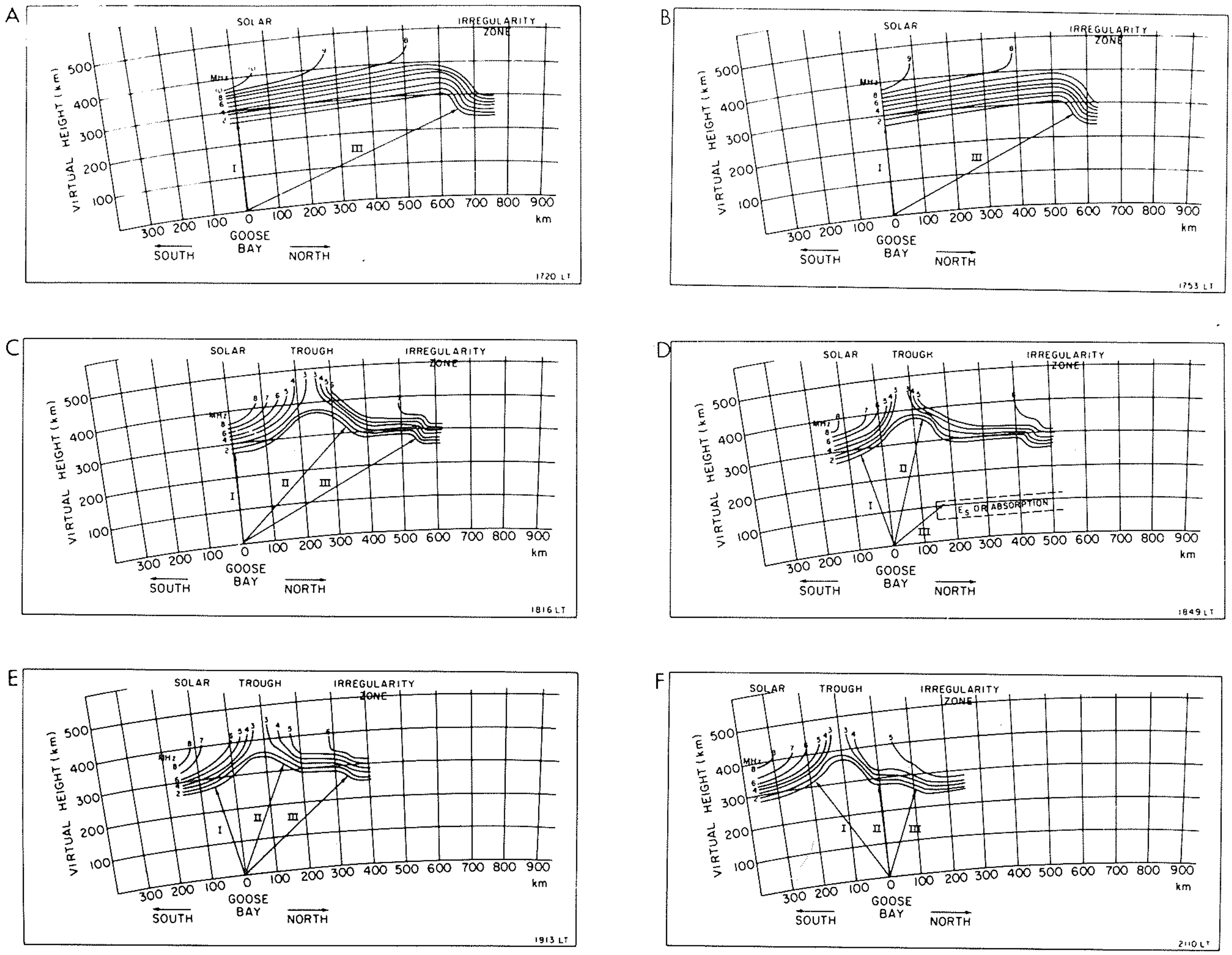
11.15 F layer structure across auroral oval in Summer.

Sequence of airborne ionograms in arctic summer (11 May 1970, 1957-2105 UT) from south to north (geomagnetic latitudes are indicated) taken in the afternoon sector of the auroral oval. The F-layer irregularity zone shows up in frames (b), (c), (d) and (e) as frequency spread. In addition, frames (b), (c) and (d) show strong oblique traces. (From C. P. Pike, J.G.R., 1971, 76, p. 7745-53).



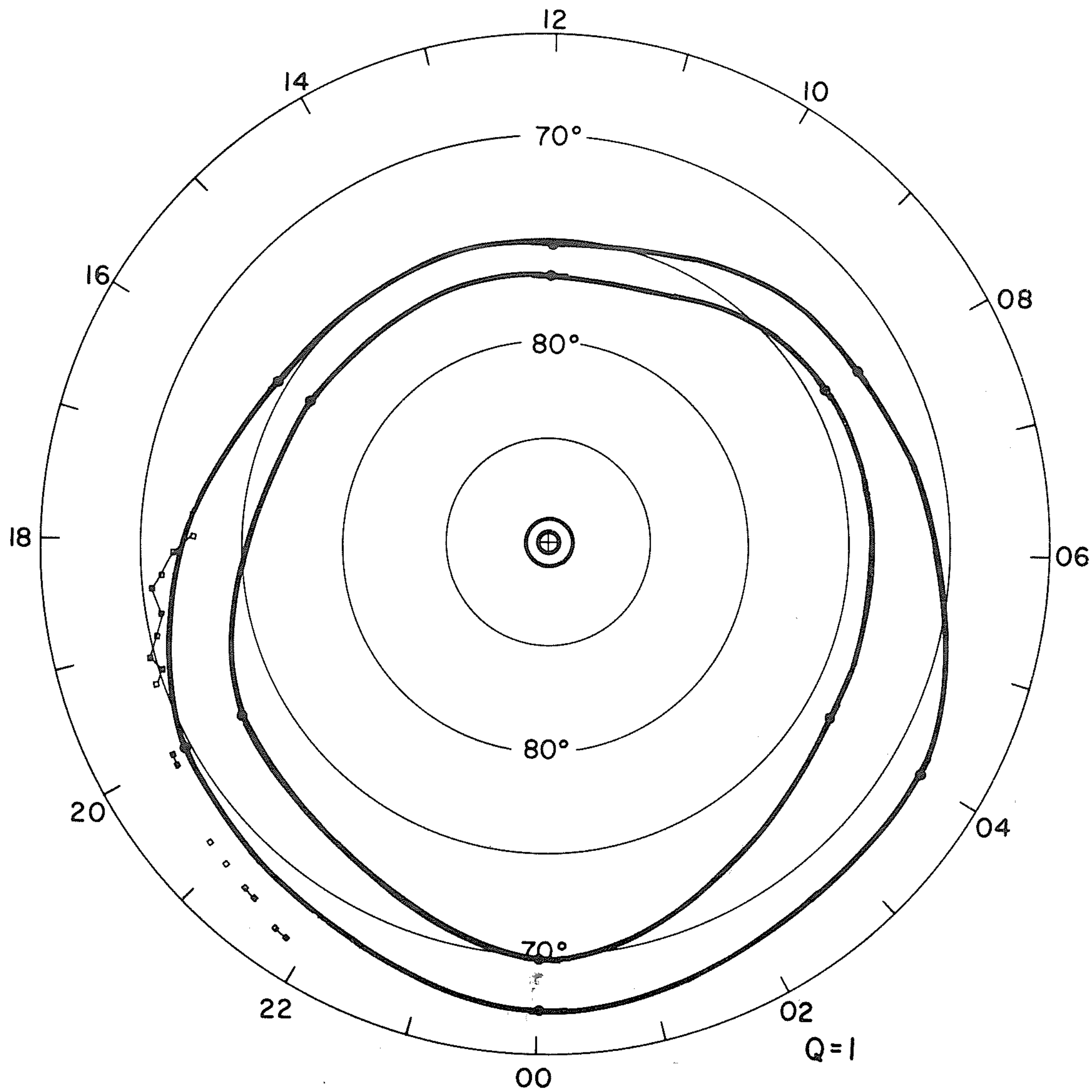
11.16 Vertical and oblique traces.

Goose Bay ionograms recorded on October 27, 1970. Several traces are oblique echoes and are identified in Fig. 11.17. (From Wagner, R. A. and C. P. Pike, AGARDOGRAPH, Nov. 1971, No. CP97, J. Frihagen, Editor).



11.17 Schematic interpretation of ionograms of Fig. 12.16.

Schematic drawings of plasma frequency contours and ray paths over Goose Bay on October 27, 1970 are shown. Roman numerals refer to respective traces in Fig. 11.16. (From Wagner, R. A. and C. P. Pike, AGARDOGRAPH, Nov. 1971, No. CP97, J. Frihagen, Editor).



11.18 Relation between Southern Edge of Irregularity Zone and auroral oval for Q = 1.

The interpretation of oblique traces on Goose Bay ionograms of October 27, 1970: The latitude of the southern edge of the F-layer irregularity zone, indicated by squares, is plotted on a geomagnetic latitude and geomagnetic local time grid. The edges of the Q = 1 oval are indicated by heavy solid lines. (From Wagner, R. A. and C. P. Pike, AGARDOGRAPH, Nov. 1971, No. CP97, J. Frihagen, Editor).

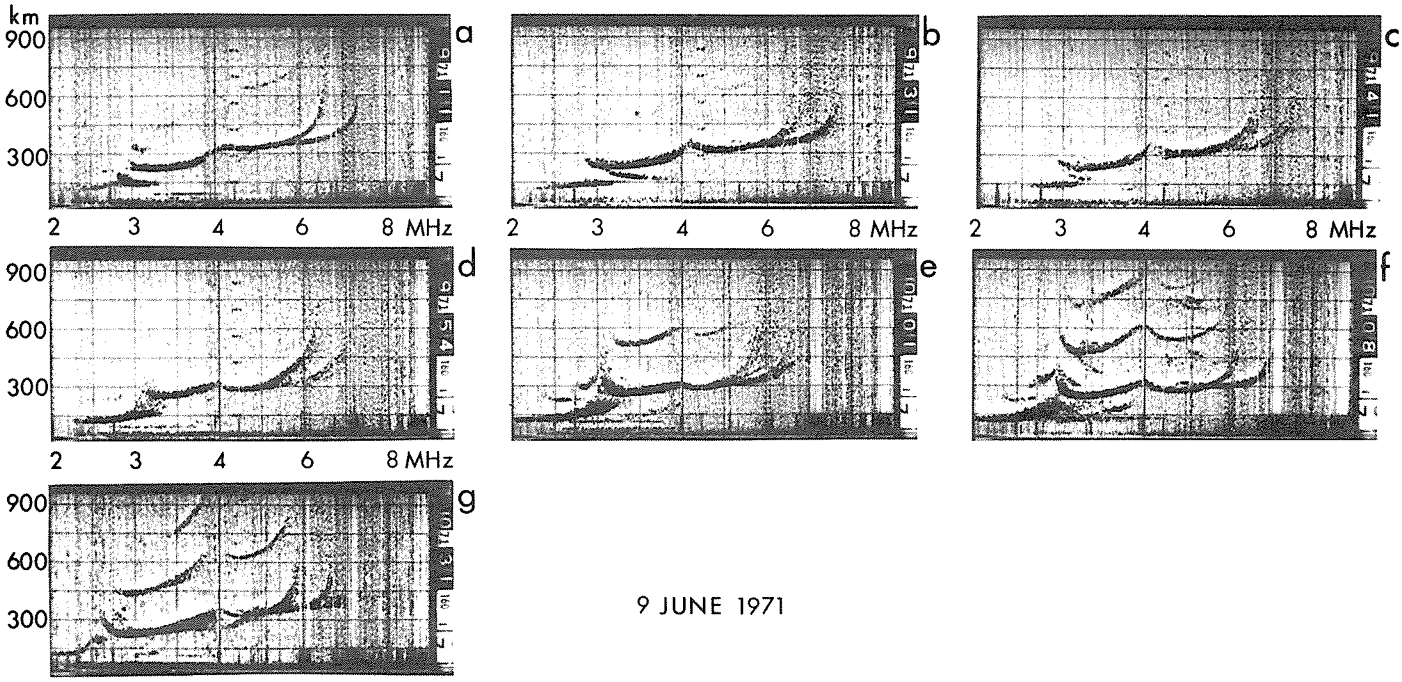


Fig. 11.19 Sequence across auroral zone showing normal E, night E and Es types r and a.

Auroral E (night E) not only occurs during the night but also during daylight hours and is then superimposed on the normal E layer. It can be identified on ionograms by a slightly enhanced foE and more safely by the spreading in frequency of the E-layer trace. In this sequence of airborne ionograms frames (d), (e) and (f) show this condition. (From Wagner, R. A. and C. P. Pike, AGARDOGRAPH, Nov. 1971, No. CP97, J. Frihagen, Editor).

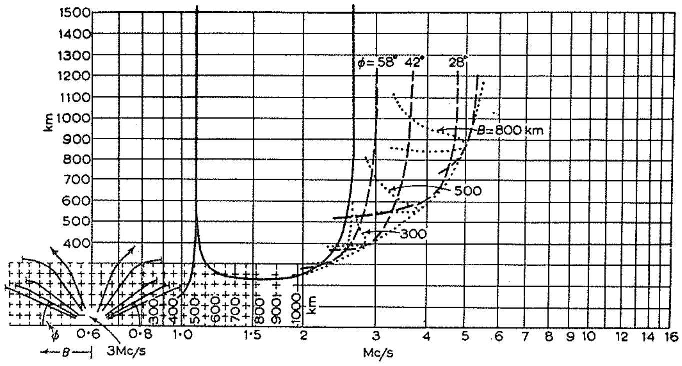


Fig. 11.20 Ray geometry for a slant trace.

A synthetic ionogram resulting from a scatter process maximizing at slant ranges of half the skip distance. The slanting envelope is less steep for a thick layer. A vertical cross-section of the ray path geometry at 3 MHz is indicated in the lower left corner. (From Gassmann, Polar Atmosphere Symposium II, pp. 44-51, Pergamon Press, 1957).

NOTES

12 SUGGESTIONS FOR PARTICULAR STUDIES AT INDIVIDUAL STATIONS

12.0 Introduction

12.01. The production of standard data for world-wide studies of the characteristics of the ionosphere represents only a small part of the capacity of a station to contribute significantly to our knowledge. Inevitably a large number of potentially fruitful investigations cannot be included in a world system because the total effort available is limited. These form natural subjects for local study either using ionograms alone or in association with special experiments. It is obvious that many phenomena shown by ionograms, particularly those which are only seen in limited areas of the world, cannot be studied by present methods and, in fact, may only be known to those actually reducing the ionograms at one or two stations. Also, the type of characteristic reduced for world-wide purposes has sometimes been selected from a number of alternatives, some of which might be developed to give very valuable information, particularly in local investigations.

12.02. Developments of advanced methods of studying or predicting radio propagation conditions have introduced a number of new problems, many of which demand local study for their solution. Some of these have been summarized by McCue:

(a) On a world-wide basis, foF2, M(3000)F2 and MUF(3000)F2 are generally available. For simple MUF predictions these are adequate. However, for sophisticated computer based prediction methods, it is desirable to use ionospheric models which have as their parameters, true layer heights, thicknesses, electron densities and in some cases collision frequencies.

(b) The prediction of the height of maximum ionization of the F2-layer is at present done by the method of Shimazaki* as modified for the effects of underlying layers by Wright and McDuffie**. Shimazaki's method postulates a simple relationship between layer height and M(3000)F2. Since world-wide data on layer heights are not generally available, the Shimazaki-Wright-McDuffie method should be checked against the data that are available and special analyses done to provide sample comparisons (see section 1.08).

(c) Data on the variation of layer semi-thicknesses are not generally available. The ratio of h max/y_m as a function of solar zenith angle and geomagnetic latitude has been derived by Wright, Wescott and Brown*** from data mainly along the 75th meridian. It is desirable to have detailed results for the world-wide variations of this parameter.

(d) Information on the statistical variation of ionospheric parameters is meagre, and not available on a world-wide basis. Most data that are published in readily available form relate to median conditions. Good statistical predictions, in addition to the median predictions, must take account of the variations of the ionospheric parameters. These must be based on local statistical studies at a widely spaced group of stations.

(e) Sporadic-E ionization can radically affect predictions through Es propagation, Es blanketing and off-great-circle effects. It is essential that world-wide statistical data be provided on these Es effects in a form suitable for prediction purposes.

(f) Inadequate information is available on the equatorial ionosphere. There are not enough equatorial ionospheric stations. Propagation predictions for circuits within and across the geomagnetic equatorial regions are not satisfactory. This is because there are inadequate relevant data on layer heights, thicknesses, tilts, Es distribution and propagation modes.

(g) Some variations of foF2 with varying geomagnetic activity have been studied, but the phenomena are very complex, vary with latitude and longitude, season and often from storm to storm. It would be desirable for this work to be extended to variations of other ionospheric parameters, including absorption, with varying geomagnetic activity.

(h) For field strength predictions there are inadequate data on electron densities and collision frequencies as a function of height. The physical problems of obtaining satisfactory data are very great but the availability of reliable data is important. The variation of anomalies in the D-and E-region absorption as a function of geomagnetic latitude is also not known adequately.

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* Shimazaki, T., J. Radio Res. Lab., Japan, 2, 85-97, 1955

** Wright, J. W. and R. D. McDuffie, J. Radio Res. Lab., Japan, 7, 409-420, 1960.

*** Wright, J. W., L. R. Wescott and D. T. Brown, N.B.S. Technical Notes, Nos. 40-1 to 40-13, 1960-1963. N.B.S. Washington D. C. 20234, U.S.A.

(i) Recent theoretical and experimental work in Australia suggests:

(i) That the deviative absorption on F modes in the E region is often much greater than the non-deviative D-region absorption.

(ii) That any field strength prediction technique for F modes must include the effects of defocusing in the lower F1 and E layers. These points require more detailed evaluation.

Editorial note: Normally the quantile range of ionospheric parameters is small relative to the median value, e.g., 10-15%. Where this is not true it is important to find the reason for the large dispersion. This can be due to abnormal sensitivity, to changes in solar activity, to changes in magnetic activity, to the presence of travelling ionospheric disturbances or to the presence of moving ridges of troughs. These are all important subjects for study as well as important for prediction analysis.

12.03. The new applications of satellites to provide communication links are often limited by refraction effects in the ionosphere and troposphere. These can cause the signals to fade and can limit the precision of high accuracy tracking and direction finding systems available for monitoring satellites and other spacecraft. This requires in addition to standard parameters:

(a) Measurement of the whole electron density profile of the F layer both topside and bottomside.

(b) Measurement of total electron content.

(c) Production of predictions of average profiles for the whole ionosphere as a function of hour, season, location and solar activity.

12.04. The demands of space research have increased the demand for new parameters and investigations to establish the physical significance of changes in layer shape and height.

12.05. In contrast to the contents of the main part of this book, which may reasonably be expected to be applicable with only minor changes for many years, the techniques and emphasis of special problems, as considered in Chapters 12 and 13, will change with the development of the subject. However, experience has shown that some guidance on these problems is essential to stimulate interest, to indicate the main difficulties to be overcome and to assist in the rather specialized job of working out practical methods of measurement.

12.1 E-Region Studies

12.11. <u>Normal E Layer</u>: Most normal E-layer studies fall into two groups: (1) studies of changes in the characteristics of the layer designed to detect and measure changes in the ionizing solar radiation which generates the layer, and (2) studies of changes in the layer due to terrestrial phenomena. These may, alternatively, be regarded as studies of the differences between the observed behaviour of the layer and the corresponding variations of a simple theoretical model layer. In general both types of experiment demand high-quality ionograms.

(a) Where the ionosonde can record to low frequencies, e.g., 250 kHz, the study of normal E at night is very important though difficult experimentally. The absorption band near foE is sometimes more easily detected by suitably planned experiments than the critical frequency (e.g., when interference is severe). At some stations, it is often possible to observe fzE when it is below the MF broadcast band.

(b) Short lived perturbations in foE and the associated variations in critical frequency and virtual height of E2 substratifications are useful for studying gravity wave phenomena, particularly when carried out in collaboration with other stations in the same region. At a single station, corresponding effects in F2, F1, E2, E and Es can give information about the vertical behaviour of these phenomena. (See section 13.13).

(c) Potentially, studies of E-layer stratification at constant zenith angle near sunrise and sunset can give information about the different ionization and loss processes effective in the E region and their variation with solar activity.

(d) Systematic deviations occur in the diurnal variations of foE. Their interpretation in terms of layer relaxation time and location perturbation by magnetic phenomena are important (both local and regional research).

(e) Day-to-day changes in foE and their relation to changes in solar radiation as shown by satellite and indirect parameters are important.

(f) Short time changes in foE can be studied in relation with changes in absorption, e.g., as measured by fmin or other data. The changes during SIDs are particularly interesting with respect to the IUCSTP-program (see Chapter 9).

(g) Accurate measurements of diurnal variations of minimum virtual height can give data about lunar tides and the perturbation of layer height with magnetic phenomena. (Note: Care is needed to keep data homogeneous when stratifications are present.)

(h) It is valuable to study the characteristics and incidence of the z trace, particularly for investigation of the valley between the E and F layers (see section 10.12) and nighttime D-region ionization.

(i) In some zones the change in mode from o to z at the lower frequencies is particularly regular and interesting. The critical frequency and shape of the E layer may vary with changes in minor constituents of the atmosphere and thus be used to monitor them. It is possible that some changes in the F region are associated with changes in the E region.

12.12. E2 and similar phenomena: The presence of ionization between the normal E layer and the F layer is often disclosed by the intermittent or continuous appearance of subsidiary thick layers. These are sometimes very regular, particularly near sunrise and sunset, and are clearly significant. It must always be remembered that these phenomena only correspond to minor changes of the ionization profile.

(a) Studies of the incidence and characteristics (e.g., critical frequency and height of E2 and other substratifications may be worthwhile).

(b) Where rocket data are available the relations between rocket profiles and the incidence of E2 and substratification in the E layer are very interesting.

12.13. Es phenomena: It appears certain that the group name Es covers several independent phenomena, many of which can only be studied by methods which separate the different phenomena. The "types of Es" may be considered as a first approach to this distinction.

