REPORT UAG - 23A

WORLD DATA CENTER A
for
Solar-Terrestrial Physics

REVISION OF CHAPTERS 1 – 4

U.R.S.I. HANDBOOK OF IONOGRAM INTERPRETATION AND REDUCTION

Second Edition November 1972

July 1978

WORLD DATA CENTER A
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C., U.S.A., 20418

World Data Center A consists of the Coordination Office

and seven Subcenters:

World Data Center A
Coordination Office
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C., U.S.A., 20418
[Telephone: (202) 389-6478]

Glaciology:

World Data Center A: Glaciology
[Snow and Ice]
Inst. of Arctic & Alpine Research
University of Colorado
Boulder, Colorado, U.S.A. 80309
[Telephone: (303) 492-5171]

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Federal Building
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[Telephone: (704) 258-2850]

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[Telephone: (202) 634-7249]

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[Telephone: (303) 499-1000, Ext. 6521]

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edited by

W.R. Piggott

Radio and Space Research Station, Slough, U.K.

and

K. Rawer

Arbeitsgruppe für Physikalische Weltraumforschung
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FOREWORD

The Second Edition of the URSI Handbook of Ionogram Interpretation and Reduction (WDC-A Report UAG-23, November 1972) differed greatly from the first edition. It included much additional material requested by operators with problems when conditions were difficult, also rules and descriptions of phenomena whose importance had not been realized when the first edition was written.

Inevitably mistakes and ambiguities were discovered, and some of the rules for parameters important for the International Magnetospheric Study (IMS) needed further refinement. Many of these corrections and amendments were collected and published in the INAG Bulletin (in particular 16, 17, 21, and 23, and in the High Latitude Supplement (W. R. Piggott Report UAG-50, WDC-A October 1975)). The work of amending the original Handbook is now very considerable, and the Ionospheric Network Advisory Group (INAG) and the Editors therefore decided to reprint the first four Chapters, which contain most of the changes. This book is the result.

It must be stressed that the value of the data for regional or worldwide 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 INAG. Particular care is necessary that local "house-rules" 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.

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.

When using the Manual for teaching purposes, it is advisable to teach the simple rules for the horizontally stratified ionosphere first, then to add special cases and the treatment of difficult ionograms. In the original planning of the rules, it was intended that a few simple principles should be applied to cover a wide range of phenomena. This was not entirely possible, and in a few cases some arbitrary rules must be learned. The accuracy rules are essential for the identification of accurate values, and for the systematic use of the letter symbols, when accurate data cannot be obtained. It is essential to stress this point since departures from these rules can cause great difficulty both to those reducing the ionograms and those using the data obtained.

Cross Reference to Ionograms

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).

Since it was not possible to illustrate the Handbook with ionograms, INAG and the Editors decided to supplement the references to ionograms in the *Annals of the IGY*, Volume III, Part I by references to ionograms published in the *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....

The High Latitude Supplement (Report UAG-50) was written primarily for those working at high latitudes, and gives many ionogram sequences showing typical high latitude phenomena. However, it also contains many hundreds of ionograms which can be used to clarify the interpretations at lower latitudes. Many of these have been annotated by the Editor (W. R. Piggott) thus giving examples of how the rules should be applied.

It must be stressed that this publication (UAG-23A) is not intended to be a complete guide to ionogram interpretation and reduction, and should be read in conjunction with the remaining chapters of UAG-23, and, where appropriate, UAG-50. In particular, the chapters on tabulations, medians and f plots have not been revised here, since they contain few amendments and the general interest chapters have been amended only where typing errors occurred or the text was obscure. As in all work of this type, the final document owes much to comments made by INAG members and consultants, and, in particular, to Ray Conkright, Alan Rodger and Richard Smith. It could not have been produced without the constant interest of Miss J. V. Lincoln, and the support of WDC-A. The accuracy of a document of this type depends greatly on the care taken both by the typists of WDC-A who prepared the master copies, the careful proofreading by WDC-A staff, and by those mentioned above. The Editor wishes to convey his thanks to all concerned and, as Chairman of INAG, to convey the thanks of the users of this Manual, who will be saved much work by its publication.