(a) At high altitudes Es types a (auroral) and r (retardation) are both closely associated with magnetic disturbance and smooth changes from one to the other occur at certain stages in the disturbance. These vary with latitude and longitude in a way which is not understood.

(b) Sequential Es often starts as an abnormal thick layer trace above the E layer. F0.5 or E2 changes to a high Es, then to a cusp and finally to a low type. The presence of this phenomnon can only be detected by the characteristic sequence of events in time since the actual ionogram traces are indistinguishable from those due to other phenomena. Some particular techniques which have been found useful are discribed in Chapter 11.

(c) When choosing Es studies for any one station or region, the subjects should be decided by the kinds of Es phenomena found at that station.

Statistical study of the incidence of different types or kinds of Es and their association (if any) with other phenomena. Some typical examples of the problems worth investigating are:

(i) Which of the standard types frequently occur at the station?

(ii) Do transitions from one type to another occur?

(iii) How do the types vary with changes in magnetic or solar activity? At some stations sequential Es occurs mainly on magnetically quiet days.

Among the many other Es problems well adapted to individual station study the following may be mentioned:

(iv) Is any particular type of Es concurrent with severe local thunder-storm activity?

(v) If magnetograms are obtained locally, are the occurrences of certain types of Es related to distinctive magnetic field changes?

(vi) Can meaningful values of Es thickness be deduced, for example, by the use of M-type echoes or with the aid of soundings using expanded height scales or with modern digital techniques ?

(vii) What is the effect of receiver gain (and, if possible, transmitter power) on foEs, fbEs?

(viii) What types of Es are associated with visible aurora?

12.14. Studies of Es layers by rockets: Rocket experiments designed to test theories of the origin of the Es layer require very accurate measurements of Es parameters, particularly heights. This is particularly true when the rocket determines neutral wind, ion mass composition, ion density, electron temperature or electron density. Ionosonde measurements give data about an extended surface of the layer whereas the rocket samples a much smaller area. For foEs or fxEs, this area according to the relevant frequency may reach a few times 100 km^2 before obviously oblique traces are seen whereas for fbEs the equivalent area is only up to a few times 10 km^2 - sufficient to obscure the first Fresnel zone at the layer.

Thus in situ rocket measurements and ionosonde data will not be exactly comparable even when both methods are correctly applied and are giving significant data.

12.15. Es characteristics: A few subjects needing study are:

(a) Variations of foEs, fbEs or h'Es with time for particular types of Es.

(b) Measurement of transparency of Es by the relations between foEs and fbEs (a very valuable parameter to use is fbEs/foEs).

(c) Studies of sequential Es. These demand frequent soundings or recording of the characteristic ftE, see section 11.32.

(d) Use of higher order traces to study the size of blanketing areas. This is usually only satisfactory when absorption effects are small.

(e) Local studies of the new Es type "d" (where a very low stratification is present as shown by (generally weak) traces below about 90 km.)

12.2 F-Region Studies

12.20. Very few of the peculiar changes in the F region have been adequately studied. Probably the most important phenomena are due to movements of ionization under the influence of atmospheric winds or electric fields. For most stations epochs can be found for which one particular driving force causes the largest perturbations of the F-layer structure. At these times, detailed studies of the perturbation can give valuable information on the physical phenomena present. Thus at many latitudes wind effects are important. The diurnal phase of these varies rather slowly with season and solar cycle but the effects depend critically on the time of sunrise and sunset, which may vary much more rapidly. Little is known about localized zonal wind phenomena, lasting for a few days or less. Lunar tidal effects, if detectable, are particularly interesting for comparison with tidal theories.*

12.21. F1 layer: Most of the suggestions listed under 12.11 can be applied to F1 also, though accuracy is often limited by poorly defined transitions between F1 and F2 traces on the ionogram. The main limitations are that the apparent critical frequency is often perturbed or absent owing to overlapping by the higher F2 layer and group retardation effects considerably modify the interpretation of the minimum height. Movement phenomena are more important for this layer than for E and these form the main theme of the remaining class of special F1 studies listed below:

(a) Incidence of a separate F1 layer, for example, as shown by the incidence of unqualified and qualified values of foF1.

(b) Development of new techniques for studying the development of F1, e.g., measurement of the virtual height of the retardation cusp, or, more accurate profile studies.

(c) Distinction between F1 and transient deformations of the lower F region and its use for studying such transients. Substratifications are often associated with the passage of traveling ionospheric disturbance (TIDs) above the station.

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* Matsushita, S., in Handbuch der Physik (Encyclopedia of Physics), Vol. 49/II, pp. 547-602.

(d) Study of the systematic anomalies in the diurnal variations of the F1 layer found at very low and very high latitudes.

(e) Behaviour of the F1 layer during magnetic storms; particularly the relation between foF1 and magnetic activity.

(f) Application of F1-trace pattern matching techniques* to determine changes in composition of the atmosphere and their effects on the ionization balance in the F2 layer. This is said to be a useful tool for both single station and morphological studies.

(g) Studies of perturbations in hmF2 and/or hmF1 using the incidence of qualified and unqualified values of foF1. The count of foF1 can be very sensitive to the value of hmF2 and/or hmF1.

12.22. F1.5 and other substratification phenomena: Substratification phenomena appear to fall into three main groups, which are mainly concentrated into particular latitude zones.

(a) Substratifications at high latitudes appear to be transient in nature and have been surveyed to some extent using moving picture techniques (see section 11.2). It might be advantageous to apply these at other latitudes also.

(b) At temperate latitudes many transient substratifications appear to be associated with the formation of sequential Es.

(c) At low latitudes F1.5 and other substratifications are closely linked with the fundamental movements of ionization which generate the peculiar behaviour of the F2 characteristics.

12.23. F2 layer: Probably all measurable characteristics of the F2 layer are indirect in the sense that they show the final effect of two or more different phenomena acting together and the critical frequency, foF2, when clearly defined on the ionogram, is the only parameter which gives a physical quantity directly and accurately. A central problem in studying the layer is to derive parameters which are easy to measure, give worthwhile information about the properties of the layer and whose limitations can be understood fairly easily. The parameters M(3000)F2 and MUF(3000)F2 can be very useful for geophysical studies. In particular M(3000)F2 is a good measure of the height of the maximum of the layer and can be used for studying variations in this height (section 1.08), provided that the ratio of foF2 to foF1 is not smaller than about 1.2. Methods are available for correcting for the group retardation when foF2 and foF1 are similar but these are rather laborious.

The occurrence at moderate and high latitudes of the third magneto-electronic component (z trace) above the gyro-frequency has important implications in magneto-ionic theory. The amplitude and virtual height variations of the F-region z echo in the vicinity of foE are of special interest.

The relation between disturbed and quiet conditions is very complex, changing with time of day, season, solar activity and often with lunar phase and time of incidence of corpuscular phenomena, and rather elementary experiments can give valuable new information. Some particular problems are listed below.

(a) Disturbance studies:

(i) Determination of local criteria for the existence of disturbed conditions in the F2 layer.

(ii) Selection of local quiet and disturbed days and their relation to world disturbance.

(iii) Changes in the standard F2 parameters during magnetic and ionospheric storms, particularly foF2, h'F, parameters dependent on the height of maximum density such as M(3000)F2, MUF(3000)F2, substratification incidence.

(iv) Studies of "moving clouds of ionization" and their relation to magnetic disturbance.

(b) Dynamic phenomena in quiet conditions:

(i) Characteristics and incidence of F-layer perturbations which are not associated with magnetic disturbance.

* King, G. A. M. and M. D. Lawden, J. Atmos. Terr. Phys., 26, pp . 1273-1280, 1964.

(ii) Studies of transient phenomena, particularly incidence, speed of development, relation with ionospheric drifts and with atmospheric gravity waves.

(iii) Studies of incidence and magnitude of ionospheric ripples and layer tilts for example as shown by rapid changes in foF2, h'F or the appearance of oblique traces. Here, again, a relation with atmospheric gravity waves may be expected.

(d) Other phenomena:

Few studies of oblique incidence traces shown on ionograms have as yet been made. It is well known that the doubling of the F trace often accompanies large layer tilts or gradients but this has not been studied systematically. This is sometimes a precursor of spread F conditions, particularly at very low and rather high latitudes.

(i) In some zones major ionospheric movements are shown by the presence of oblique incidence traces which move slowly, but usually systematically, in time. Bowman* has given an excellent example of this type of analysis. Some of these may be related with atmospheric gravity waves.

(ii) The separation of the components given by fxF2 - foF2 is often a good indication and measure of gradients of ionization in the north-south plane and is very useful where these gradients are important. These are explained as due to lateral deviation of the o and x components in opposite directions to points where horizontal irregularities cause variations in the expected critical frequencies. This same phenomenon accounts for differences in shape of the o and x traces from the same layer.

(iii) At stations where large tilts occur sufficiently frequently to permit their investigation, there is a great need for auxiliary experiments designed to aid in their interpretation, e.g., interferometer measurements to show the angle of incidence and position. The ionogram patterns depend on the direction of tilt relative to the magnetic meridian and direction relative to the station both of which can change with season, solar activity, etc. The most common cases are discussed in section 2.7 and Chapter 3. This is especially important where the tilts have geophysical significance, e.g., monitoring the exact position of the plasmapause trough or an equatorial anomaly peak from a nearby station.

12.3 Spread F

12.31. Studies of spread F phenomena: Several studies of spread F have been made and reported in the literature. Spread F is also discussed in section 2.7 and 11.6. Relations between spread F at one station and oblique traces at others, e.g., polar spurs, should not be overlooked. Some useful techniques for regional studies will be found in Chapter 13.

Some typical problems are: the development of spread echoes in time; relations with ionization density and magnetic activity; the frequency ranges over which penetration occurs; presence or absence of a main ray; changes in scattering power of spread F as shown, for example, by the presence or absence of multiple reflections are all important; intercomparison of spread on two fixed frequencies may also be worthwhile. It is probable that all these characteristics vary rather rapidly with position.

There is at present much interest in studying the relation between spread F, satellite beacon scintillations and spread F traces on topside ionograms. Ground based data are needed:

(a) to establish the variations of these phenomena with time of day and with season (the satellite can only give data at two times for each day)

(b) to establish the morphology of the phenomena statistically (satellites only give a few samples for any given epoch).

Geostationary beacon satellites on the other hand may allow continuous observation in time.

* Bowman, G. G., Plan. Space Sci., 17, 777-796, 1969.
** Bramley, E. N. and W. Ross, Proc. Roy. Soc. (London), A 207, 251-267, 1951.
Bibl, K., E. Harnischmacher and K. Rawer, The Physics of the Ionosphere, (Phys. Soc. Conference, Cambridge, 1954), Phys. Soc., London, 1955.

12.32. Spread F indices: The application of the accuracy rules to the use of qualifying and descriptive letters in effect gives an index of spread F occurrence and intensity near the critical frequency. It is important, for this reason, that the spread F symbol, F, be used as the descriptive letter in cases where spread F is present near the critical frequency.

(a) The scale of the index depends on the presence of the symbol F in the normal tabulation of foF2 and is as follows:

0 no significant spread F - numerical value unqualified.

1 numerical value described by letter F.

2 numerical value qualified by U and described by letter F.

3 non-numerical value, entry is F alone.

(b) The same principle can be applied to the spread F occurrence at frequencies near those giving h'F using the conventions in this Handbook strictly and noting that when no principal trace can be seen h'F must at least be qualified by U and described by F, even if the lower edge of the trace is fairly sharp. The scale is clearly:

0 no significant spread F - numerical value unqualified.

1 numerical value described by F - appreciable spread F present near h'F but principal ray present.

2 numerical value qualified by U and described by F - severe spread F present near h'F with no clear principal ray present, but lower edge of trace sufficiently well defined for measurement to be made.

3 non-numerical value, lower edge of F trace diffuse, no principal ray.

The incidence of range spread has been little studied. At high latitudes this appears to be associated with magnetospheric tail phenomena. Further studies are needed both at stations where the phenomena are observed frequently and at lower latitudes influenced by these phenomena during periods of magnetic storm.

(c) The combination of entries in the foF2 and h'F tabulations appears to be adequate to enable the main classes of spread F to be recognized and to provide a system of indices for studying the incidence and distribution of the phenomena.

(d) Possible classification schemes have been described by Penndorf (see section 12.33). These need testing at more stations.

(e) A number of explanations for spread F have been given in the literature, sometimes with elaborate testing and proof.*

12.33. Classification of spread F types: There is a widespread feeling that spread F should be classified and that this might have the same effect on the development of spread F studies as the typing of Es had on Es studies during and after the I.G.Y. Unfortunately there is, as yet, no internationally agreed classification system usable by all stations. Several groups have studied spread F intensively and given explanations for the types of spread F most often seen at their stations. These types, however, change with the position of the station and it is obviously desirable that the types adopted should be, if possible, dependent on the physical process which is causing the spread traces. For world-wide use it is also necessary that the distinctions between types are clear and easy to learn. Pending the establishment of an International spread F-type system we reproduce here Penndorf's classification and suggest that it is worthwhile to start with this, noting that it is probably not complete and that some of Penndorf's classes are not easily distinguishable. Penndorf's classification scheme is shown in Fig. 12.1. This is not very satisfactory

* McNicoll, R. W. E., H. E. Webster and G. G. Bowman, Aust. J. Phys., 9, 247-271, 1956. McNicoll, R. W. E. and H. C. Webster, loc.cit., 272-285. Munro, G. H. and L. H. Heisler, loc.cit., 343-372 (two papers). Bowman, G. G., Plan. Space Sci., 2, 133-156, 1960.

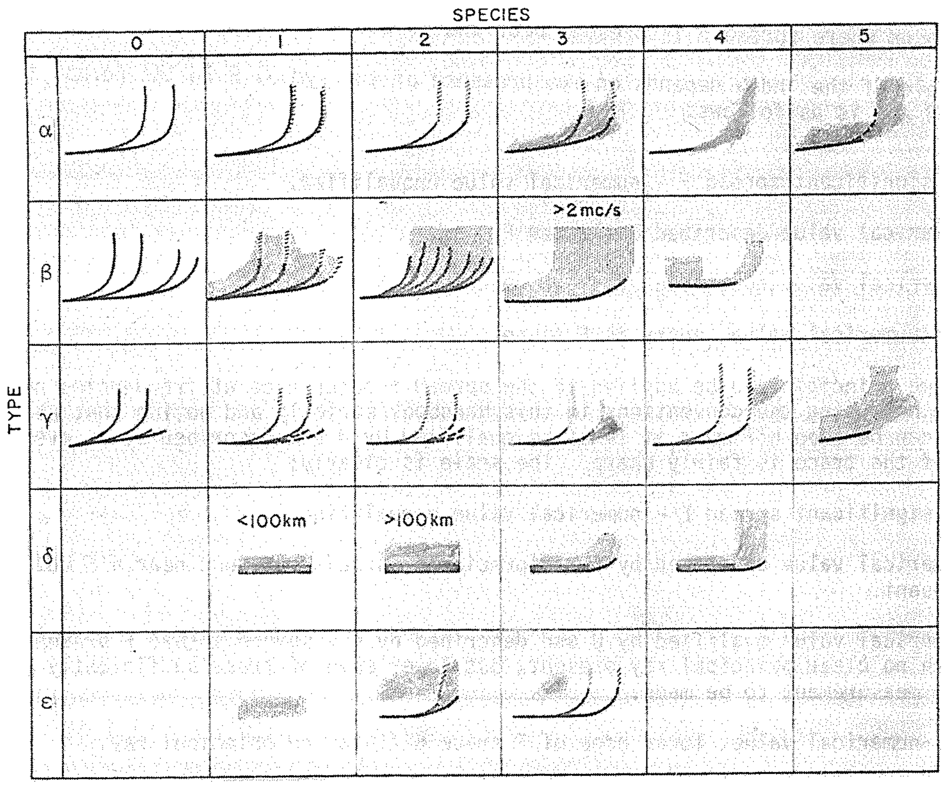

Fig. 12.1. Penndorf's Classification Scheme for Spread F l.c.

The five type α to ε are divided into five species (Nos. 1 to 5). The severity of spread F increases toward the right (higher numbers). In the first column, α0, β0, γ0 are added to show the basic type without spread F.

at stations which are near the plasmapause trough. These show a number of additional traces reflected from the field aligned structures and the steeply sloping sides of the trough. A description of Penndorf's types is given below.

Type α: "Spreadish F"

The type "spreadish F" is the most common type. All species have in common:

(a) The frequency spreading is solely confined to the two critical frequencies,

(b) at least one critical frequency (foF2) can be determined quite clearly, and

(c) no additional complicating echoes appear as in type β and γ.

The name "spreadish F" has been given because this type is the basic type of spread-F echoes. Species $\alpha0$ is the normal return without any spread-F echoes, and is included in the scheme for completeness. In species $\alpha0$ to $\alpha3$, foF2 and fxF2 appear quite distinctly. In type $\alpha1$ and $\alpha2$, just the tips of the two components show some spreadiness, these types occur regularly around sunrise and sunset, and also, sporadically during sunlit periods of the day at some stations. They are not found at night. For both types $\alpha1$ and $\alpha2$, the question arises whether the descriptive scaling symbol "F" should be used or not. Great inconsistencies have been found because some scalers use the letter F in these cases, whereas others do not employ it. This difference of opinion is reflected in the statistics of the occurrence of spread F.

Species $\alpha3$ shows spreadish tips of the critical frequencies as well as spread echoes between lower part of foF2 and fxF2. In addition, some range spreading occurs well below the critical frequencies.

Species $\alpha4$ shows foF2, but a mass of spread above foF2, so that fxF2 cannot be determined at all, or only with a low degree of accuracy. Species $\alpha5$ is quite similar to the last one; however in addition, range spreading occurs which may result in great difficulties in evaluating foF2.

Type β: "Furcated F"

The type "furcated F" occurs quite frequently. It is divided into four species, which have in common:

(a) multiple traces of similar strength occur giving two or more values of foF2 and fxF2, and

(b) the individual critical frequencies are well defined.

It can be interpreted as a return from one or more overhead clouds or ridges of ionization, having different electron concentration. Frequently, it is difficult to identify the components belonging together.

The species $\beta0$ and $\beta1$ refer to a bifurcated case; $\beta0$ shows no spread-F echoes, whereas $\beta1$ shows quite considerable frequency and range spreading. In species $\beta2$, one can see distinct traces, but it is impossible to arrange them in a unique order. In species $\beta3$, there exists a very wide frequency spread of more than 2 MHz and no distinct traces can be seen. The species $\beta4$ shows two distinct regions of frequency spreading, in each of which no trace of critical frequencies appears. In addition, range spreading appears.

Type γ: "Spurred F"

In the case of "spurred F," in addition to the normal critical frequencies and spreadish-F echoes, one or more spurs appear. These spurs are most probably caused by oblique reflections. They are quite different from the furcated F type, showing a gradual increase of virtual height frequency retardation.

These spurs can occur with any of the spreadish-F echoes (type α), and are shown here in combination with species $\alpha2$. If other combinations occur, two symbols are used, such as $\alpha3 + \gamma2$, $\alpha4 + \gamma4$. Species $\gamma0$ shows the case of a spur with no spread F present; i.e., a clear oblique echo. Species $\gamma1$ shows clearly visible rays embedded in spread-F echoes. Species $\gamma2$ shows many spurs, not just two, they extend just a few tenths of a MHz beyond fxF2. In species $\gamma3$, the spurred area is filled with a solid mass of spread-F echoes which extends to much higher frequencies than fxF2. Another case ($\gamma4$) arises when the spur begins not at the base height of the echoes, but sits on the vertical part of the trace. Finally, the combination of the species $\alpha5$ and $\gamma3$ is shown as species $\gamma5$, which does not allow for determining any critical frequencies.

Type δ: "Range Spread F"

The return well below the critical frequency frequently shows a solid trace with a mass of spread echoes at larger virtual heights. At any specified frequency the normal trace from the F layer is somewhat broadened and in addition isolated traces may be seen at greater heights. The spread corresponds to a virtual height $\Delta h'$ of from 50 to 150 km on the average. Several explanations have been proposed. Quite arbitrarily, the range spread has been divided here into two groups, one where $\Delta h'$ is less than 100 km ($\delta1$), which is the most common case, and one with $\Delta h' > 100$ km ($\delta2$). In some species, such as $\alpha3$, $\alpha5$, $\beta2$, $\beta4$, and $\gamma5$, the range spread F is already included, if the thickness $\Delta h'$ is less than 100 km.

In species δ3, the range spread ends in an amorphous frequency spread, so that foF2 cannot be determined. In species δ4, this frequency spread is more outstanding, but still no critical frequency can be found.

Type ε: "Cloudy F"

Some very strange cases of range spreading have been found on some days, and they are shown here as a type called "cloudy F". In species ε1, no solid trace appears under the range spreading, indicating no firm layer base. In species ε2, a cloud of range spread echoes occurs after a clear height interval, but merging with the frequency spreading. In case ε3, this cloud lies completely isolated from the rest of the trace.

Further discussion on the effects of spread F and tilted layers will be found in section 2.7.

12.34. INAG proposals for spread F classification: At the time of going to press, the general view of INAG members and consultants was that Penndorf's scheme should be greatly amplified. The proposal for initial study is to divide the phenomenon into four types:

(i) Frequency spread, proposed letter symbol F:
All cases where the spread shows frequency structure and not range structure (see sections 2.70, 2.72) (Penndorf Fig. 12.1, α1, α2, α3, α4; β2, β3, β4).

(ii) Range spread, proposed letter symbol R:
All cases where the spread shows spread in range but not frequency structure (see section 2.74) (Penndorf Fig. 12.1, δ1, δ2, ε1).

(iii) Mixed spread, proposed letter symbol M:
Patterns which show a range spread at lower frequencies changing to frequency spread at higher frequencies, the lower edge of the range spread trace being continuous with the lower edge of the frequency spread trace. (e.g., Penndorf Fig. 12.1, β3, δ3, δ4). Cases where the limitation is not true are treated as superposed independent F and R traces and are tabulated F,R. Thus cases where a range spread trace is seen either above or below the trace giving the frequency spread are tabulated separately.

Note: One of the purposes of the classification is to show when an oblique structure becomes overhead by entry F,R being replaced by M. Also the sequences of F turning to R or R to F may represent different situations to F,R turning to M.

(iv) Spur (historically polar spur) proposed letter symbol S:
This includes the range of patterns found when the ionosphere is very tilted or a second reflecting structure is visible at oblique incidence. There are two main groups:

(a) Spurs or noses superposed on a normal F or M pattern (Penndorf type γ).

(b) A spread trace at a different apparent virtual height to the normal traces and with considerably different top frequency (Fig. 3.39 (c) and (d)). These have been called polar spurs as they often show group retardation near foF2 and are closely associated with the plasmapause trough in years of large solar activity. This type is usually present at the same time as type F or M; sometimes with F,R, so that it is possible to have entries
single type present F; R; M; S;
two types present F,R; F,S; M,S; R,S; R,M;
three types present F,R,S; M,R,S.

It is suggested that, until more experience has been obtained, no attempt be made to make the tabulation more complex.

Note that if these proposals obtain general approval, the definitions and detailed rules are likely to be refined in the future and published in the INAG Bulletin.

12.35. Use of fxI and associated parameters: The new parameter fxI offers a number of new possibilities and it is important to find the relation between fxI and fxF2 (or fxI and foF2) at as many stations as possible. This information shows the relative importance of spread F conditions in different parts of the world and is also needed for practical purposes; oblique transmissions are most commonly determined by fxI whereas current predictions are based on foF2 or fxF2.

At stations where fxI is determined from oblique traces (equatorial or polar spurs, etc., see section 2.7) it is valuable to measure h'I the slant range to the fxI structure. The time variation of h'I gives both the apparent speed of movement of the ridge of ionization towards the station and its distance from the station. These are often associated with changes in the position of the plasmapause with time*.

Several groups, particularly at high and low latitudes, are studying the frequency range of spread F echoes dfS, or the minimum frequency of spread fmI and similar experiments are needed at other stations.

12.36. Lacuna: It is probable that lacuna phenomena are much more widely distributed than is known at present and may have different causes in different parts of the world. High latitude lacuna appear to have strong associations with the auroral oval. Somewhat similar physical conditions could arise near the magnetic equator. It is also seen at the magnetic poles. Letter Y denoting defocusing at layer tilts, e.g., associated with TIDs could provide information on their incidence and characteristics.

12.4 Miscellaneous Studies

12.41. Studies of diurnal and seasonal phenomena in E and F1: Some detailed instructions for these investigations are given in Chapter 13. There are great advantages in making these studies for the E and F1 layers locally at stations because they draw attention to peculiarities at the station which would otherwise almost certainly be overlooked. Also it is much easier to establish that an unexpected phenomenon is real when the original ionograms are available than from tables of data. It is quite common for "house-rules", adopted to save time in reduction, to give the desired data at some seasons but to be misleading at others. Thus a trace correctly interpreted as an F2 trace in one season may be shown to be a normal E trace in another, the critical frequencies being compatible and forming one sequence with normal E. Thus anomalous phenomena deduced from tables of foE are often suspected.

(a) Practical and geophysical problems both demand studies of the diurnal and seasonal variations of foE, foF1, M(3000)F1. These have rather large abnormal variations with season and position in certain zones which need measuring and clarifying.

(b) Sunrise effects. These appear very complicated. Since the layer is not in equilibrium many new phenomena can appear. There is a need for surveys to find if systematic sequences of events occur at fixed times relative to the time when new ionization is first formed. A contribution of ground based observations with an occasional rocket experiment could clarify the problems.

(c) Systematic pre-sunrise phenomena appear to occur in the F2 layer but the factors involved are unknown.

(d) The study of sunrise phenomena at very high latitudes is particularly important since at certain seasons very large solar zenith angles are found for long periods, thus eliminating the usual transient phenomena.

12.42. Studies of importance to plasma theory: Although most of the emphasis in ionospheric research is directed to the acquisition of knowledge about the ionosphere, it must be remembered that these regions of the atmosphere provide a unique laboratory for the study of the propagation of radio waves. In many instances the ionogram contains information which is not regularly scaled but which is of great interest from this point of view.

(a) In the case of the E layer it is usually possible to use the separation (fxE - foE) to measure the apparent value of the gyrofrequency, fB, and hence the magnetic field. Care is needed to avoid times when systematic tilts are present but this is usually easily confirmed. Data obtained so far show curious anomalies which have not been explained, the computed magnetic field appearing slightly too small even after allowing for the inverse cube decrease with height. Confirmatory work is needed at other stations - it may well be that some of these phenomena are restricted to particular zones.

* Bowman, G. G., Planet. Space Sci., 17, 777-796, 1969.

(b) The presence of unusual group retarded traces below the gyrofrequency on a few ionograms was at one time taken as proof that a correction to the equations of magneto-electronic theory was needed (Lorentz polarization term in the original Appleton-Hartree equations).

The use of the correction has since been discouraged for good reasons. The Appleton-Lassen equation where this term is not present is now generally used. However, an explanation of the early soundings has never been made. Thus the observation of penetration frequencies in the vicinity of the gyrofrequency would be of considerable interest. The incidence of this phenomenon is not understood.

12.5 Measurement of absorption

12.51. fmin as index for absorption conditions: The minimum frequency at which echoes are observed in vertical incidence sounding, fmin, is clearly dependent, amongst other terms, on the absorption present and thus can be used as an absorption index. In practice it is particularly useful for discovering the incidence of the larger changes in absorption with time and position. It is possible, though difficult, to calibrate the records of an ionosonde so that quantitative measures of small absorption changes can be made.

The minimum frequency occurs when the received echo signal falls below the minimum recordable level. This may be fixed either:

(i) by the amplification of the recorder, or

(ii) by the noise level present.

In case (i) the variation of fmin with changes in absorption depends on the variations of absorption and of equipment sensitivity with frequency. It is desirable that the latter should not vary discontinuously with frequency, e.g., at the end of receiver ranges, since otherwise fmin will be insensitive to certain ranges of absorption changes. (This is easily identified by the occurrence statistics of fmin numerical values.)

In case (ii) the variations of fmin with time are not entirely due to absorption changes but also depend on the variations of noise level with time. In this case only measurements made when the noise level is the same are strictly comparable. Since both noise level and absorption usually decrease with increase of frequency, the variation of fmin for a given change in absorption is less than that which would occur if fmin depended solely on echo strength. When noise is present the index fmin is thus less sensitive to absorption changes than in the absence of noise.

Since critical frequencies and equivalent heights are of major interest, the sensitivity of the ionosonde is usually adjusted so as to obtain the best recordings of these parameters. Such equipment adjustments inevitably alter fmin, and hence it is necessary to compromise between the normal requirements of the sounding and those which produce the most useful values of fmin.

If fmin data are to be really valuable as absorption indices, it is essential that the sensitivity of the ionosonde be kept constant for periods as long as possible and that the inevitable day-to-night adjustment be carried out at the same time for each day in a particular month. It is, however, most desirable that the times when the gain is altered should be clearly stated on the summary sheets of fmin and, if possible, the amount of the change indicated. To aid comparison of observations taken in different months it is also desirable that any changes in gain should be stated. A simple procedure, which is adequate for these purposes, is to measure the input at a convenient frequency needed to give a standard output at each of the gain settings used. These figures (expressed in dB above a fixed arbitrary level) should be included in the summary sheets.

When observations are made in close succession at three gain settings considerable additional information can be obtained using all three fmin values. Here again it is advantageous to know the relative magnitude of the gain settings. Where it is not possible to tabulate all three values of fmin the mean of the three is a better measure of absorption than fmin alone.

Some typical experimental results obtained from routine measurements of fmin made at Slough are shown in Figs. 12.2 and 12.3. The ionosonde was not specially monitored for these observations and the gains were changed as necessary for the production of good ionograms.

Fig. 12.2 illustrates the use of fmin as an index for recognizing the incidence of the abnormally large absorption which occurs during the winter period. In this Figure the average value of fmin obtained from the three ionograms for 1100, 1200, 1300 h are compared with the absorption measured on 2.0 MHz obtained as part of the Slough noon routine observations. Despite the fact that the equipment used for fmin was rather insensitive to absorption changes it will be seen that the two sets of measurements generally agree to within the estimated error ± 0.05 fmin, ± 2dBA. It is clear that fmin could be used as a reliable index of the incidence of the winter anomaly.

Fig. 12.3 shows a comparison of the average diurnal variation of absorption measured on 2.0 MHz (excluding times when foE = 2.0 MHz) and fmin over periods of 10 days for summer and winter months. Gain changes are indicated by arrows of length roughly proportional to the changes involved. It is again found that the relation between fmin and the absorption loss, A, is linear in both summer and winter and, despite the changes in noise level between the two seasons, the differences between the values of A observed and those deduced from fmin do not exceed 6 dB. It is to be noted that a single graph of the type shown in Fig. 12.2 cannot be used to determine the variation of absorption with frequency, but only calibrates fmin in terms of the absorption at one particular frequency. The period marked S in Fig. 12.3 shows the effect of intense interference due to medium wave broadcasting stations which often render fmin insensitive to changes in absorption in the evening period.

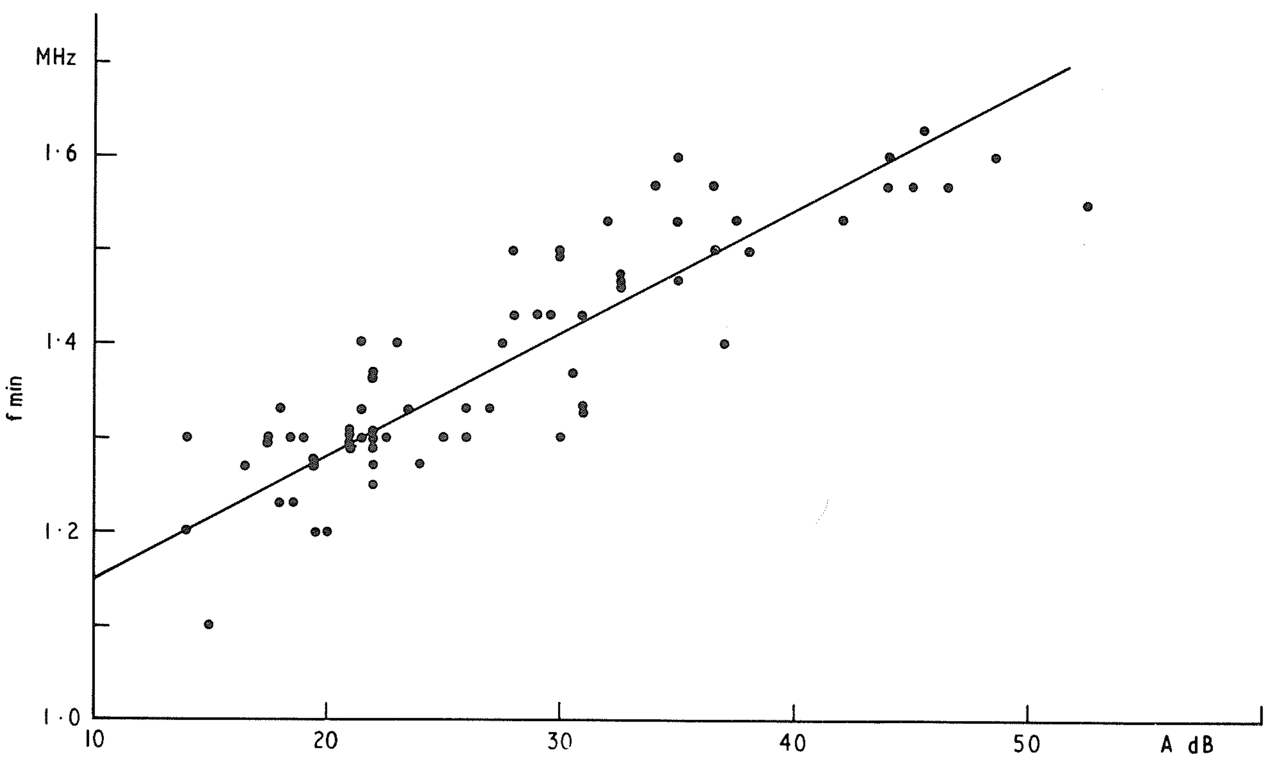

Fig. 12.2 Relation between fmin and absorption measured on 2 MHz at noon, Slough, winter 1954-5.

12.52. Use of fmin, fm2, fm3: Provided that the ionosonde is well maintained and gain changes are strictly monitored (section 12.51), fmin, fm2, and sometimes fm3 can be used to give very valuable information about absorption. Recent work has shown that the normal absorption variations over the earth can be nearly as complicated as those of foF2 whereas the number of stations measuring this absorption is only about 10% of the number of ionosonde stations. Thus it is very important that more ionosonde stations attempt to make usable fmin, fm2 or fm3 data to fill some of the gaps. It is important to calibrate gain changes and their effect on fmin so that the results can be expressed in at least relative gain levels.

At a single station fmin is most useful for studying the character of large absorption changes, for example, variations of absorption during and after a SID, incidence of days of high absorption in winter in temperate latitudes, incidence of periods of high absorption at high and very low latitudes. The value of results is greatly increased if a calibration of fmin values can be obtained by comparison with absorption measurements from amplitude readings.

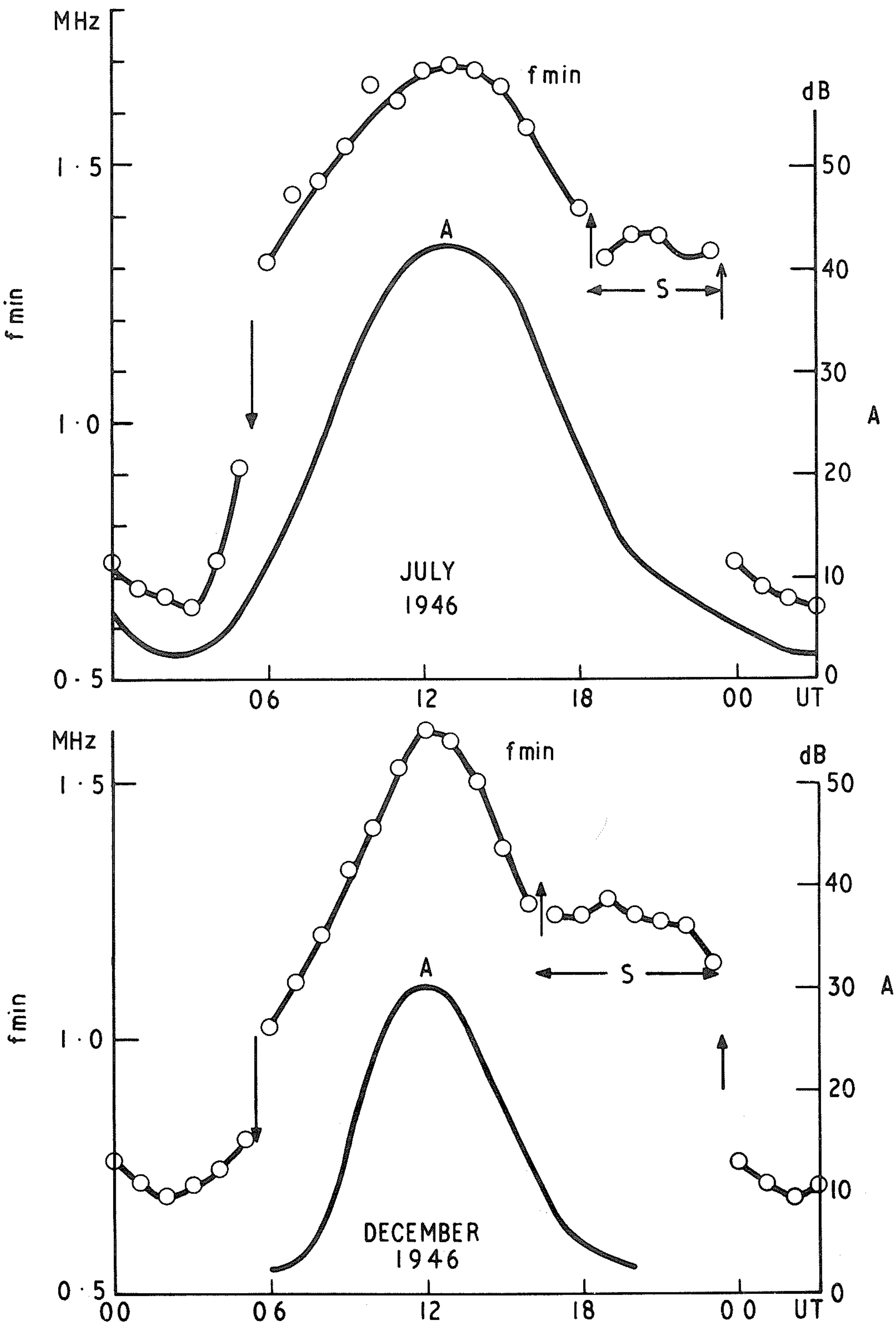

Fig. 12.3 Diurnal variations of fmin and absorption A measured on 2 MHz at Slough, July and December 1946. Arrows indicate gain changes.

It often happens that the minimum frequency of a higher order trace can also be used for absorption measurements. Care must be taken to see that it is not determined by blanketing or the deviative absorption associated with a lower critical frequency. The following rough rules may be used as a guide though the actual circumstances of the station really determine when fm2 can be used.

fm2 given by (i) Second order E trace - fmin 2E - usually reliable.
(ii) Second order F trace - fmin 2F - usually reliable if fmin F2 $\geq$ 1.2fc (fc = critical frequency) of densest thick E layer present and fmin 2F is not attributable to fbEs.

The rules for fm3 are identical.

12.53. Calibration of fmin parameters: For large changes in fmin or fm2, the calibration in terms of absorption is practically independent of type of ionosonde, antennas, etc., provided that the ionosonde is properly maintained and adjusted. For small changes, e.g., day-to-day variations in normal absorption fmin-type parameters can often only give qualitative data.

At stations with a riometer (absorption A2 technique), strong absorption events can be used to calibrate large changes in fmin. Either auroral events or SIDs may be used. In general it is difficult to calibrate and interpret diurnal riometer data sufficiently well to measure normal absorption or to give a reliable calibration. The parameter fmin can only be used as a quantitative index if it is calibrated in terms of known absorption changes. Detailed instructions are given in the Absorption Manual (section 4.9.8).

Accurate absorption measurements are rather difficult to obtain and demand strict attention to the detailed rules. For the purpose of estimating the large changes in absorption causing big changes in fmin it is sufficient to estimate the normal and abnormal absorption present on a number of occasions and to compare these with the corresponding values of fmin. The absorption is given by the difference in decibels between the average unattenuated night echo intensity and that found on the same frequency when the absorption is present (after correction to the same virtual height value). It is necessary to avoid the deviative absorption which is prevailing within about ± 20% of a critical frequency. For temperate latitudes the reference level is most accurately found during late night hours, but spread echoes should always be avoided. The calibration relation with fmin usually varies with time of day since the noise level, and hence the lowest signal detectable, also varies with time of day. Calibration of fmin is usually restricted to the noon period only, unless particular phenomena of interest are found. fmin cannot be used for these purposes when automatic gain controls are used, as its significance depends on the sensitivity of the ionosonde remaining reasonably constant with time.

12.54. Echo amplitude and absorption studies: A powerful tool in the hands of the station operator is the use of the ionosonde receiver gain to study certain types of echo. While useful inferences may often be made using uncalibrated gain controls, the value of experiments will increase materially if the results can be expressed in at least relative gain levels.

(a) Simple, routine noon or hourly measurements of absorption are of great value if long continuous series of observations are obtained.

(b) Only at a few locations has experimental work on deviative absorption yet been done: thus an ionosonde receiver calibrated throughout the frequency range could produce unique data on the variations of echo amplitude along the h'F curve (see also section 11.5).

(c) Measurements similar to (b) above, but permitting comparisons between o and x components (and z, when observed) would be of equally great value.

(d) Absorption studies from rapid sequence soundings immediately following large solar flares are potentially capable of providing valuable information on abnormal ionization in the D region. The unique difficulty of such measurements (and the reason why they are best made by the station observers) is that the flares are of infrequent occurrence and are impossible to anticipate. Special fast sequences of ionograms should always be taken if a SID is observed.

(e) The effect of variation of receiver gain on the frequency range of spread echo - especially of the equatorial night-time type - would be very interesting.

(f) Amplitude measurements taken of F2 echoes on otherwise quiet night-time soundings, if sufficiently accurate, can be useful in the study of curvature of the layer. Also echoes known to be oblique may be interesting in this respect.

12.55. The new digital ionosondes (section 11.4) are particularly helpful for absorption studies and allow very high flexibility with the handling of an unusually large number of data, e.g, for more frequencies and longer periods than used before. Some examples are found in the Absorption Manual (section 4.9.2).

NOTES

13.0 General

Special schemes of analysis have been developed for certain typical problems. It is worthwhile to consider these when similar problems are to be investigated (sections 13.1 - 13.3).

Certain ionospheric perturbations are closely related to geophysical phenomena which are observed using methods different from those of ionospheric sounding. A short discussion and some explanation of how to use these are given in sections 13.4 - 13.6.

Finally it is important to know the behavior of the Sun and the tools necessary for analyses. Some indications may be found under section 13.7.

13.1 Techniques and Precautions Applicable to Studies of Diurnal and Seasonal Phenomena

13.11. The Chapman function and sec χ: While numerous studies of diurnal and seasonal phenomena of the E and F1 layers have been made, they are still giving worthwile additions to our knowledge. Much of the early work is rather misleading owing to widespread use of sec χ, where χ is the zenith angle of the Sun, as an adequate approximation for the more exact Chapman function Ch $(\times,\chi)$. Due to the Earth's curvature the approximation is unsound when $\chi > 75°$. (Formula for Ch: S. Chapman, Proc. Phys. Soc., 43 (1931) 483. A table of Ch is given in the URSI Ionospheric Stations Manual.) It should be noted that while sec χ does not vary with height, $\times$ is the ratio of the radius (from the center of the Earth) of the level of maximum electron production (for $\chi = 0$) to the scale height at that level. Care must be taken to use a true scale height for the layer; an apparent scale height deduced from the apparent thickness of the layer neglecting the effect of the magnetic field upon the virtual height may be very far from true. Thus the scale height of the E layer is nearer 7 km than the 10 km usually quoted, an error which may be important in calculating the parameter $\times$ in Chapman's formula.

Certain techniques or precautions have proved to be particularly important and widely applicable. The most important are summarized below.

13.12. Determination of layer relaxation time: The apparent relaxation time at noon is a useful parameter indicating the character of the equilibrium process. It is usually measurable using foE or foF1 but the phenomena in F2 are sometimes too complicated for it to be evaluated or interpreted. The delay (positive or negative) of the time of maximum critical frequency relative to noon is measured. True Sun noon must be used. This is found by adding or subtracting the difference between Sun noon and local mean noon using the equation of time, which can be found in the Nautical Almanac, and correcting for the time interval due to the difference between the time meridian and the longitude of the station, (4 minutes per degree of longitude). Thus at a time of year when Sun noon is 14 minutes ahead of LMT a station at 50°E using LMT of 45°E will have a local Sun noon 14 + 20 = 34 minutes before the noon given by local civil time (15° longitude E is equivalent to 60 min in this calculation, 15°W corresponds to -60 min).

It is often useful to study evening and night phenomena by noting that if the ionization dissipation process is the same at all times, and the zero time is taken when the critical frequency has a fixed value and the ion production is negligible, the critical frequency will be dependent on time only. This can be used to summarize data over widely different epochs, or to show the presence of perturbing phenomena by departures from the rule.

13.13. Determination of relations between layer characteristics and the zenith angle of the Sun: Once again it is essential to use Sun time in finding the zenith angle. Values of cos χ given in the URSI Stations Manual are corrected for the equation of time at the epoch of the IGY (1957-8) and will usually be correct within about one minute for other years. The correction for longitude is also included. This has been calculated for the longitude quoted in the Stations Manual.

Experience has shown that graphs of critical frequency as function of time are very inefficient and often misleading for determining the solar control. The best procedure known at present is to replot the data on graph paper with logarithmic scales in both directions, using the critical frequency in one direction and the appropriate Chapman function in the other. Alternatively, of course, the logarithms of these quantities can be plotted on linear graph paper. This can be applied to both diurnal and seasonal variations.

The effect of relaxation phenomena is to make the morning value found at a given time interval before Sun noon smaller than the corresponding afternoon value. The mean of these values gives the required variation.

13.2 Solar Eclipses

During a solar eclipse the shadow of the moon runs across a part of the Earth's surface blocking off, more or less completely, the ionizing solar radiation for a short interval. This is a very interesting phenomenon as the radiation is interrupted at almost constant solar zenith angle, χ, while the normal interruption at sunset occurs as a result of a continuous increase of this angle.

13.21. The main object of most eclipse observations has been to determine the rate of decrease of ionization during the shadow period and, finally, to find the recombination constants for the different layers.

The critical frequencies of the lower layers, including F1, reach a minimum near the time of maximum obscuration of the Sun. From the time delay of this minimum after the end of the totality (or with the moment of maximum screening) a relaxation time can be determined. This gives a value for the effective recombination coefficient.

13.22. Unfortunately, the simple recombination equations currently used for these deductions are inadequate. Experience has shown:

(a) That the ionizing solar radiation is far from having a homogeneous distribution over the Sun's surface and that it may come from a larger disk than is optically visible, so that even with a total eclipse some ionizing radiation is left.

(b) That the recombination mechanism and parameters vary considerably with the height.

(c) That, at least for the F region, vertical movements considerably alter the ionization found at each height.

(d) That the observations by soundings may be misleading, since the eclipse effect produces a considerable tilt of the surfaces of constant ionization. Thus the soundings are not always accurately vertical during the eclipse period.

As a result of (a) direct methods of finding recombination coefficients (section 13.21) can be completely misleading, in some cases the time delay of minimum ionization may even be negative. Details can be found in the eclipse literature (14.21.c).

13.23. The importance of obtaining very accurate eclipse observations from, preferably, at least one ionogram every minute, cannot be underestimated. Special methods of analysis should be applied, such as the following:

(a) The first analysis should provide an appropriate description of the distribution of ionizing radiation over the Sun's disk. The variation of the apparent rate of electron production with area of the Sun's disk exposed is particularly valuable. Different sources of information should be used, such as optical and radio-astronomical observation before, during and after the eclipse, intercomparison of ionospheric eclipse data from different stations taking account of the screening of different parts of the Sun, etc. Normally the latter will require the collaboration of many scientists (see Chapter 9).

(b) A curve of the effective variation of solar ionizing radiation should be deduced from this distribution using accurate geometrical data obtained from the astronomical services.

(c) Electron density profile technique should be applied to the eclipse ionograms (see Chapter 10) and studied in detail, taking account, however, of the limited accuracy of these techniques when the ionosphere is tilted, as occurs in eclipses.

(d) The undisturbed, normal behavior of the ionosphere must be known by control observations covering a period of about five days before and five after the eclipse day.

13.3 Some Tests for Correlation

It is very often of primary importance to discover whether concurrently observed changes of two different parameters are due to chance or whether they are likely to be related physically. This question cannot be answered without ambiguity in geophysics since nearly every change can result from one of several different causes. The geophysicist is satisfied if the probability that an observed similarity was due to pure chance is shown to be very low.

13.31. Correlogram: Experience has shown that intercomparison of time-dependent curves is very dangerous in this respect. A much better direct method of testing is a simple plot, called a correlogram (example: Figs. 13.1 and 13.2). Two parameters x_i and y_i, obtained simultaneously, are plotted on a graph showing x against y. Every point corresponds to a certain instant; the corresponding values observed give the coordinates of the point. If enough points have been obtained it can often readily be seen whether a significant correlation exists or not. In the first case the points have a tendency to be arranged along a certain line or to give at least an elliptical distribution which is inclined with respect to both axes. If both x and y increase together the correlation is called positive (Fig. 13.1), if not, negative (Fig. 13.2). If, on the contrary, the points form a cluster which does not show any systematic obliqueness (Fig. 13.3) the two parameters are not correlated.

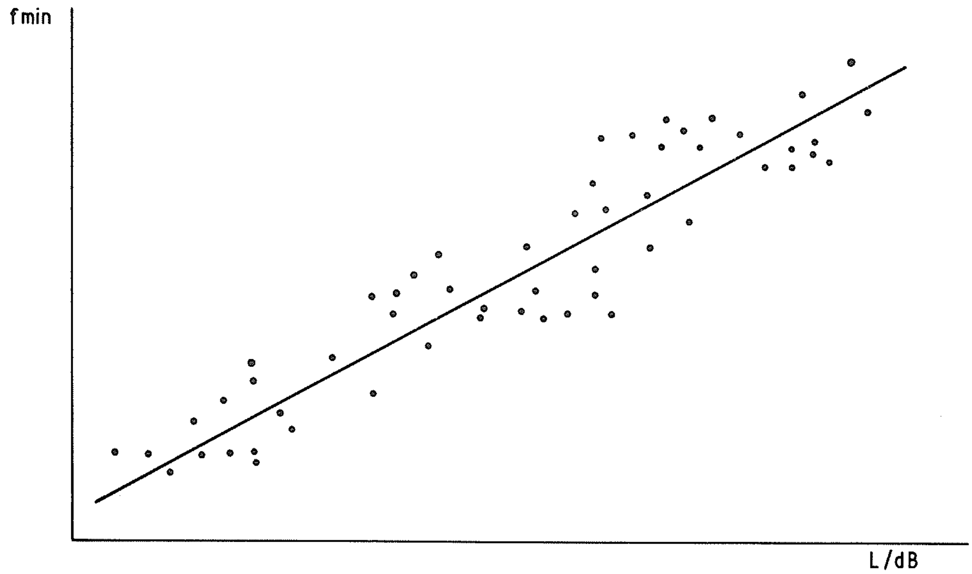

Fig. 13.1 Example of a positive correlation: fmin and absorption loss.

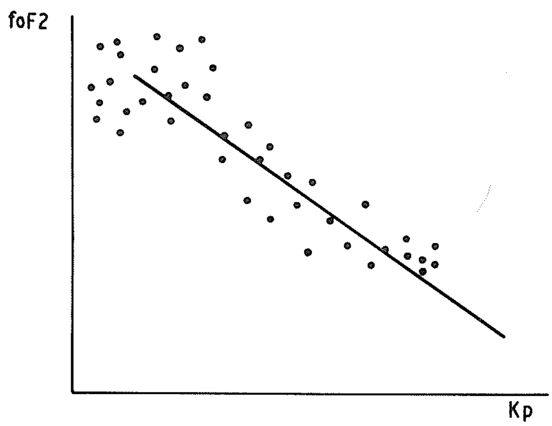

Fig. 13.2 Example of a negative correlation: Noon values of foF2 against magnetic activity, summer.

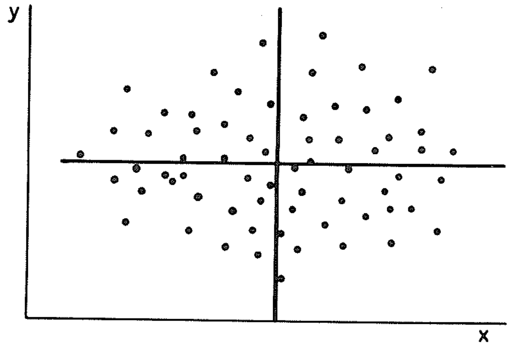

Fig. 13.3 Example of zero correlation.

13.32. Correlation coefficient: One numerical measure of correlation is the classical correlation coefficient, r. If $\overline{x}$ and $\overline{y}$ are the mean values of the x_i and y_i the definition of r is

$$r = \Sigma_i (x_i - \overline{x}) (y_i - \overline{y}) \Big/ \sqrt{\Sigma_i (x_i - \overline{x})^2 \cdot \Sigma_i (y_i - \overline{y})^2} \qquad (13.1)$$

In this expression the denominator has been introduced so that normalized values are obtained. The numerator is the essential expression, it gives the moment (with respect to a central point corresponding to the averages $\overline{x}$, $\overline{y}$) of all points of the correlogram. The normalized moment is greatest if all points are aligned on a straight line and is zero for a symmetrical cluster of points. We obtain r = + 1 for a perfect positive correlation, r = - 1 for a perfect negative correlation and r = 0 for the case with vanishing correlation.

13.33. Correlation number, R: Another numerical measure of correlation, which is more rapidly determined, has been given by Rawer. It has been normalized with respect to the correlation coefficient r by Lovera (also by Taubenheim). The correlation number, R, is obtained from the correlogram by a simple counting method. This has the advantages of the median, e.g. it is invariant to monotonic transformations of the axes. Four fields are determined on the correlogram according to the conditions x_i > or < x and y_i > or < y where x and y are the median values of the x_i and y_i. If, with n points, the number of points in these four fields is given by

A	B
C	D

the definition is

$$R = \sin \left[\frac{\pi}{2}\left(\frac{4B}{n} - 1\right)\right] \qquad (13.2)$$

Note: By definition A = D, B = C, $A = \frac{n}{2} - B$.

R = + 1 means that no points are found where one parameter was greater and the other was less than the median, i.e., A = D = 0, while R = - 1 means B = C = 0. R = 0 means equal distribution over the four fields. Lovera's definition is such that for a "normal" distribution on both axes, the correlation number, R, and correlation coefficient, r, reach the same limiting values as $n \rightarrow \infty$.

13.34. Partial correlation: In cases where different physical causes simultaneously influence a measured parameter it is advantageous to apply the concept of partial correlation, provided the amount of observed data is large enough. The idea is to neutralize the influence of all but one cause, $\times$, by dividing the total number of observations into classes according to the values taken by the other influencing parameters, and then determine the correlation with $\times$ class by class. Thus when the influences of two different causes tend to have opposite effects upon the observed parameter, almost zero correlation is found by straightforward correlation, whereas the use of the method of partial correlation will show both of the underlying relations.

13.35. Cross-correlation: In geophysics the correlation between two physically different parameters is most often obtained by combining values observed at the same time; the result is called cross-correlation. It is also interesting to see if pairs of values obtained from one physical parameter at different times show some correlation. A correlation obtained with a fixed time delay τ (i.e. $x_i = f(t_i)$, $y_i = f(t_i + \tau)$) is called auto-correlation. It is a measure of continuity in the development of the parameter.

The auto-correlation function gives r, or R, as a function of τ. By definition it must have a maximum 1 for $\tau = 0$. The presence of periodical variations is shown by equally spaced maxima of the auto-correlation function r (τ) as a function of time. In the general case of monotonically decreasing r (τ), i.e. when the parameter does not oscillate periodically, a quasi-time constant can be defined by the steepness of the decrease, e.g. by the time for which r falls to 1/2.

13.36. Superposed epochs: Another very useful method for finding cross-correlation between two time-dependent parameters f and g is the so-called method of superposed epochs. Instead of calculating the cross-correlation with variable time difference τ one uses a selection method. A "zero-time" for each event is defined by a selection of outstanding f values, e.g. values greater (or less) than some limiting values. Now the time variation of g for the same events is plotted centered on this zero time. Finally the values obtained for each time unit are averaged, both before and after the zero time. This gives a curve which shows an important variation if a correlation exists between f and g; the time delay at which this variation reaches its maximum (or minimum) marks the average time difference between corresponding events of the f and g parameter; an example is shown in Fig. 13.4.

13.4 Studies of Black-out Phenomena

During black-out conditions absorption is so severe that no, or nearly no, echoes can be observed using conventional ionospheric sounding methods. This is normally due to non-deviative absorption in lower layers, and lower frequencies are most heavily influenced. Sometimes low-altitude echoes from the D layer may appear during a black-out at rather low frequencies on the ionogram. These are partial reflections and the corresponding coefficient of reflection is small; echoes of this type are disregarded when fmin is determined (according to the principles explained in section 2.0). It is interesting to correlate the occurrence of these echoes with that of high values of fmin.

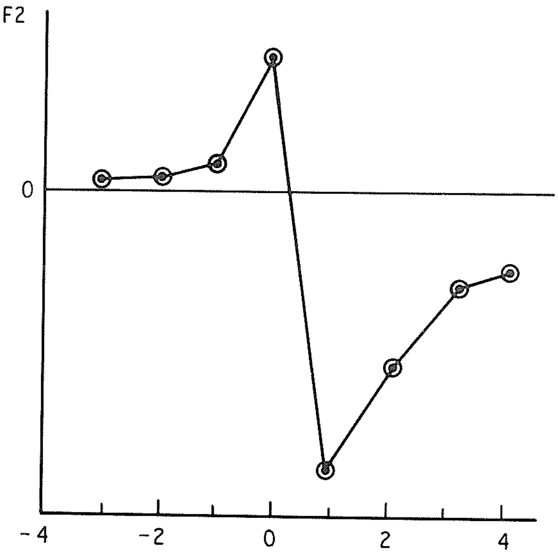

Fig. 13.4 Superposed epoch pattern

Zero days: First day of magnetic activity.
⊚ Differences of noon foF2 from median noon foF2 at Equinox, temperate latitude.

13.41. <u>fmin as an indicator of high absorption</u>: The usefulness of fmin as an indicator of high absorption conditions is considerably increased if a calibration in terms of absorption has been made, e.g. by comparison with amplitude observations (see section 12.5). In this case the observed variations of fmin can directly be expressed in terms of absorption. Otherwise it is difficult to take account of the sensitivity of the ionosonde, which is generally rather variable with frequency.

As very high fmin values occur only during black-out conditions, it is difficult to extend the calibration to higher frequencies. Also, unfortunately, the echoes disappear completely during the most severe black-outs. Therefore fmin cannot be a satisfactory parameter in these cases. However, the absorption of cosmic noise on frequencies between 20 and 30 MHz (see Absorption Manual, Chapter 5, Method A2d riometer) can extend fmin measurements for the case where absorption is especially high (see Annals of the IGY, Vol. III, Part II, p. 207-217).

In present conditions black-outs cannot be predicted. As radio propagation is also prevented during black-outs it is not difficult to verify whether widespread black-out conditions exist or not, especially if the ionograms can be compared with reception conditions. A field-strength recorder working on a suitable HF broadcasting station can easily be used as an indicator (Absorption Manual, Chapter 6, Method A3). When a black-out has been recognized it is interesting to make frequent ionograms until fmin returns to normal values. The presence of a black-out can usually be confirmed by the disappearance of the interference due to the HF broadcasting bands - particularly those near 6 MHz and 7 MHz - on the ionogram itself.

13.42. <u>Sudden ionospheric disturbance</u>: A short-lived black-out conditon may be found at most latitudes in the sunlit hemisphere as a consequence of a solar flare. This is called a "sudden ionospheric disturbance" (SID). Three forms can be distinguished, according to the variation of absorption: the most normal one begins with a very sudden, nearly discontinuous increase followed by a much slower decrease, the total phenomena lasting between 10 min and, rarely, 2 hours. A type showing a continuous increase of fmin followed by a slower decrease is less often found. A type with regular but quite continuous variation is sometimes seen but is less well correlated with solar flares. Nevertheless, at low and medium latitudes the correlation between solar flare and black-out conditions is the highest one found between any solar and terrestrial sudden phenomena. As there exists a special observation network for solar flares it is important that SIDs be regularly observed.

For comparison with the solar phenomena now observed by optical methods in the soft X-ray range aboard satellites, it is important to have very accurate time scaling for the SID-observations, if possible to a fraction of one minute.

Black-out of this kind occurs only on the sunlit hemisphere of the earth and there only at locations where the sun's altitude is not too low. It is never localized in a small region and in this respect is quite different from polar black-outs (see 13.43). For further information see also Chapter 12.

13.43. Polar black-outs: In polar regions black-out conditions are very often found during magnetic and auroral disturbances, especially during ionospheric and magnetic storms. Polar black-outs are widely variable in space and time, they may last between a few minutes and many hours, but most cases are rather short events, best measured by the technique of continuous recording (section 11.3) or with a riometer.

Full interpretation of the substorm activity responsible for the black-out demands measurements at a group of stations, preferably supported by rocket or satellite measurements, of particle activity, electric fields, etc. Conversely studies of these types can gain much in value from adequate ground based measurements. The incidence of polar black-out is a good indicator of local disturbance. Long-lasting absorption in both "polar caps" can occur after certain solar flares. Since these are produced by solar cosmic ray protons, they are now usually called "proton events" and the flares, "proton flares". In the older literature they were called "type IV flares" (For a survey see A. D. Fokker, Space Sci. Rev. 2, 70-90, 1963). These very energetic protons enter the lower ionosphere at latitudes determined by the Earth's magnetic field. Hence the minimum latitude at which polar cap absorption (PCA) is seen can measure changes in the outer part of this field. Further measurements are needed as the events are relatively rare, chiefly occurring in sunspot maximum years, and can modify radio propagation in the VHF bands as well as at HF. The relative intensity of the PCA is greater in daytime than at night and depends on the frequency band used. Thus it is important to compare HF and VHF data, fmin with riometer (Absorption Method A2). Forward scatter propagation in the ionosphere is also affected by this phenomenon.

13.5 Indices of Magnetic Perturbations and Storms

The time variations of the Earth's magnetic field observed at a fixed station are primarily due to electrical currents in the ionosphere.

13.51. Quiet daily variations: There are regular daily variations due to the "dynamo effect" of the conducting layers in the E and D region moving up and down in the magnetic field of the Earth. This is called the quiet daily variation, Sq (solar, quiet), and is greatest near the equator. Sq also contains a solar tidal component. A lunar tidal component, L, can easily be found by statistical analysis in terms of lunar hours. As ionospheric parameters are dependent on solar photon radiation, apparent correlations between Sq or L and any ionospheric parameter cannot be directly interpreted in terms of cause and effect.

13.52. Disturbed conditions: Irregular variations of the magnetic field are found during disturbed conditions. They are sometimes related with aurorae (see section 13.6) and are often associated with important D-, E- or F-region disturbances. It is quite certain that these are caused by corpuscular radiation originating in some way from the Sun, though the detailed mechanism is not yet well understood.

Corpuscular effects show a more irregular behavior than the quiet day variations and can easily be recognized on records of even one of the components of the magnetic field. Some storms begin with a well-defined precursor, a sudden jump in the magnetic field record, called an SC ("sudden commencement"). The main fluctuations of the storm often begin somewhat later. Other storms begin with a slow continuous increase of the degree of perturbation. These are particularly evident in the declining part of a solar cycle and, when recurrent with a period of about 27 days, (see section 13.72, 27 days is the average apparent rotation period of the Sun seen from the Earth) are called M-type storms. In both cases the storm variation is usually complicated. The analysis is simplified by distinguishing two different components, a disturbed daily variation depending on local solar time, called Sd, and a specific disturbance component, called D. As the solar influence is different during disturbed conditions we must take account of two time systems, local time and storm time. The latter is constant for the whole Earth and starts at the beginning of the storm. This is defined by the SC, if such a peak occurs. It is often very useful to plot ionospheric results for intercomparison in storm time, first removing the normal daily variation. This may be done by taking the ratio of actually observed ionospheric values to the corresponding monthly median, or simply by the difference. The method of "superposed epochs" (section 13.36) can be applied to studies of ionospheric data in magnetic storm time by selecting storms starting in restricted periods of LMT.

13.53. The more important solar flares are accompanied by a characteristic magnetic effect; the field variation has the form of a hook, known as a crochet. Its amplitude is not comparable with that occurring during a magnetic storm but the form is very typical and easy to identify.

13.54. K index: The K index due to Bartels (section 13.56) Fig. 13.5 provides a very valuable measure of the degree of magnetic disturbance for comparison with major changes in the values of ionospheric parameters such as foF2, M(3000)F2, foF1, M(3000)F1, fxI, foEs, fmin. Bartels' K-figure is obtained from the maximum fluctuation of the three components of the magnetic field occurring during an interval of three hours UT. A nearly logarithmic numerical scale is used to delimit the ten classes. As perturbation fluctuations are not uniform all over the world the scale in gamma units is changed with magnetic latitude in such a way that the middle K-figures occur almost equally frequently at all locations. Thus, apart from the effects due to local magnetic currents, all stations on the average give the same K index for the same world-wide perturbation. For the purposes of ionospheric research we may usually say that:

K values:	0, 1, 2	represent very quiet and quiet conditions;
	3, 4	represent small disturbances;
	5, 6	represent disturbed conditions;
	7, 8, 9	represent very disturbed, i.e., storm conditions;

where 8 is rare and 9 is a very rare degree of disturbance. For a rapid analysis of perturbation phenomena it is often convenient to select all occasions when the K-figure is greater than 5 or 6.

Three-hourly K-figures are now published by most magnetic observatories. Local K-figures are particularly useful for studies of local ionospheric phenomena or for preliminary studies carried out before world-wide indices are available.

13.55. Kp, ap and Ap indices: Many ionospheric phenomena appear to be dependent on world-wide magnetic activity and it is often desirable to be able to select periods when this activity was abnormally large or small. The International Association of Geomagnetism and Aeronomy publishes planetary K-figures called Kp ("planetary magnetic three-hour range indices") Fig. 13.5. The planetary Kp figure is obtained by averaging the K-figures from 12 selected observatories between geomagnetic latitudes 47° and 63° (section 14.7). This is a fairly good index of world-wide corpuscular activity and is widely used.

For some purposes the logarithmic character of Kp is undesirable. The corresponding linear parameter in gamma units is denoted ap for each three-hour period or Ap for the average for the day as a whole. These indices are expressed in units of amplitude, i.e. half the appropriate extreme ranges, and are known as Equivalent Planetary Amplitudes.

13.56. Charts of Kp: The incidence of magnetic activity is most easily surveyed using the "musical-note" charts of Kp prepared monthly using Bartels' methods, an example of which is shown in Fig. 13.6. Every year a similar diagram for the complete year is prepared and published. The data are arranged with a period of 27 days (the approximate period of the solar rotation). These are particularly valuable when ionospheric phenomena are delayed relative to the magnetic activity and, in particular, in studies of disturbances in the F region.

It is sometimes convenient to use cruder indices of activity based on half or whole days when selecting periods for study. Typical indices are:

(a) the sum of the values of K or Kp for the day or half-day;
(b) the number of times K or Kp exceeds, say, 5 in a day or half-day.

Where delays occur it is often preferable to adopt time intervals ending at a certain hour, e.g. 0600 LMT.

13.57. Cp index: Since 1884 the magnetic activity for each day has also been measured by a Daily International Character Figure C, based on a 0, 1, 2 scale at each station. Since 1937 this has been replaced by a similar figure, based on the Kp indices, known as the Daily Planetary Character Figure, Cp. Cp runs by units of 0.1 from 0 to 2.5 but is sometimes contracted to a ten-unit scale denoted by C_9 (0, 1..., 9).

13.58. Q index: Another magnetic index, Q, has been found to be particularly useful for ionospheric studies at the higher magnetic latitudes. This is analogous to K but is based on the sum of the extreme positive and negative deviations of the magnetic field from the quiet day average curve during individual intervals of 15 minutes. It gives a detailed measure of magnetic activity centered on each quarter-hour which may be compared with quarter-hourly ionograms, or with recordings of characteristics. Such comparisons show many unexpected and interesting phenomena at all levels in the ionosphere and clearly demonstrate that many magnetic and ionospheric phenomena are short-lived and cannot be studied using three-hourly indices. Values of Q for every quarter-hour UT are available from

I U G G: ASSOCIATION OF
GEOMAGNETISM AND AERONOMY

(International Service of Geomagnetic Indices)

GEOMAGNETIC PLANETARY INDICES

Three-hourly: Kp
Daily: Ap and Cp

February 1972

	1 2 3 4	5 6 7 8	Sum	Ap	Cp
1	0+1-2-3-	3o2+1o2o	14-	7	0.4
2	3o3+4-2+	3o3-2+2-	22o	13	0.8
3	2+2+1-2-	2+4-2o1o	16o	9	0.5
4	3-3o3o3-	2-1-2-2-	17o	9	0.5
5	1o1+2-2-	1o1o3-2o	12+	6	0.3
6	1o2-2-1o	0+1-3-2+	11+	6	0.3
7	2o1+1+1o	1o2-2+4o	15-	8	0.5
8	3-3o1o2o	2-1-0+1o	12+	7	0.3
9	1o1-0+0+	0+1-2o2-	7o	4	0.1
10	3o3-2-1o	2o2-3+3o	18+	10	0.6
11	2o1o2+3o	2o1+1-1+	14-	7	0.3
12	2+2+1o0+	1-0+0o0+	7+	4	0.1
13	0+2+1+5-	4+4+4o4o	25+	22	1.1
14	4o3+3o2+	1o2o3o4o	23-	15	0.9
15	3-4o3+3-	3-1+2-2+	21-	13	0.7
16	3o3-2o2-	2o2-1+1+	16-	8	0.4
17	2o2o1o3+	4+4+5o4o	26o	22	1.1
18	3-3o3o1+	0o0+1o5-	16o	12	0.7
19	5+2+1o0+	3-3o3-2-	19o	14	0.8
20	4-4-2+3-	3-1+1-2o	19o	12	0.7
21	2+3o2o2o	3-3o2-1-	17+	9	0.5
22	0+0+2-2-	1o2o1-1+	9o	4	0.2
23	1+1+1o1o	1+2o2+2+	13-	6	0.3
24	2o3o5-5+	5o5-5-4-	33o	33	1.3
25	4-4-3-2o	3o4-3o2+	24o	16	0.9
26	3o2-1+1o	1o0+2o1-	11o	6	0.3
27	0+0o0o1+	1o1o2+3-	9-	4	0.2
28	2-3-2o1o	1-0+2-1+	11+	6	0.3
29	0+1-1-0+	0o0+0+0+	3o	2	0.0
			Mean	10	0.52

Preliminary ssc: 13 d 09 h 39 m
18 d 23 h 38 m
24 d 06 h 42 m

For explanation see: J. Bartels
IGY Annals Vol. 4, p. 227-236
London, Pergamon Press, 1957

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Postfach 876
34 Göttingen (Germany)

Fig. 13.5 Monthly Geomagnetic Planetary Indices.

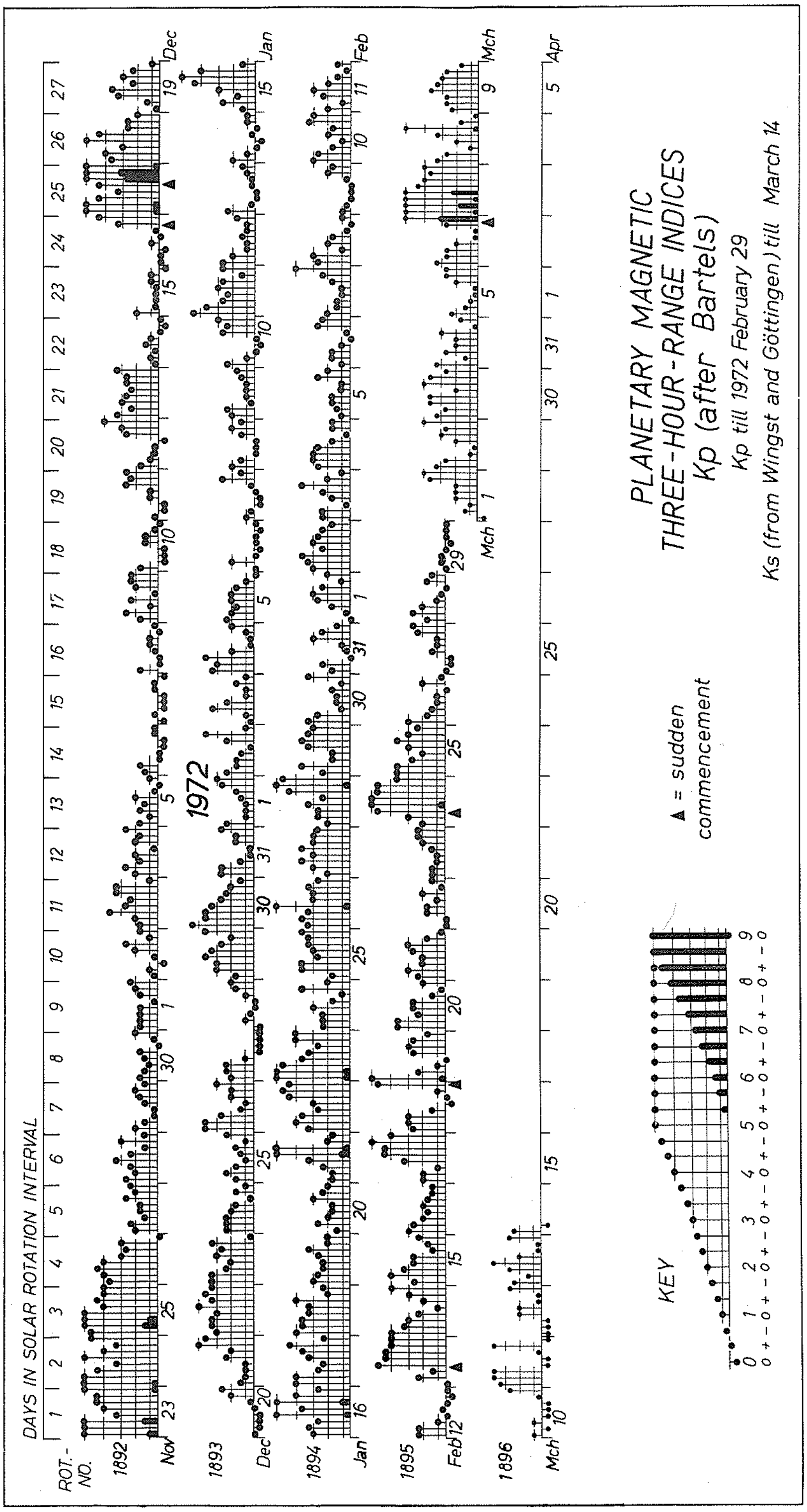

Fig. 13.6 Planetary magnetic three-hour range indices Kp till February 29, 1972.

certain magnetic observatories at high magnetic latitudes. The exact definition and scale of Q is as follows:

The Q index measures the total deviation from the quiet day variation, i.e. the sum of the positive and negative extreme deviation from this curve, during the 15-minute intervals centered on the quarter-hours UT.

Thus, if the extreme deviations are +250, +70 γ or +150, -50 γ or -50, -250 γ, the range for Q is 250 γ, 200 γ or 250 γ respectively. The interval 0000 refers to the period 23h 52m 30s - 00h 07m 30s. Q refers to the amplitude of the most disturbed horizontal components of the field - never the vertical component. Unlike K, the scale of Q is not dependent on position.

Table 13.1

Scale of Q (All Stations)

Q	0	1	2	3	4	5	6	7	8	9	10*	11*
Upper limit [γ]	10	20	40	80	140	240	400	660	1000	1500	2500	∞

*Q values of 10 and 11 are represented in tables by the letters T and E respectively.

The upper ranges of Q may be useful for special studies, even at low latitudes.

13.59. Other magnetic indices: In recent years more specialized magnetic indices have been devised. The most widely used of these are:

(i) The hemisphere K values Kn, Ks, Km which are based on data from the North or South hemisphere separately and the combination of these.

P. N. Mayaud "Indices Kn, Ks, Km" Ed. du CNRS, Paris, (Institute de Physique de Globe, 9 Quai St-Bêrnard, Tour 14, Paris Ve, France, monthly French). An example is shown in Fig. 13.7.

(ii) The Equatorial Dst values, published annually by M. Sugiura and S. T. Cain, Goddard Space Flight Center, Greenbelt, Md. 20771 U.S.A. (English, Annals of IGY 1964, Pergamon Press 3519).

(iii) The Auroral Electrojet Index, AE (by Davis, T. N. and Sugiura, M, J. Geophysical Res. 71, 785-801, 1966 and subsequent papers).

Kn, Ks, Km are similar to Kp but are better balanced (Kp is excessively weighted by northern hemisphere data). Fig. 13.7.

Hourly equatorial Dst values provide an index of geomagnetic activity as a function of Universal Time (UT). Large negative variations in Dst are produced by low-energy particles in the magnetosphere. Smaller variations are caused by changes in the solar-wind pressure exerted on the magnetospheric boundary. In addition, Dst may reflect variations in the magnetospheric tail current and field-aligned currents in the magnetosphere. At each UT, the disturbance field is averaged over local time (or longitude) so that Dst represents the constant term in a Fourier expansion in local time of the disturbance field on the geomagnetic equator.

For AE, the positive or negative perturbations of the horizontal component of the geomagnetic field are derived from magnetograms from a net of observatories in the auroral zone. The separation at any given time T between the upper and lower envelopes (AU(T) and AL(T)) for the perturbations provides a measure of the total maximum amplitude of the symmetric eastward and westward electrojet currents flowing in the auroral zone ionosphere. Thus, the auroral electrojet index is defined as:

$$AE(T) = AU(T) - AL(T).$$

Asymmetries in the eastward and westward electrojet currents as well as the axially symmetric fields from distant sources are reflected in the displacement of the midpoint of the AU(T) and AL(T) envelopes. The index defined by:

$$AO(T) = (AU(T) + AL(T))/2$$

thus provides a measure of such current systems. Fig. 13.8 shows a computer graph of AE and AO produced by P. Stanning (Ionospheric Lab., Technical University DK-2800, Lyngby, Denmark).

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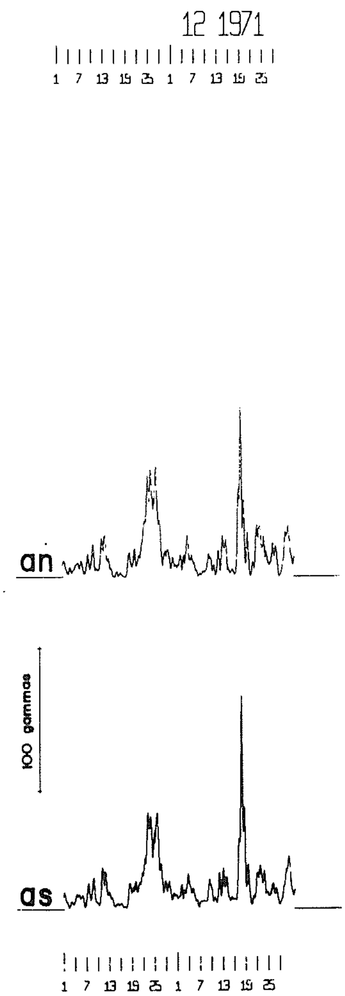
Tableaux Mensuels d'Indices Mondiaux d'Activité Magnétique

(Valeurs provisoires)



Moyennes glissantes sur 12h des indices trihoraires an et as

MOIS 12 1971

	3 Km		Σ Km	am		Am	Am2
1	2 3 3 6	3 5 8 8	12.7	5 7 7 14	7 13 25 21	12	
2	2 4 1 3	6 8 4 5	11.0	5 10 2 6	16 22 9 12	10	
3	4 4 9 7	8 10 10 4	18.7	9 10 26 19	21 36 34 9	21	
4	6 6 7 4	4 5 6 8	15.3	14 15 17 10	9 12 16 23	15	
5	3 3 5 5	5 1 1 4	9.0	7 6 13 11	12 2 2 9	8	
6	4 3 0 0	0 1 2 2	4.0	8 6 1 0	0 2 5 5	3	
7	1 2 1 1	1 4 2 1	4.3	2 5 3 3	2 8 5 3	4	
8	3 2 2 2	3 3 2 4	7.0	7 4 4 5	6 7 4 10	6	
9	7 8 5 8	3 6 7 6	16.7	17 24 11 26	7 15 18 15	17	
10	4 0 1 2	6 4 4 2	7.7	10 1 2 5	14 8 8 4	7	
11	1 2 0 4	4 8 8 9	12.0	2 4 1 8	10 24 25 28	13	
12	5 4 3 3	3 8 9 10	15.0	13 8 7 6	6 26 30 38	17	
13	8 4 8 8	6 7 8 10	19.7	23 10 22 21	16 20 26 37	22	
14	2 3 2 4	4 1 1 2	6.3	4 6 5 10	10 2 2 4	5	
15	5 1 3 2	3 3 2 1	6.7	11 3 7 5	7 7 5 3	6	
16	3 2 2 3	1 3 10 11	11.7	7 4 4 6	3 7 37 44	14	
17	14 12 11 10	4 19 19 15	38.0	73 59 42 35	74 192 181 95	94	
18	9 9 9 16	5 8 8 7	27.0	30 29 27 104	92 26 23 17	44	
19	1 3 10 11	8 9 6 5	17.7	3 7 34 41	23 28 16 13	21	
20	2 1 0 1	1 2 5 7	6.3	4 2 1 2	2 5 11 17	6	
21	3 2 2 4	7 6 11 10	15.0	7 5 5 9	18 15 43 39	18	
22	8 8 8 9	0 10 9 9	23.7	21 21 25 29	40 34 30 27	28	
23	8 7 7 6	8 9 11 3	19.7	23 20 18 14	26 30 41 7	22	
24	6 5 6 6	7 2 6 4	14.0	14 12 15 15	18 5 15 10	13	
25	3 4 4 4	5 6 4 7	12.3	6 10 9 9	13 15 10 18	11	
26	8 8 6 3	4 6 8 8	17.0	25 25 16 7	9 16 21 24	18	
27	5 4 6 3	1 0 1 1	7.0	11 9 14 7	2 1 2 2	6	
28	1 2 3 2	2 5 7 7	9.7	3 4 6 5	5 12 17 18	9	
29	4 6 9 10	9 7 7 11	21.0	9 15 29 38	32 20 18 43	26	
30	10 9 9 11	7 8 6 6	22.0	38 31 33 41	18 24 15 14	27	
31	6 6 5 2	4 5 6 7	13.7	15 15 11 5	8 13 16 19	13	
						17.3	

MOIS 12 1971

	3 Kn		σn	an		An
1	3 2 3 5	4 6 7 7	4442 5444	6 5 7 13	8 15 20 19	12
2	2 4 0 2	6 9 3 5	3303 1423	5 8 0 4	15 29 6 12	10
3	4 4 9 7	6 11 10 4	2332 1452	8 10 30 19	15 44 39 8	22
4	5 6 5 5	5 6 5 8	4333 3525	13 15 11 11	11 15 12 23	14
5	3 2 5 5	5 1 0 3	1233 3312	7 5 11 13	13 2 1 7	7
6	2 4 0 0	0 0 2 1	3610 0043	5 8 0 0	0 0 4 3	3
7	0 2 0 0	0 4 2 0	1520 0530	0 4 1 0	0 8 4 0	2
8	3 1 1 1	3 3 1 3	4223 1121	7 2 3 3	7 7 2 7	5
9	6 8 3 8	3 5 6 6	1313 1214	15 21 7 24	6 13 15 15	15
10	5 0 0 1	7 3 3 1	3102 5422	11 0 0 2	18 7 6 2	6
11	0 0 0 4	4 8 7 8	2003 2353	1 0 0 8	9 24 20 21	10
12	4 3 1 2	1 9 9 11	3232 3634	10 6 2 4	3 29 27 42	15
13	7 4 9 8	6 8 9 10	3223 1335	20 10 29 22	16 21 28 40	23
14	1 1 2 4	5 0 0 1	2335 3012	3 3 4 8	11 0 1 2	4
15	3 0 3 1	3 3 2 0	4212 4130	6 1 6 3	6 6 4 0	4
16	2 1 0 2	1 3 9 11	3202 2425	4 2 0 5	2 7 32 42	12
17	14 13 12 9	13 19 19 12	3323 3274	83 70 53 28	64 180 184 56	90
18	9 9 8 15	14 8 7 5	4532 5223	27 28 22 88	77 26 20 11	37
19	0 2 9 10	8 10 7 3	2313 3341	1 4 28 38	24 34 20 7	20
20	1 0 0 0	1 3 5 7	2000 2152	2 0 0 0	2 6 13 18	5
21	3 2 1 4	7 6 12 11	1323 2135	6 4 3 9	19 15 51 44	19
22	8 8 9 9	11 10 9 9	3452 3353	24 26 29 27	44 39 32 28	31
23	8 8 6 6	8 9 11 2	4312 2442	25 25 16 14	25 31 44 5	23
24	6 6 7 7	7 1 7 4	4432 5256	14 15 18 19	20 3 18 10	15
25	2 4 4 3	5 5 4 7	4521 2325	5 10 9 7	12 12 9 17	10
26	9 9 7 4	4 7 8 9	3534 2456	27 32 20 8	10 18 24 29	21
27	6 5 7 4	1 0 0 0	3344 2000	14 12 17 8	2 0 0 0	7
28	0 1 2 1	2 4 5	0233 3436	0 2 5 3	4 10 12 15	6
29	4 7 9 10	10 7 6 11	4425 3212	9 17 29 38	39 20 15 41	26
30	11 8 9 10	7 8 6 5	5213 3353	43 26 33 37	18 22 16 12	26
31	6 7 4 2	4 5 7 7	4623 3355	16 18 8 4	8 12 17 20	13
						16.5

MOIS 12 1971

	3 Ks		σs	as		As
1	2 4 3 6	2 4 9 8	3414 3253	5 9 7 15	5 10 30 24	13
2	3 5 2 3	7 6 5 5	2322 4121	6 12 4 7	17 16 11 12	11
3	4 5 8 7	8 9 9 5	3331 1222	10 11 26 18	26 29 29 11	20
4	6 6 8 4	3 4 7 8	0133 0333	15 16 22 9	6 10 20 24	15
5	3 3 6 4	4 1 1 5	2101 2122	6 7 15 9	10 2 2 11	8
6	4 2 1 0	0 1 3 4	3331 0234	10 5 2 1	0 3 6 8	4
7	2 3 2 3	2 4 3 3	2211 2105	4 6 5 6	4 8 6 6	6
8	3 2 2 3	3 3 3 5	0330 4012	6 5 4 6	6 6 6 12	6
9	7 8 6 9	3 7 8 6	3124 2430	20 26 14 27	7 17 21 15	18
10	4 1 2 3	4 4 4 3	3232 2130	10 2 4 7	10 8 10 6	7
11	1 4 1 4	4 8 9 10	2131 4304	2 8 2 8	10 25 29 35	15
12	6 4 5 3	4 8 10 10	1312 4411	16 9 12 7	8 24 34 34	18
13	8 4 6 7	6 7 8 10	1213 5315	26 10 16 20	16 19 23 34	21
14	2 4 3 5	4 1 1 3	1142 1331	5 8 7 12	9 3 3 6	7
15	6 2 4 3	3 4 3 3	5312 4104	16 4 9 7	7 8 6 6	8
16	4 3 3 4	2 4 11 11	3124 1421	10 6 7 8	5 8 47 45	16
17	13 11 9 11	14 20 19 17	3122 1816	64 49 32 42	84 205 177 134	98
18	10 9 9 17	16 8 8 8	4243 1112	34 29 32 121	106 26 26 22	50
19	2 4 10 11	8 8 5 7	2223 2225	4 10 40 44	21 22 12 19	22
20	2 2 1 2	1 2 4 6	3222 1231	5 4 3 5	2 4 9 16	6
21	4 3 3 4	7 6 10 10	1423 1031	8 6 7 9	18 15 36 34	17
22	7 7 8 9	10 9 9 8	1122 1231	17 17 21 32	37 29 28 26	26
23	8 6 8 6	8 9 10 4	3222 1231	21 15 21 15	26 29 39 9	22
24	5 4 5 5	6 3 5 4	1143 4553	13 8 13 12	16 7 12 10	11
25	3 5 4 5	6 7 5 7	1232 4473	7 11 9 11	14 14 11 20	13
26	8 7 5 3	4 6 7 7	1132 4213	23 18 12 7	8 15 17 19	15
27	4 3 5 3	1 1 2 1	3224 2323	9 7 11 7	3 2 4 3	6
28	3 3 3 3	3 5 8 8	1112 2423	6 6 7 7	7 13 22 21	11
29	4 5 9 10	8 8 8 11	1103 4221	9 13 29 39	24 21 22 45	25
30	10 10 10 11	7 8 5 6	1113 3211	34 37 34 45	19 25 13 16	28
31	6 5 5 2	4 6 6 7	0211 1221	15 11 13 5	8 14 16 17	12
						17.9

For explanation see P. N. Mayaud "Indices Kn, Ks, Km 1964-7", Ed.du CNRS, Paris 1968.

Fig. 13.7 Kn, Ks and Km indices

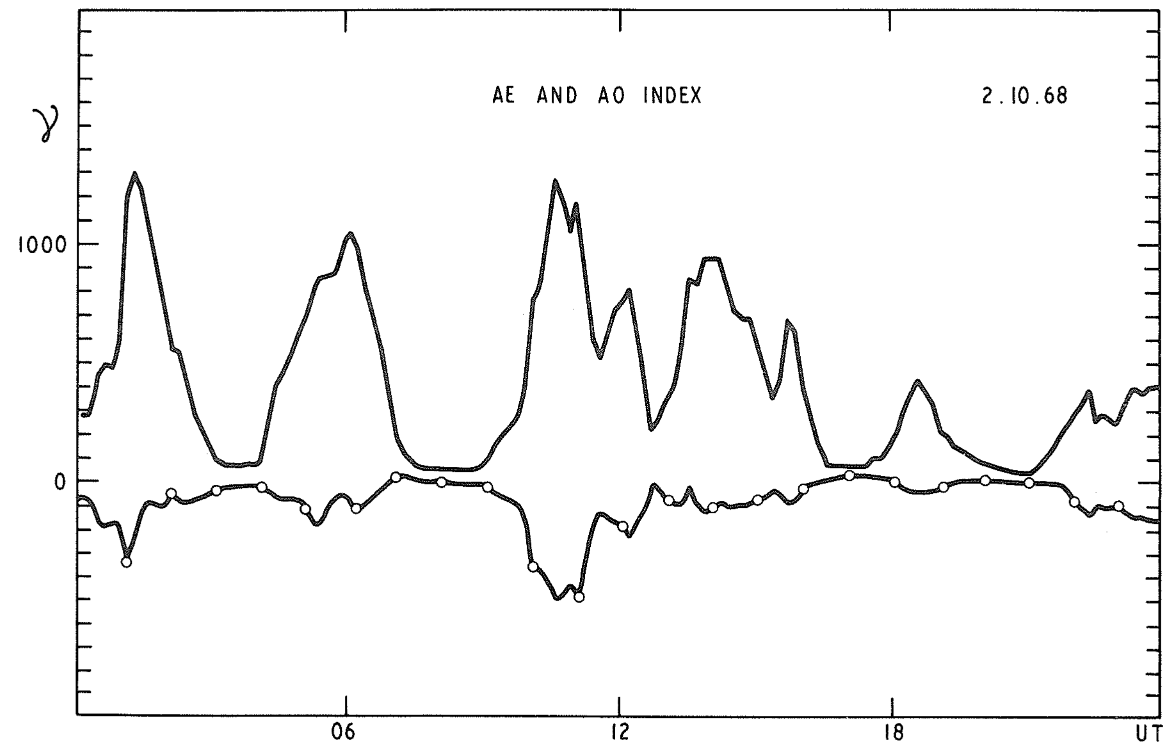


Fig. 13.8 AE and AO graph, Northern Hemisphere for October 2, 1968
Also available in hourly tabular form. AE —, AO o—o

13.6 Aurora

Aurorae are very impressive features of corpuscular perturbation and are often associated with large magnetic and ionospheric perturbations. They give a good idea of the way conditions are varying in space. With practice, it is often possible to identify particular oblique traces on the ionogram with particular features in the aurora.

13.61. The systematic observation of aurorae has been a rather difficult task owing to the complexity of the forms seen, until the panoramic aurora-recording "all-sky" camera was introduced for the IGY 1957/58. With this camera a picture of the whole sky can be obtained at one exposure, and film recording is relatively easy when a color filter is used to select the light emitted by the aurora. Of course, as in all optical observations from the ground, the possible observation times are limited by clouds and moonlight.

13.62. When an observatory recording the aurora is not too far from the ionospheric station (say within 100 km), aurora records should be compared either one by one with ionograms or as a sequence with a suitable ionospheric parameter. Not only every F-region parameter may be interesting but also the occurrence of night E (see foE tabulations), auroral Es and other Es types. Absorption, too, is a very important feature of these perturbations and fmin or the black-out incidence may give interesting results. In general, correlations are markedly greater when aurorae are overhead at the station.

13.63. While at higher latitudes it is important for intercomparison to have a complete picture of a local aurora this is not so for low latitudes, where aurorae are very rare. Here the observation of an aurora always demonstrates that for a short time at least the conditions of the auroral zone existed locally: so look especially for night E, auroral types of Es, for extra-absorption, oblique traces or abnormal types of spread F. z-mode reflections may also occur under these conditions at stations where they are never seen for normal conditions. It is difficult to obtain statistics of aurora at low latitudes and therefore it is important to report such phenomena if seen by chance. In many cases the main evidence for the existence of a low latitude aurora is the abnormal behavior of the ionosphere.

13.7 Solar Phenomena and Indices of Solar Activity

13.71. Sunspot numbers: The Sun's activity is monitored by the "relative sunspot number" R introduced by Wolf in 1849 at the Zürich Observatory (section 14.6). A long series of numbers has been published (E. J. Chernosky and M. P. Hagan, J. Geophys. Research, 63, 775, 1958). The monthly mean sunspot number is a fairly good measure of mean activity, but for investigations over several years it is often better to use sliding means, usually made over 12 or 13 months. It should be noted that the Wolf number is entirely empirical, being the number of isolated spots plus ten times the number of groups of spots as seen by a standard low-power telescope. In particular, many spots and spot groups are not associated with changes in either the photon or the particle emission from the Sun. Thus the sunspot number can vary considerably on certain occasions without any comparable effects being seen on Earth. On the average, particle emission is greatest near sunspots in the radial direction so that spots looking roughly towards Earth are more prone to cause magnetic, auroral and ionospheric disturbances than those nearer the edges of the Sun. For this reason magnetic activity reaches a maximum two or three years after sunspot maximum, and also shows maxima at the equinoxes when the spots are concentrated at more favorable latitudes as seen from Earth.

For many purposes the sunspot number R is not sufficiently accurate and is replaced by other parameters which are more closely associated with the appropriate photon or corpuscular radiation from the Sun. It is often convenient to express these on the same scale as the Wolf number. The scale factors are found by studying long-period average values of both parameters and using the most probable relation between them. Thus, in effect, the newer parameters identify corresponding epochs in solar activity with greater accuracy than can be obtained using sunspot numbers.

13.72. Other indices: Typical parameters which have been widely used are:

(i) The intensity of solar radio noise as measured on decimeter wave-lengths, e.g. at 2800 MHz. This is sometimes called the 10 cm flux index or the Covington index, Φ. The numerical value of Φ in units of 10^{-22} W·m^2 Hz^{-1} is used as a dimensionless character figure.

(ii) E-region character figures, like $(foE)^4$. Ch $(x\chi)$.

(iii) IF2, a world index of foF2 at noon, obtained from a set of selected stations distributed over both hemispheres at widely separated longitudes. This is a measure of the combined effects of photo-ionizing radiation and the solar wind on the F region.

Empirical average relations have been established between monthly averages of R, ϕ and IF2 over the sunspot cycle. Typical relations are:

$$(foE)^4 \sec\chi = 1.55\,\Phi\,(1 - 0.00065\,\Phi) - 142 \quad \text{(Minnis and Bazzard 1959)}$$

$$\Phi = 0.38\,(R - 8)^{1.17} + 69 \quad \text{(Eyfrig 1967)}$$

$$(IF2)^2 = 6.92\,(R - 10)^{1.66} \text{ for } R<150 \quad \text{(Ramakrishnan 1971)}$$

IF2 was originally standardized to be equivalent to R on the assumption that R and foF2 were linearly related. IF2 is smaller than R for high values of R (saturation effect in foF2 with R). Current work suggests that the relations may show long term variations.

Alternative measures of solar activity are being considered by the International Radio Consultative Committee (C.C.I.R.) and there is considerable literature on the subject.

13.73. Solar rotation: Different parts of the Sun rotate at different rates so that the apparent rate of rotation varies with solar latitude, lying between one rotation in about 26 days and one rotation in about 28 days. The mean rate of rotation is near 27 days so that a disturbed part of the surface disappears within 14 days. Two different systems of identifying rotation numbers are used by astronomers and geophysicists. The latter adopt the round number 27 for the period. This is more practicable for ionospheric purposes (see J. Bartels, Terrestrial Magnetism and Atmospheric Elec., 44, 411, 1939).

13.74. Solar flares and proton events: A solar flare is one of the most marked astrophysical events observable by optical means. It is characterized by a very high increase of solar (red) hydrogen (Hα) radiation within a small area on the Sun's disk. Flares often produce highly increased absorption (SID) and a small increase of E-layer ionization. Some flares, the so-called type IV or proton flares, are also associated with abnormal cosmic ray emission from the Sun and a special type of very high latitude absorption called "polar cap absorption". The whole event is now called a "proton event".

Flare patrols (see Chapter 14) are maintained by the astronomical observatories working on a world-wide duty cycle, and world-wide communications networks collect data on the incidence of SIDs.

13.75. Solar flux: More detailed solar flux data in the extreme ultraviolet ("Lyman alpha" line L_{α}, of hydrogen), and in the very soft X-ray range are now currently available from the SOLRAD-satellites, transmitting these data in real time telemetry. (Details and codes available on request from U. S. Naval Research Laboratory, Washington, D. C., U.S.A.) (Hourly values and special events are published monthly in NOAA's "Solar-Geophysical Data" (see section 14.6).

13.76. Solar sector structure: Another important detection of space research is concerned with the variable directions of magnetic fields in the solar wind, repeating themselves for an observer on Earth with the 27 days period of solar rotation. The different sectors, rather irregular in width, have field directions towards or away from the Sun, alternatively. The sector structure is usually almost unchanged during many months. Data about sector structure must be looked for in the scientific literature as they are obtained only occasionally by highly eccentric satellites or space probes outside the magnetosphere (i.e. at distances beyond 60000 km). The famous figure by Wilcox and Ness* describing the sector distribution for the years 1963-4 is shown in Figure 13.9.

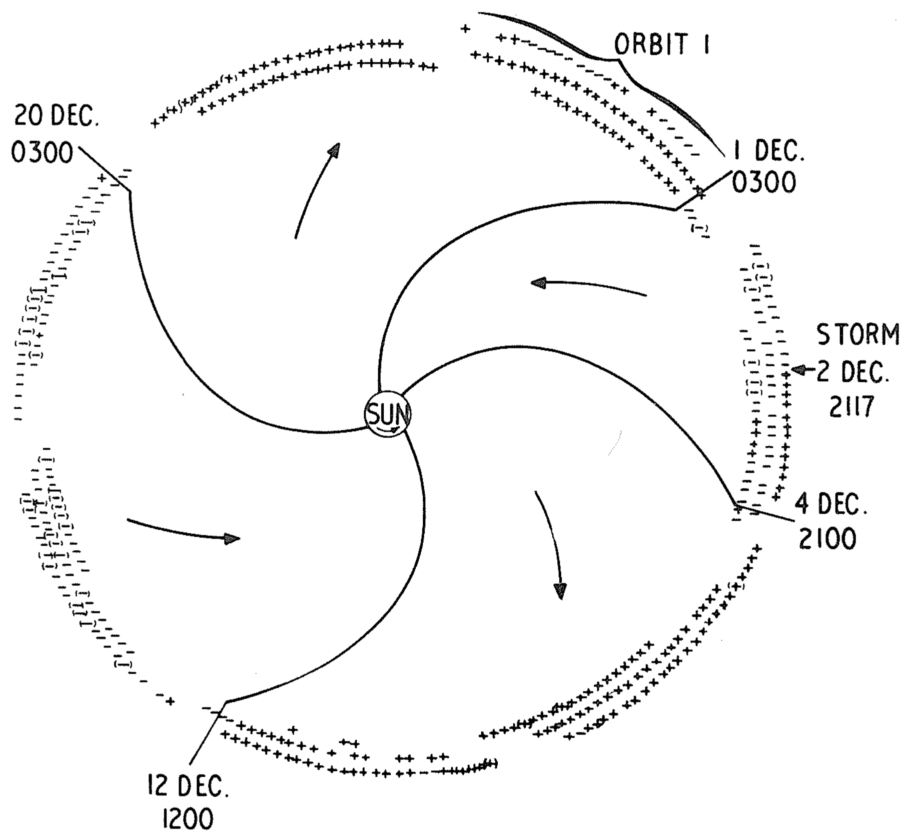


Fig. 13.9 Characteristic sector structure of interplanetary magnetic field 1963-4.

* Wilcox, J. M. and N. F. Ness, J. Geophysical Res., 70, 5793, 1965.

NOTES

14 REFERENCE MATERIAL AND FACILITIES

14.0 General

The following books and sources of data may be useful at ionospheric stations. The language and year of publication of the last edition are indicated in parentheses.

14.1 Special Manuals

(a) Annals of the International Geophysical Year (IGY Instruction Manuals):

Vol. I,		Geophysical Measurements
Vol. III,	Part I:	Ionospheric Vertical Soundings
	Part II:	The Measurement of Ionospheric Absorption
	Part III:	The Measurement of Ionospheric Drifts
	Part IV:	Miscellaneous Radio Measurements
Vol. IV,	Part II:	Aurora and Airglow
	Part IV	and V: Geomagnetism
	Part VII:	Cosmic Rays

Parts II, III, IV of Vol. III and Parts IV, V, VII of Vol. IV are bound together in the published volumes. All published by Pergamon Press (London, New York, Paris) (English 1957-60).

(b) Annals of the International Quiet Sun Years (seven volumes).

The instruction manuals for the IQSY have been published in Vol. I of Annals of the IQSY. General Editor A. C. Stickland, MIT Press, Cambridge, Mass. U.S.A. (English with some French 1968-70). Vol. I. Geophysical Measurements, Ed. C. M. Minnis, 1968.

(c) New manual series of the URSI Commission III (started by URSI/STP Committee).

These are being published in the same way as this edition of the URSI Handbook, and will appear as UAG Reports from World Data Center A for Solar-Terrestrial Physics, NOAA, Boulder, Colorado 80302, U.S.A. (English 1971 - continuing).

URSI Handbook of Ionogram Interpretation and Reduction (edited by W. R. Piggott and K. Rawer). (First Edition English 1961. Second Edition 1972 (this volume) English, French, Spanish, Russian).

Manual on Absorption (Ed. K. Rawer) to be published in this series by WDC-A.

Manual on Drifts.

(d) International Manuals:

Atlas of Ionograms (Ed. A. H. Shapley) Report UAG-10 (English 1970).

Guide for International Exchange of Data in Solar-Terrestrial Physics, STP Notes No. 6 (Special issue), IUCSTP Secretariat, National Academy of Sciences, Washington, D. C., U.S.A. (English Oct. 1969).

(e) Current Information:

(i) URSI Information Bulletin: Changes in the instructions and rules for ionospheric soundings will be published in the URSI Information Bulletin, Brussels, which is distributed through the National URSI Committees. This material is also reproduced in the INAG Bulletin.

(ii) INAG Bulletin: The Ionospheric Network Advisory Group, INAG, issues this Bulletin quarterly which is sent to all known ionospheric stations and to other interested people. All changes in rules are circulated in this together with articles from stations and individuals, from the WDCs and discussion of problems in ionospheric monitoring. If you have difficulty in understanding any part of this book, write to the INAG Bulletin, World Data Center A for Solar-Terrestrial Physics, NOAA, Boulder, Colorado, 80302, U.S.A.

(iii) STP Notes: Proposals and Recommendations for special International Collaboration are published in STP Notes (irregular; annually or more frequently as required). IUCSTP Secretariat, National Academy of Sciences, Washington, D. C. or WDC-A for Solar-Terrestrial Physics, NOAA, Boulder, Colorado 80302, U.S.A.

(f) Current information on Solar and Terrestrial conditions are published monthly in Solar-Geophysical Data issued by NOAA, Boulder, Colorado 80302, U.S.A.

(g) Tables of atmospheric constants from 30 km to 800 km are edited by COSPAR and published as The COSPAR International Reference Atmosphere, CIRA, North Holland Publ. Co., Amsterdam; (English First edition 1961; Second edition 1965; Third edition expected 1972).

(h) International Reference Ionosphere. Height variations of electron density, electron temperature and ion composition are being prepared by URSI and COSPAR for selected locations (mainly incoherent scatter stations). A preliminary edition is expected to be available in 1972.

14.2 Upper Atmosphere and the Ionosphere and Associated Subjects

14.21. Upper atmosphere and the ionosphere:

(a) Popular surveys

BENNINGTON, T. W.	1950 English	Short Wave Radio and the Ionosphere, Iliffe and Sons, London.
BOYD, R. L. F. and H. S. W. MASSEY	1958 English	The Upper Atmosphere, Hutchinson, London.
DUMONT, R.	1958 French	L'Ionosphere et L'Optique Geometrique des Ondes Courtes, Dunod, Paris.
RATCLIFFE, J. A.	1970 English	Sun, Earth and Radio, Weidenfeld (Publishers) Ltd., London.
	1970 German	Sonne, Erde, Radio - die Erforschung der Ionosphäre Kindler, Munchen.

(b) General treatises

ALPERT, J. L., V. L. GINZURG and E. L. FEINBERG	1953 Russian	Rasprostranenie Radiovoln (Propagation of Radio Waves).
DE WITT, C., J. HIEBLOT and A. LEBEAU (eds.)	1963 English	Geophysics. The Earth's Environment (Lectures at Les Houches, Summer School of Theoretical Physics, Univ. of Grenoble 1962). New York: Gordon & Breach.
GALKIN, A. I., N. M. EROFEEN, E. S. KAZIMIROVSKIJ and V. D. KOKOUROV	1971 Russian	Ionosfernye Izmerenija (Ionospheric Measurements) Izdatel'stvo, Nauka, Moscow
HBOSTIKOV, I. A.,	1963 Russian	Fizika Ozonosfery i'Ionosfery (Physics of the Ozonosphere and Ionosphere), Izdatel'stvo Nauka, Moscow.
HINES, C. O., I PAGHIS, T. R. HARTZ and J. A. FEYER (eds.)	1965 English	Physics of the Earth's Upper Atmosphere, Prentice-Hall, Englewood Cliffs, New Jersey, U.S.A.
KUIPER, G. P.	1954 English	The Earth as a Planet, Chicago University Press, Chicago.
MITRA, S. K	1947 English	The Upper Atmosphere, Royal Society of Bengal, Calcutta.
ODISHAW, H. (ed.)	1964 English	Research in Geophysics, Vol. 1: Sun, Upper Atmosphere and Space, Cambridge, Mass.: MIT Press.
RATCLIFFE, J. A.	1960 English	The Physics of the Upper Atmosphere, Academic Press, London.

RAWER, K.	1953 German	Die Ionosphäre, P. Noordhoff N.V., Groningen.
	1956 English	The Ionosphere, F. Ungar Co., New York.
RAWER, K. and V. SUCHY	1967 English	Radio observations of the Ionosphere, Encyclopedia of Physics 4912, 1-546, Springer Verlag Heidelberg.
RISHBETH, H. and O. K. GARRIOTT	1969 English	Introduction to Ionospheric Physics, Academic Press, New York and London.
VALLEY, S. L. (ed.)	1965 English	Handbook of Geophysics and Space Environment, New York, McGraw-Hill 1965. (In particular Chapt. 18 through 22). First edition (unsigned); Handbook of Geophysics, New York; Macmillan 1960.

(c) Particular fields of ionospheric physics

BEYNON, W. J. G. and G. M. BROWN	1956 English	Solar Eclipses and the Ionosphere, Pergamon Press, London, New York, Paris.
	1960 English	Later additions to the Eclipse Bibliography can be obtained from the Director, Radio Research Station, Slough, SL3 9JX, England.
BOWHILL, S. A. and E. R. SCHMERLING	1961 English	The Distribution of Electrons in the Ionosphere, Adv. Electronics and Electron Physics 15, 265-326.
DE MENDONCA, F. (ed.)	1965 English	Proceedings of the Second International Symposium on Equatorial Aeronomy, Conselho Nac. Pesquisas, Sao Paulo.
FRIHAGEN, J. (ed.)	1966 English	Electron Density Profiles in Ionosphere and Exosphere, North-Holland Publ. Co., Amsterdam.
HELLIWELL, R. A.	1965 English	Whistlers and Related Ionospheric Phenomena, Stanford University Press, Stanford.
LANDMARK, B. (ed.)	1963 English	Advances in Upper Atmosphere Research, Pergamon Press, London.
MAEHLUM, B. (ed.)	1962 English	Electron Density Profiles in the Ionosphere and Exosphere, Pergamon Press, London.
RAWER, K. (ed.)	1967 English	Wind and Turbulence in Stratosphere, Mesosphere and Ionosphere, North-Holland Publ. Co., Amsterdam.
SMITH, E. K. and S. MATSUSHITA (eds.)	1962 English	Ionospheric Sporadic E, Pergamon Press, London.
STICKLAND, A. C. (ed.)	1963 English	Proceedings International Conference on the Ionosphere. (London 1962); The Institute of Physics and the Physical Society, London.
THRANE, E. (ed.)	1964 English	Electron Density Distribution in Ionosphere and Exosphere. (Proc. NATO Advanced Study Inst., Skeikampen 1963), North-Holland Publ. Co., Amsterdam.
WHITTEN, R. C. and I. G. POPPOF	1965 English	Physics of the Lower Ionosphere, Prentice Hall, Englewood Cliffs, N. J.
WILKES, M. V.	1949 English	Oscillations of the Earth's Atmosphere, Cambridge University Press, Cambridge.
Radio Wave Absorption in the Ionosphere	1962 English	J. Atmosph. Terr. Phys. 23, 1-379.

Scatter Issue	1960 English	Proc. Inst. Radio Engrs., N. Y. 48, 4-44
Special Issue on Topside Soundings	1969 English	Proc. I.E.E.E., 57, p 859-1116, June 1969, I.E.E.E., New York. (See also section 5.76).

(d) Radio waves in plasma

ALLIS, W. P., S. J. BUCHSBAUM and A. BERS	1963 English	Waves in Anisotropic Plasmas, MIT Press, Cambridge, Mass.
BRANDSTATTER, J. J.	1963 English	An Introduction to Waves, Rays and Radiation in Plasma Media, McGraw-Hill, New York.
BUDDEN, K. G.	1961 English	Radio Waves in the Ionosphere, Cambridge University Press, Cambridge, Mass.
DENISSE, J. F. and J. L. DELCROIX	1961 French	Théorie des Ondes dans les Plasmas, Dunod, Paris.
	1963 English	Plasma Waves (English translation), Interscience, New York.
GINZBURG, V. L. and A. V. GUREVIC	1960 German	Nicht-lineare Erscheinungen in einem Plasma, das sich in einem veränderlichen elektromagnetischen Feld befindet. Fortschr. Phys. 8, 97-189 and Uspehi Fiz. Nauk 70, 201-246, 393-428.
	1960 English	Soviet Phys. Usp. 3, 115-146, 175-194.
GINZBURG, V. L.	1960 Russian	Rasprostrahenie Elektromagnitnih Voln v Plazme. Moskva: State Publ. House for physico-mathematical literature.
	1961	Propagation of Electromagnetic Waves in Plasma, North-Holland Publ. Co., Amsterdam.
	1962	Gordon & Breach, New York.
	1964 English	Pergamon Press, Oxford
JANCEL, R. and TH. KAHAN	1963 French	Electrodynamique des Plasmas, Dunod, Paris.
RATCLIFFE, J. A.	1959 English	The Magneto-ionic Theory and its Applications to the Ionosphere, Cambridge University Press, Cambridge.
STIX, T. H.	1962 English	The Theory of Plasma Waves, McGraw-Hill, New York.

(e) Practical wave propagation and ionospheric predictions

AGY, V. (ed.)	1970 English	Ionospheric Forecasting, C.F.S.T.I., Springfield, Virginia 22151, U.S.A.
BLACKBAND, W. T.	1970 English	Advanced Navigational Techniques Technivision Services, Slough.
BLACKBAND, W. T. (ed.)	1964 English	Propagation of Radio Waves at Frequencies below 300 kc/s., Pergamon Press, London.
BUDDEN, K. G.	1961 English	The Waveguide Mode Theory of Wave Propagation (Theoretical), Logos/Academic Press, London, New York.

DAVIES, K.	1965 English	Ionospheric Radio Propagation, National Bureau of Standards, Monograph 80, U. S. Government Printing Office, Washington, D. C. 20402 - (Second Printing November 1965).
	1969 English	Ionospheric Radio Waves, Blaisdell Publishing Company, Waltham, Mass.
GASSMANN, G. J. (ed.)	1963 English	The Effects of Disturbances of Solar Origin on Communications, Pergamon Press, London.
ECKART, G. and K. RAWER	1956 1st ed. 1968 2nd ed. German	in Taschenbuck der Hochfrequenztechnik, section "Ausbreitung", H. MEINKE and F. W. GUNDLACH (eds.), Springer Verlag, Berlin.
GERSON, N. C.	1962 English	Radio Wave Absorption in the Ionosphere, Pergamon Press, London.
JONES, T. B. (ed.)	1969 English	Oblique Ionospheric Radio Wave Propagation at Frequencies Near the Lowest Usable High Frequency, Technivision Services, Slough, England.
KELŠO, J. M.	1964 English	Radio Ray Propagation in the Ionosphere, Mcgraw-Hill, New York.
NEWMAN, P.	1966 English	Spread F and its Effects upon Radio-wave Propagation and Communications, Mackay and Co., London.
SMITH, E. K. and S. MATSUSHITA (eds.)	1962 English	Ionospheric Sporadic E, Pergamon Press, London (some papers only).
WAIT, J. R.	1962 English	Electromagnetic Waves in Stratified Media, Pergamon Press, London
Comite Consultative International des Radiocommunications New Delhi 1970	1970 English French Spanish	C.C.I.R. Reports Nos. 252-2 (Field Strength), 340-1 (M.U.F.) (updated roughly every three years, with change in final figure -1 becomes -2).
Convention on H.F. Communication I.E.E. London.	1963 English	I.E.E. London, England.
MF, LF and VLF Radio Propagation	1967 English	I.E.E. Conference Publication No. 36, I.E.E. London, England.
Predictions of radio communication conditions	1970 English French Spanish	Collected and published by the CCIR, New Delhi (International Telecommunication Union, Geneva, Switzerland) for use at its International Frequency Regulation Board (I.F.R.B). The following two reports have been issued by International Working Party VI/1 and by International Working Party VI/3, respectively:

(i) Report 252-2 C.C.I.R. interim method for estimating sky-wave field strength and transmission loss at frequencies between the approximate limits of 2 and 30 MHz.

(ii) Report 340-1 C.C.I.R. Atlas of Ionospheric Characteristics. This report contains a set of maps of foF2 and M(3000)F2 which are derived from a computer program based on the GALLET-JONES method for interpolating from the observed monthly median ionospheric data. The program is available from the Institute for Telecommunication Sciences, Boulder, Colorado 80302, U.S.A., or from the C.C.I.R. (U.I.T., Geneva, Switzerland).

(f) Bibliographies of papers

MANNING, L. A.	1962 English	Bibliography of the Ionosphere, Stanford Univ. Press, Stanford, California.
Progress in Radio Science	Up to 1972 English French	These contain reviews of research and Proceedings of URSI General Assemblies. The future of this publication is uncertain.
URSI Information Bulletins	Up to date English French	Brussels (See also sections 14.4 and 14.5).

14.22. Associated subjects:

(a) Popular surveys

ABETTI, G.	1956 English	The Sun, Faber and Faber, London.
CHAPMAN, S.	1936 English	The Earth's Magnetism, Methuen Monograph, London.
ELLISON, M. A.	1959 English	The Sun and its Influences, Routledge and Kegan Paul, London.
IVANOV-HOLODYJ, G. S. and G. M. NIKOL'SKIJ	1969 Russian	Solnce i Ionosfere (Sun and Ionosphere), Izdatel'stvo, Nauka, Moscow.
KIEPENHEUER, K. O.	1957 German	Die Sonne, Springer Verlag, Berlin.
NEWTON, H. W.	1958 English	The Face of the Sun, Penguin Books A422, London.
WALDMEIER, M.	1945 German	Sonne und Erde, Büchergilde Gutenberg, Zurich.

(b) General treatises

AKASOFU, S.-I.	1968 English	Polar and Magnetospheric Substorms, Springer Verlag, New York
BRUHAT, G. and L. D'AZAMBUJA	1951 French	Le Soleil, Presses Universitaires, Paris.
CHAPMAN, S. and J. BARTELS	1951 English	Geomagnetism, Vols. I and II, Clarendon Press, Oxford.
DAUVILLIER, A.	1962 French	Physique Solaire et Géophysique, Masson et Cie, Paris.
HARANG, L.	1951 English	The Aurora, Chapman and Hall, London.
	1960 German	Das Polarlicht, Akad Verlagsges, 1 Leipzig.
KUIPER, G. P. (ed.)	1953 English	The Sun, University Press, Chicago.
MACKLIN, R. J., Jr., and M. NEUGEBAUER	1966 English	The Solar Wind, Pergamon Press, London.
MC CORMAC, B. M. (ed.)	1970 English	Particles and Fields in the Magnetosphere, Reidel & Co., Dordrecht, Holland.

MAEHLUM, B. (ed.)	1965 English	High Latitude Particles and the Ionosphere, Logos Press/Academic Press, London.
MATSUSHITA, S. and WALLACE H. CAMPBELL	1967 English	Physics of Geomagnetic Phenomena, Vols. 1 and 2, Academic Press, New York and London.
STÖRMER, K.	1955 English	The Polar Aurora, Clarendon Press, Oxford.

(c) Reviews

Aeronomy Conference Reports	English	University of Illinois, Urbana, Illinois, U.S.A. International meetings are held in most years and these Reports give a good view of current research.
STP Notes	1969 English	Inter-Union Commission on Solar-Terrestrial Physics Issued by: IUCSTP Secretariat, c/o National Academy of Sciences 2101 Constitution Ave., N.W. Washington, D.C. 20418 (USA)
Reviews of Plasma Physics (issued yearly) LEONTOVICH, M. A. (ed.)	1963 Russian 1965 English	Voprozy Teorii Plazmy, published by Gosatomizdat, Moscow. Later vols., Atomizdat, Moscow. Consultants Bureau, New York, London, Vol. 1.
Space Research	1960 English 1960-65 English 1967-69 English 1970-71 English	This is published yearly and contains the Proceedings of the COSPAR Space Sciences Symposia, Vol. 1. Published by North Holland Publ. Co., Amsterdam, Vols. 1 - V. Spartan Books, New York, Vols. VI - IX. Akademie - Verlag, Berlin, Vols. X - XI.
Solar Terrestrial Physics, Solar Aspects STICKLAND, A. C. (General ed.)	1969 English	Annals of IQSY Vol. 4. MIT Press, Cambridge, Mass., U.S.A.
Solar Terrestrial Physics, Terrestrial Aspects STICKLAND, A. C. (General ed.)	1969 English	Annals of IQSY Vol. 5. MIT Press, Cambridge, Mass., U.S.A.
Triannual Review of Radio Science MINNIS, C. M. (ed.)	English	(Reports to URSI General Assemblies). Edited by the URSI Secretary General, C. M. Minnis.

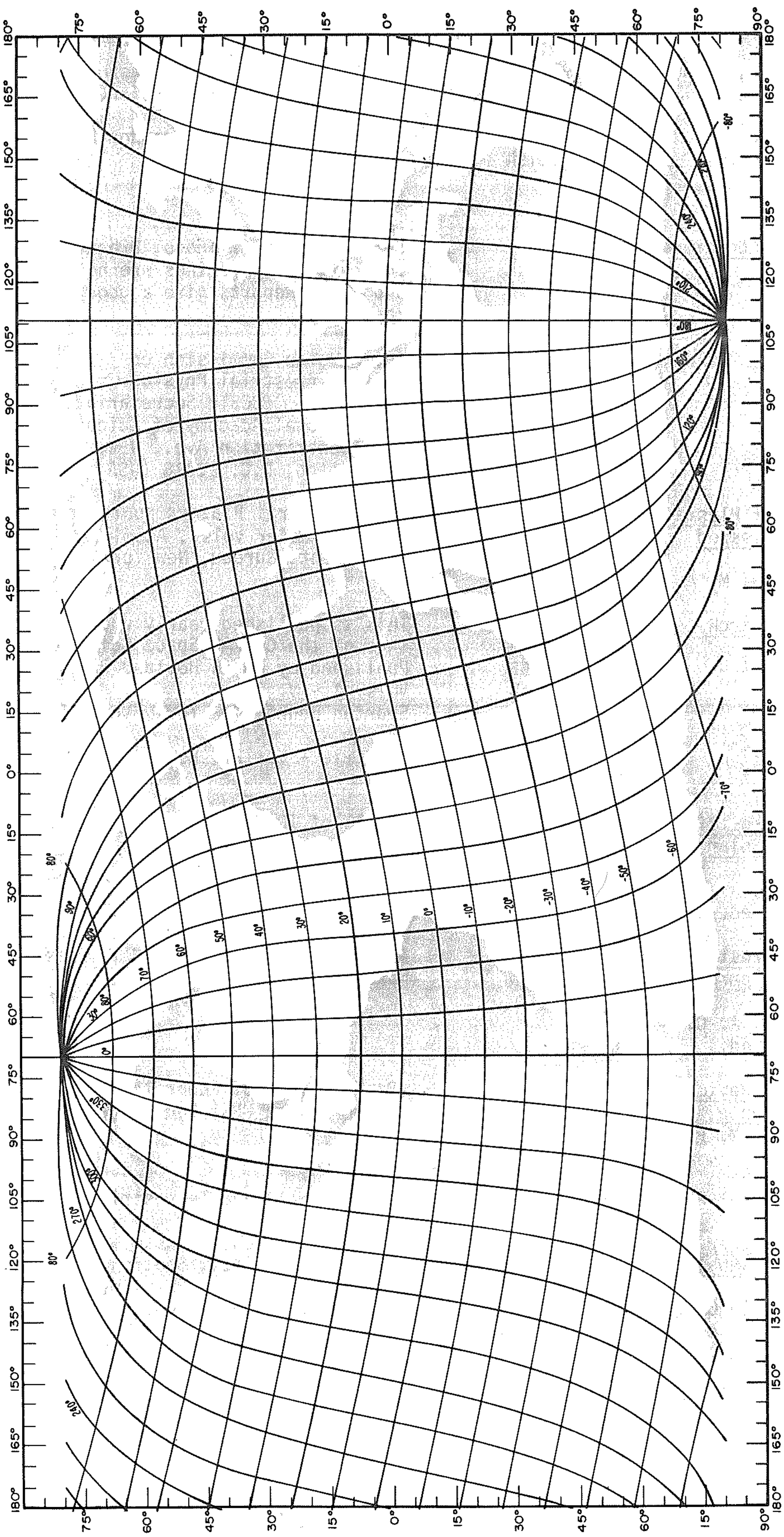
14.3 Geographical Position of Stations, Solar Zenith Angle and Terrestrial Coordinates

14.31.	URSI Ionospheric Stations Manual HERBAYS, E., W. J. G. BEYNON and G. M. BROWN (eds.)	1958 English French	URSI Publications, Brussels. Sections I, II and IV - Station lists; Section III - Cosine of zenith angle; Section V - Tables of "Chapman Function"; Supplement issued, 1964.

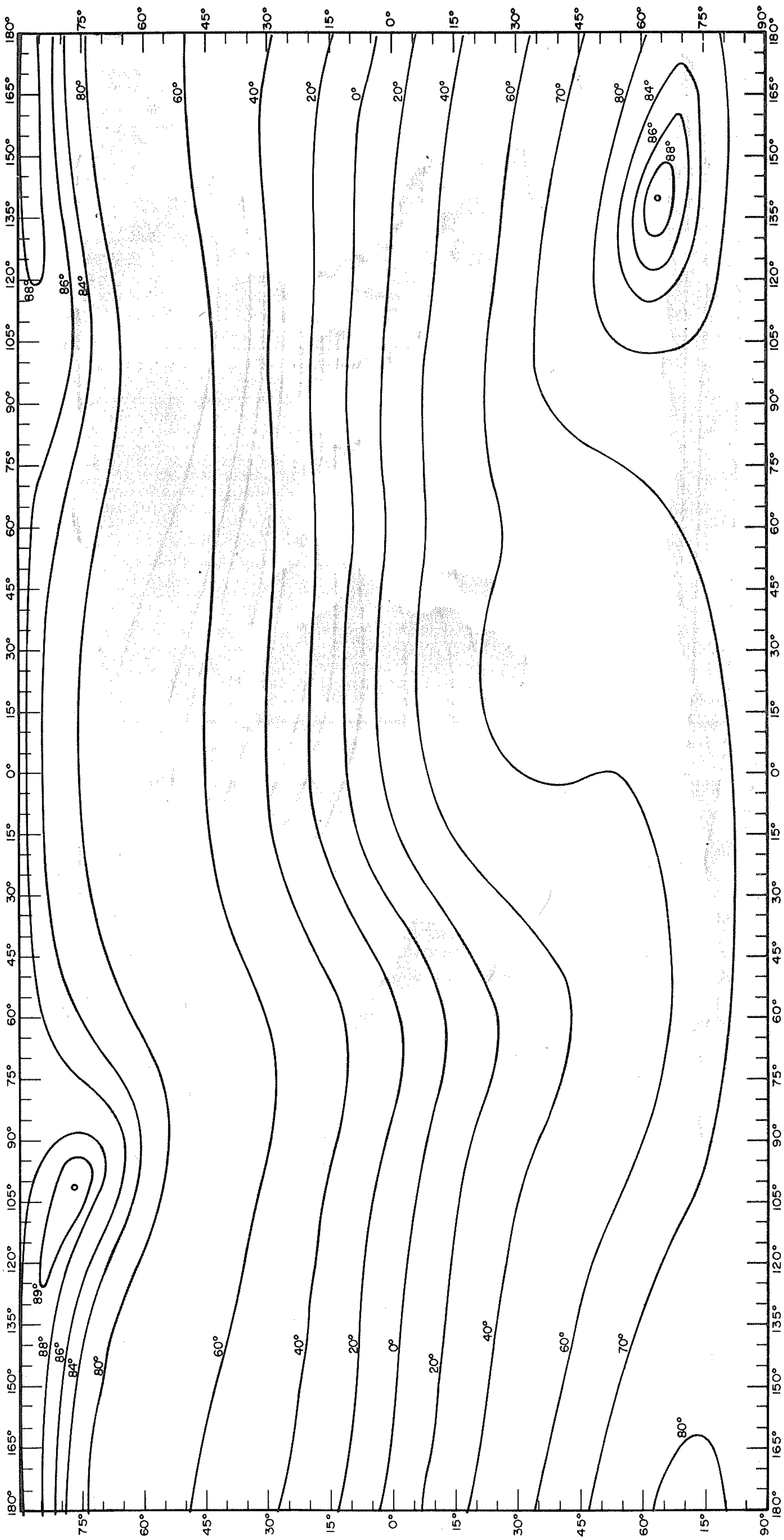
14.32. Terrestrial coordinates

(a) Geographical coordinates refer to the Earth's rotation axis: geographical latitude ϕ and geographical longitude λ (zero longitude at Greenwich) are given in all maps.

(b) Geomagnetic coordinates are obtained by a rotation of the ϕ, λ system from the rotation axis to the axis of an average magnetic dipole field: geomagnetic latitude Φ and geomagnetic longitude Λ refer to the conventional dipole axis $\phi = 78.5°$ N, $\lambda = 69.1°$ W. (See Fig. 14.1)

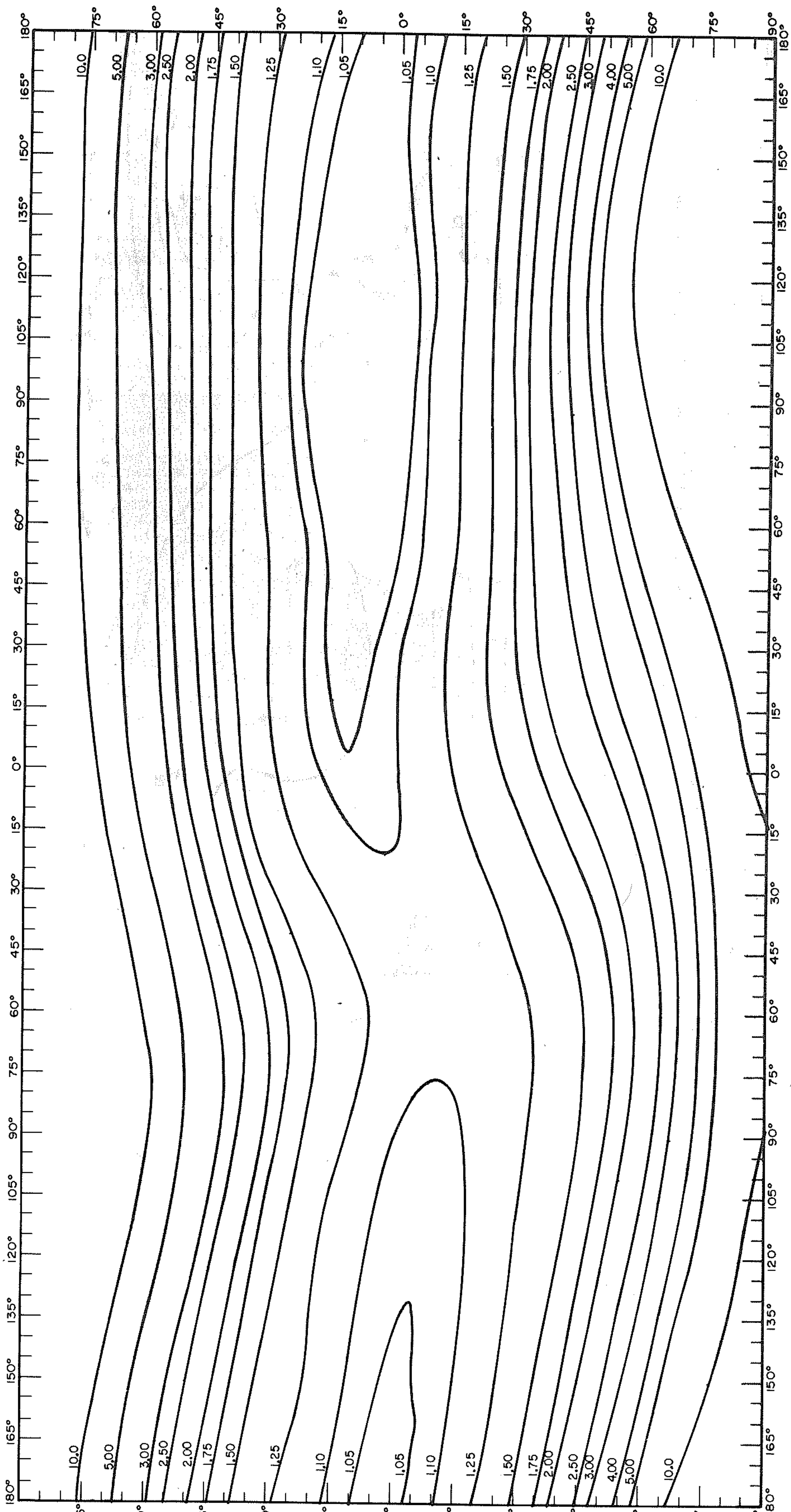


GEOMAGNETIC COORDINATES
Fig. 14.1



MAGNETIC DIP

Fig. 14.2



CONSTANT L SHELL PARAMETER AT 400 KILOMETERS

Fig. 14.3.

(c) Magnetic inclination (or dip) ψ is one of the magnetic components, viz., the angle between the magnetic vector and the horizontal plane. For most ionospheric investigations the dip is the appropriate magnetic element. All components of the magnetic vector (at the surface of the earth) can be found in a set of maps (No. 1700 to 1703) 8th Edition, 1966, published by the U. S. Naval Oceanographic Office, Washington, D. C., U.S.A. The components have a secular variation which can also be found in these maps. An example of a dip map is shown in Fig. 14.2.

(d) Magnetic latitude Ψ is a coordinate which is obtained from the dip by

$$\tan \Psi = \tfrac{1}{2} \tan \psi$$

The isoclines (ψ = const.) are the coordinate lines in the Ψ system. Contrary to the Φ, Λ system they are not circles, but they would be if the magnetic field was a dipole field. Ψ (like ψ) is a very useful parameter for ionospheric investigations.

(e) The field B of a magnetic dipole is often used as a (local or global) approximation to the true field of the Earth. It is described by the equation

$$B = B_0 \left(\frac{R_E}{r}\right)^3 (1 + 3\sin^2 \Phi)^{\frac{1}{2}}$$

where r is the radius from the center of the Earth and R_E the radius of the Earth.

(f) The McIllwain parameter, L, identifies particular field lines, or shells of field lines, of the actual magnetic field by indicating the radial distance of their peak height from the center of the Earth, r_{max}. L is defined as the ratio r_{max}/R_E where R_E is the radius of the Earth.

$$L = \frac{r_{max}}{R_E}$$

This parameter is particularly valuable for studying interactions between the ionosphere and magnetosphere. The form of the map varies with height, the map for an altitude of 400 km is often most convenient for studies of F region phenomena and the topside ionosphere, Figure 14.3. B and L are now often used as pairs of magnetic coordinates in the magnetosphere. L is sometimes expressed in equivalent latitude form. This is known as the Invariant Latitude.

(g) It is sometimes convenient to denote the Earth's magnetic field as a spherical harmonic expansion of the observed field. Since the axis of the Earth's magnetism makes both an appreciable angle with the axis of rotation and is displaced from the center of the Earth by several hundred km, a large number of terms are needed to describe it correctly in centered geographic coordinates. The expansion must be used in a computer and solves a wide range of field geometry problems. At present the standard model is that due to Roederer, J. G., W. N. Hess and E. C. Stassinopoulos, NASA Report X642-65-182, Goddard Space Flight Center, Greenbelt, Md. U.S.A. (1965, English) (See Figure 14.3).

Note: Much confusion can be caused by the improper use of the names Geomagnetic and Magnetic. The definitions given above are agreed internationally and should be strictly observed.

14.4 Routine Ionospheric Data

14.41. World Data Centers (WDC)

WDC-A for Solar-Terrestrial Physics, National Oceanic and Atmospheric Administration, Boulder, Colorado 80302, U.S.A.

WDC-B2 on Solar-Terrestrial Physics, Ulitza Molodezhnaya 3, Moscow B-296, U.S.S.R. Dr. V. P. Golovkov, Director.

WDC-C1, Radio and Space Research Station, Ditton Park, Slough, SL3 9JX, England.

WDC-C2, Radio Research Laboratories, 2-1 Nukui-Kitamachi 4-chome, Koganei-shi, Tokyo 184, Japan

14.42. Monthly median values from all cooperating stations are available in Ionospheric Data compiled by National Geophysical and Solar-Terrestrial Data Center, Environmental Data Service, Boulder, Colorado 80302, U.S.A. Issued monthly (English).

Issues	135 through 256	as	CRPL-F Part A
	257 through 316	as	CRPL-FA
	316 onwards	as	FA

14.43. Many stations prepare booklets of data which are available on an exchange basis. The data currently available are listed in the catalogs of the WDCs, obtainable from them. The catalog of WDC-A also contains much information of general value. All median data and detailed data from some stations exist in punched card or tape forms. Details can be obtained from the WDCs.

14.44. STICKLAND, A. C. (General ed.), Survey of IQSY Observations and Bibliography. Annals of IQSY, Vol. 7, gives sources and use of data in IQSY (1970, English), MIT Press, Cambridge, Mass., U.S.A.

14.5 Special Events

14.51. In recent years data from a wide range of disciplines has been collected periodically and published so as to facilitate study of particular events. This will continue in the future. In addition, an Abbreviated Geophysical Calendar Record is prepared monthly which gives the main features of each day. This is published in Solar-Geophysical Data in the seventh month after the month involved (issued by National Geophysical and Solar-Terrestrial Data Center, NOAA, Boulder, Colorado 80302, U.S.A., English) and at wider interval in STP Notes.

14.52. LINCOLN, J. V., Solar and Geophysical Events 1960-65 (Calendar Record). Annals of IQSY, Vol. 2, MIT Press, Cambridge, Mass., U.S.A. (1968, English).

14.53. STICKLAND, A. C. (General edi.), The Proton Flare Project. Annals of IQSY, Vol. 3, MIT Press, Cambridge, Mass., U.S.A. (1968, English).

14.54. Material needed for the study of particular events is published as Upper Atmosphere Geophysics Reports (UAG) by WDC-A for Solar-Terrestrial Physics, NOAA, Boulder, Colorado 80302. U.S.A. (English, about 3 issues per year on average). A list of these to date is:

Upper Atmosphere Geophysics Report UAG-5, "Data on Solar Event of May 23, 1967 and its Geophysical Effects" compiled by J. Virginia Lincoln, World Data Center A, Upper Atmosphere Geophysics, ESSA, February 1969, single copy price 65 cents.

Upper Atmosphere Geophysics Report UAG-8, "Data on Solar Geophysical Activity October 24-November 6, 1968", Parts 1 and 2, compiled by J. Virginia Lincoln, World Data Center A, Upper Atmosphere Geophysics, ESSA, March 1970, single copy price (includes Parts 1 and 2) $1.75.

Upper Atmosphere Geophysics Report UAG-9, "Data on Cosmic Ray Event of November 18, 1968 and Associated Phenomena", compiled by J. Virginia Lincoln, World Data Center A, Upper Atmosphere Geophysics, ESSA, April 1970, single copy price 55 cents.

Upper Atmosphere Geophysics Report UAG-12, "Solar-Geophysical Activity Associated with the Major Geomagnetic Storm of March 8, 1970", Parts 1, 2 and 3, compiled by J. Virginia Lincoln and Dale B. Bucknam, World Data Center A, Upper Atmosphere Geophysics, NOAA, April 1971, single copy price (includes Parts 1-3) $3.00.

Upper Atmosphere Geophysics Report UAG-13, "Data on the Solar Proton Event of November 2, 1969 through the Geomagnetic Storm of November 8-10, 1969", compiled by Dale B. Bucknam and J. Virginia Lincoln, World Data Center A, Upper Atmosphere Geophysics, NOAA, May 1971, single copy price 50 cents.

Upper Atmosphere Geophysics Report UAG-21, "Preliminary Computation of Data for Retrospective World Interval July 26 - August 14, 1972", compiled by J. Virginia Lincoln and Hope I. Leighton, World Data Center A for Solar-Terrestrial Physics, NOAA, November 1972.

Upper Atmosphere Geophysics Report UAG-24, "Data on Solar-Geophysical Activity Associated with the Major Ground Level Cosmic Ray Events of 24 January and 1 September, 1971", compiled by Helen E. Coffey and J. Virginia Lincoln, World Data Center A for Solar-Terrestrial Physics, NOAA, December, 1972.

14.6 General Solar and Lunar Data and Solar Activity

14.61. General

(a) Current data

(i) World Data Centers (see section 14.8).

(ii) Solar-Geophysical Data, issued monthly from National Geophysical and Solar-Terrestrial Data Center, Environmental Data Service, NOAA, Boulder, Colorado 80302, U.S.A. (formerly these bulletins were known as CRPL-F Bulletin, Part B, issued by National Bureau of Standards).

(b) Tables

FANSELAU, G. and J. BARTELS, Geophysikalische Mondtafeln (1938, German), gives tables of times differences between solar and lunar noon.

NAUTICAL ALMANAC, H.M. Stationary Office, London (yearly, English).

URSI Ionospheric Stations Manual, URSI Publications, Brussels (1958, English, French), Section VI, Lunar Phase; Section VII, Rotation Number of Solar Rotations.

14.62. Indices of solar activity:

(a) Sunspot numbers, radio flux, and other solar activity indices as published monthly in "Solar-Geophysical Data", National Oceanic and Atmospheric Administration (NOAA), Boulder Colorado 80302, U.S.A.

(b) Flares (and flare-effects) are reported in "Solar-Geophysical Data" issued monthly through NOAA, Boulder, Colorado 80302, U.S.A.

(c) Solar radio noise maps are issued by Observatoire de Meudon, 92, France for Nançay, by University of Sydney, Sydney, Australia for Fleurs, and by Radio Astronomy Institute, Stanford University, Stanford, California, U.S.A. These are published in "Solar-Geophysical Data".

(d) The Union Internationale des Telecommunications (U.I.T.) publishes monthly in its Bulletin observed and predicted (up to six months in advance) Zürich Sunspot numbers, R, Covington Index (10 cm solar radio flux) and Minnis-Bazzard IF2 index.

14.7 Magnetic Data and Indices of Magnetic Activity

14.71. Data:

(a) World Data Centers (WDCs) (see section 14.82).

(b) "Solar-Geophysical Data" compiled by National Geophysical and Solar-Terrestrial Data Center, Environmental Data Service, NOAA, Boulder, Colorado 80302, U.S.A, (issued monthly, English). Part 1, Prompt Reports (two previous months), Part II, Comprehensive Reports (usually six or more months later). Descriptive Texts issued annually, usually in February.

14.72. Tables and regular publications:

(a) Current monthly and half monthly tables and graphs of Kp, Institut für Geophysik, Postfach 876, 34 Göttingen (Germany).

(b) IAGA Bulletin No. 12 (yearly, post mortem) containing K (many observatories), Ci, Kp, lists of rapid variations and special effects, lists of storms and very quiet intervals. Last volume in this series No. 12X1 for 1969, superseded by IAGA Bulletin No. 32 (yearly post mortem) containing the international quiet and disturbed days, Ci, Kp, ap, Ap, Cp, Dst and Kn, Ks and Km (hourly values of AE will probably be included in future issues). A number of interesting time-intervals each year (mostly magnetic storms) will be given, including a series of magnetograms from selected stations.

(c) IAGA preliminary quarterly report containing pulsation data only and preliminary monthly report containing Ci, the international quiet and disturbed days, preliminary data on ssc, si, sfe, pg and bays; distributed by Kon. Ned. Meteor. Inst., De Bilt, The Netherlands.

(d) Kp, Ap, Cp are published in J. Geophys. Research, monthly.

(e) Q-Indices, see J. BARTELS, Annals of the IGY, Vol. IV, pp 220; see also J. BARTELS and N. FUKUSHIMA, Abhandl. Akad. Wiss. Göttingen, Math. physik, Kl., Sonderheft, 1956, No. 3.

14.8 The World Data Center System and Addresses

14.81. World data center systems: At present the World Data Centers (WDCs) are coordinated under the auspices of the ICSU Committee on Solar-Terrestrial Physics. They were originally set up as part of the International data exchange arrangements for the International Geophysical Year (IGY). Guides for interchange are issued as required as special issues of STP Notes. Data can be obtained from any of these, usually free to stations contributing to the world data collection, though a charge may be made where appropriate; e.g., if large amounts of data have to be copied.

14.82. Addresses of STP WDCs:

World Data Center A: WDC-A is established in the United States under the auspices of the National Academy of Sciences. Communications regarding data interchange matters in general and World Data Center A as a whole should be addressed to World Data Center A, Coordination Office, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, D. C., U.S.A. 20418. WDC-A has eight subcenters for the various disciplines or groups of disciplines. Only the ones relevant to data exchange in solar-terrestrial physics are indicated here. There are very close connections between these subcenters; if it is more convenient, data may be sent to one subcenter through another one. These are all comprehensive centers.

Boulder — World Data Center A
for Solar-Terrestrial Physics
National Oceanic and Atmospheric Administration
Boulder, Colorado 80302, U.S.A.

Greenbelt — World Data Center A
Rockets and Satellites, Code 601
NASA, Goddard Space Flight Center
Greenbelt, Maryland 20771, U.S.A.

World Data Center B: WDC-B is established in the Union of Soviet Socialist Republics under the auspices of the Akademia Nauk. It consists of two subcenters: B1 for meteorological, oceanographic and solid earth disciplines, and B2 for solar-terrestrial physics disciplines. In addition, there are some specialized centers which emphasize special analyses. Only the relevant centers are listed.

Moscow — World Data Center B2
Solar-Terrestrial Physics
Ulitza Molodezhnaya 3
Moscow B-296, U.S.S.R.
(Dr. V. P. Golovkov, Director)

Ondrejov — World Data Center B for SID
Observator
Ondrejov-u-Prahy, Czechoslovakia

World Data Centers C and ICSU Permanent Services; WDC-C consists of several discipline centers in several nations. Some specialize in systematic analysis or data compilations, identified by "+" in the table. In addition, some of the ICSU Permanent Services are included in this description of the international data exchange arrangements; they perform stated services in rapid data exchange or data analysis or compilation under the auspices of URSI, IAU or IAGA.

Zürich + (sunspot numbers) — World Data Center C1
Prof. Dr. M. Waldmeier
Eidgenössische Sternwarte
Schmelzbergstrasse 25
8006 Zürich, Switzerland

Freiburg + (Hα)	World Data Center C1 Schöneckstrasse 6 Fraunhofer Institut D78 Freiburg im Breisgau Baden Federal Republic of Germany
Rome + (Hα)	World Data Center C1 Prof. M. Cimino Osservatorio Astronomico di Roma Via del Parco Mellini 84 I 00136 Roma, Italia
Meudon + (Hα) (Ca plages) (Flares)	World Data Center C1 Observatoire de Meudon F 92 Meudon, France
Arcetri + (Ca plages)	World Data Center C1 Osservatorio Astrofisico Via San Leonardo 75 Arcetri-Firenze, Italia
Pic-du-Midi (Corona)	World Data Center C1 Observatoire du Pic-du-Midi Service de la Couronne 65 Bagneres-de-Bigorre, France
Utrecht (Radio flux from sun)	World Data Center C1 Sterrewacht Sonnenborgh Servaasbolwerk 13 Utrecht, Netherlands
Munich + (Comet Tails)	World Data Center C1 Max-Planck-Insitut für Astrophysik Fohringer Ring 6 D8 München 23, Federal Republic of Germany
Slough (Ionosphere and Space)	World Data Center C1 Radio and Space Research Station Ditton Park Slough, SL3 9JX, England
Umeå (Cosmic Rays)	World Data Center C1 for Cosmic Rays Department of Physics University of Umeå 90187 Umeå, Sweden
Charlottenlund (Geomagnetic)	World Data Center C1 Meteorological Institute Charlottenlund, Denmark
Hailsham (Geomagnetic)	World Digital Data Center C1 for Geomagnetism Institute of Geological Sciences Geomagnetism Unit Herstmonceux Castle, Hailsham Sussex, England
Kiruna (Aurora)	World Data Center C1 Kiruna Geophysical Observatory Kiruna C, Sweden
Paris (Airglow)	World Data Center C1 Institut d'Astrophysique 98 bis Boulevard Arago F75 Paris 14 E, France

World Data Centers C2 (Other)

Toyokawa (Radio Flux from sun)	World Data Center C2 Research Institute of the Atmosphere Nagoya University Toyokawa, Aichi, Japan
Tokyo (Ionosphere)	World Data Center C2 for Ionosphere Radio Research Laboratories Ministry of Posts and Telecommunications 2-1, Nukui-Kitamachi 4-chome Koganei-shi Tokyo 184, Japan
Itabashi (Cosmic Rays)	World Data Center C2 Cosmic Ray Laboratory Institute of Physical and Chemical Research Itabashi, Tokyo, Japan
Kyoto (Geomagnetism)	World Data Center C2 for Geomagnetism Kyoto University Library Kyoto, Japan
Ahmedabad (Geomagnetism)	World Digital Data Center C2 for Geomagnetism Physical Research Laboratory Navranopura, Ahmedabad-9, India
Mitaka (Airglow)	World Data Center C2 for Airglow Tokyo Astronomical Observatory Mitaka, Tokyo, Japan

14.9 Permanent Services

14.91. International Ursigram and World Days Service (IUWDS): The IUWDS is responsible for short-term interchange of specially arranged data, mainly by Telex or radio methods. It is also responsible for the International Geophysical Calendar, the selection of World Days, and the declaration of Retrospective World Intervals. The purpose of RWI's is to make generally available more data for specific periods of interest than are normally circulated. For short-term warnings of disturbed conditions and short-term interchange of data, IUWDS operates through Regional Warning Centers (RWC's). The IUWDS issues a code book which enables any message to be interpreted.

Miss J. Virginia Lincoln
Secretary for World Days
Mr. R. B. Doeker
Secretary for URSIgrams
NOAA
Boulder, Colorado 80302, U.S.A.

RWC-Western Hemisphere
Attn: R. B. Doeker
Space Environment Services Center
NOAA
Boulder, Colorado 80302, U.S.A.

RWC-Western Europe-Paris
Attn: P. Simon
Ursigrammes Observatoire
F92 Meudon, France

RWC-Western Europe-Darmstadt
Attn: B. Beckmann
FTZ D33
Am Kavalleriesand 3
D61 Darmstadt
Federal Republic of Germany

RWC-Western Europe-Netherlands
Attn: G. Brussaard
Section Propagation RCL
Dr. Neher Laboratory
St. Paulusstraat 4
Leidschendam, Netherlands

ARWC-Sweden (ARWC means Associate Regional Warning Center)
Attn: P. Akerlind
Central Administration of Swedish
Telecommunications
Development Department
S-12386 Farsta, Sweden

ARWC-Czechoslovakia
Attn: P. Triska
Czechoslovak Academy of Sciences
Geophysical Institute
Ionospheric Department
Bocni II
Praha 4 Sporilov, Czechoslovakia

RWC-Eurasia
Attn: R. A. Zevakina
IZMIRAN
P/O Akademgorodok
Moscow Region, U.S.S.R.

ARWC-U.S.S.R.
Attn: E. S. Kazimirovsky
Siberian Institute of Terrestrial
Magnetism, Ionosphere and Radio
Propagation (Sib IZMIR)
664033 Irkutsk 33, p/box 4, U.S.S.R.

ARWC-India
Dr. B. M. Reddy
Radio Science Division
National Physical Laboratory
New Delhi 12, India

RWC-Western Pacific
Attn: K. Kondo
Radio Research Laboratories
Ministry of Posts and Telecommunications
2-1, Nukui-Kitamachi 4-chome
Koganei-shi
Tokyo 184, Japan

RWC-Australasia and Antarctica
Attn: C. G. McCue
Ionospheric Prediction Service Division
P.O. Box 702
Darlinghurst, N.S.W., Australia 2010

14.92. International indices: An important section of the work of the Permanent Services is the rapid provision of International Indices. The main centers are:

De Bilt [+]
International Service of Geomagnetic Indices
c/o Dr. D. van Sabben
Royal Netherlands Meteorological
Institute
De Bilt, Netherlands

Göttingen +	International Service of Geomagnetic Indices c/o Dr. M. Siebert Geophysikalisches Institut Herzberger Landstrasse 680 D34 Göttingen Federal Republic of Germany
Tortosa +	International Service of Geomagnetic Indices Observatorio del Ebro Roquetas, Tarragona, Spain
SPARMO + (Balloon Measurements)	Permanent Service - SPARMO Mr. J. P. Legrand, Secretary Laboratoire de Physique Cosmique 2 rue des Vertugadins F92 Meudon, France

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Upper Atmosphere Geophysics Report UAG-9, "Data on Cosmic Ray Event of November 18, 1968 and Associated Phenomena" compiled by J. Virginia Lincoln, World Data Center A, Upper Atmosphere Geophysics, ESSA, April 1970, single copy price 55 cents.

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