List of Abbreviations Used in this Publication

CCIR	International Radio Consultative Committee
CIG	Comite International de Geophysique (terminated 1967)
COSPAR	Committee on Space Research
COSTED	Committee on Science and Technology in Developing Countries
CSAGI	Comite Special de l'Annee Geophysique Internationale (terminated 1959)
FAGS	Federation of Astronomical and Geophysical Services
GARP	Global Atmospheric Research Programme
IAGA	International Association of Geomagnetism and Aeronomy
IAMAP	International Association of Meteorology and Atmospheric Physics
IASY	International Active Sun Years (1968-1970)
IAU	International Astronomical Union
ICSU	International Council of Scientific Unions
IGY	International Geophysical Year (1957-1958) (in French AGI)
IQSY	International Years of the Quiet Sun (1964-1965)
ITU	International Telecommunication Union
IUGG	International Union of Geodesy and Geophysics
IUPAP	International Union of Pure and Applied Physics
IUWDS	International Ursigram and World Days Service
SCAR	Scientific Committee on Antarctic Research
SCHL	Special Committee on High Latitudes
SCOPE	Special Committee on Problems of the Environment
SCOSTEP	Special Committee on Solar-Terrestrial Physics
UAG	Upper Atmosphere Geophysics
UNESCO	United National Education, Scientific and Cultural Organization
URSI	Union Radio-Scientifique Internationale (URSI/AGI and URSI/IGY)
WDC	World Data Center
WMO	World Meteorological Organization
WWSC	World Wide Soundings Committee

CONTENTS

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.

INTRODUCTION

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 Report UAG-23.

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 <u>f</u> 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, e.g., phenomena giving fxI greater than fxF2. These possibilities are discussed in the "High Latitude Supplement" (Report UAG-50).

It must be stressed that many ionospheric parameters, e.g., <u>h'F</u>, <u>M(3000)F2</u> 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, <u>foF2</u>, <u>foF1</u>, <u>foE</u>, <u>foEs</u>, <u>h'F</u>, <u>h'F2</u>, <u>fmin</u>, 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 (WDCs).
(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 of Report UAG-23.

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 Es types (see however, sections 1.9 and 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 fB 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; $N = 1.24 \cdot 10^{10}\ (fN)^2$, becomes $N/m^{-3} = 1.24 \cdot 10^{10}\ (fN/MHz)^2$ (equations 1.1 in section 1.04). This is read as N in $m^{-3} = 1.24 \cdot 10^{10}$ (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 modify, 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, Appleton Laboratory, Slough, U.K., and World Data Center A for Solar-Terrestrial Physics, Boulder, CO, 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).

The Editors wish to acknowledge the critical comments provided by Mrs. L. Hayden and Mr. T. N. Gautier of WDC-A and Mr. R. Smith of Appleton Laboratory, on behalf of station operators. Mrs. L. Hayden has checked the manuscript, proof read the whole of the text--a major task in view of the large number of cross references, and made numerous detailed suggestions.

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 Appleton Laboratory, who have supported this work.

NOTES

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] (see foreword p.i and p.iii) 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 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].

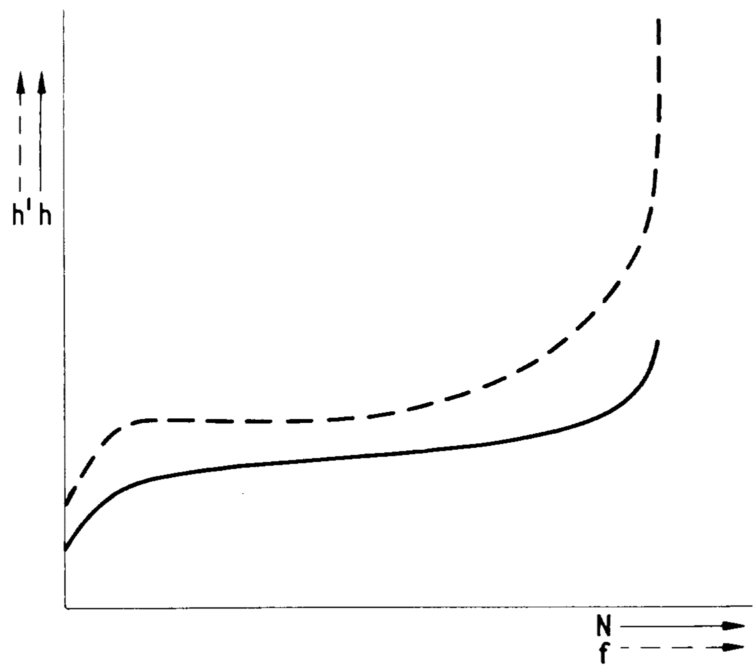

Fig. 1.1 Relations between virtual height and true height (no magnetic field).
_________ionization distribution, ------ h'(f) pattern.

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 the other, the extraordinary wave.

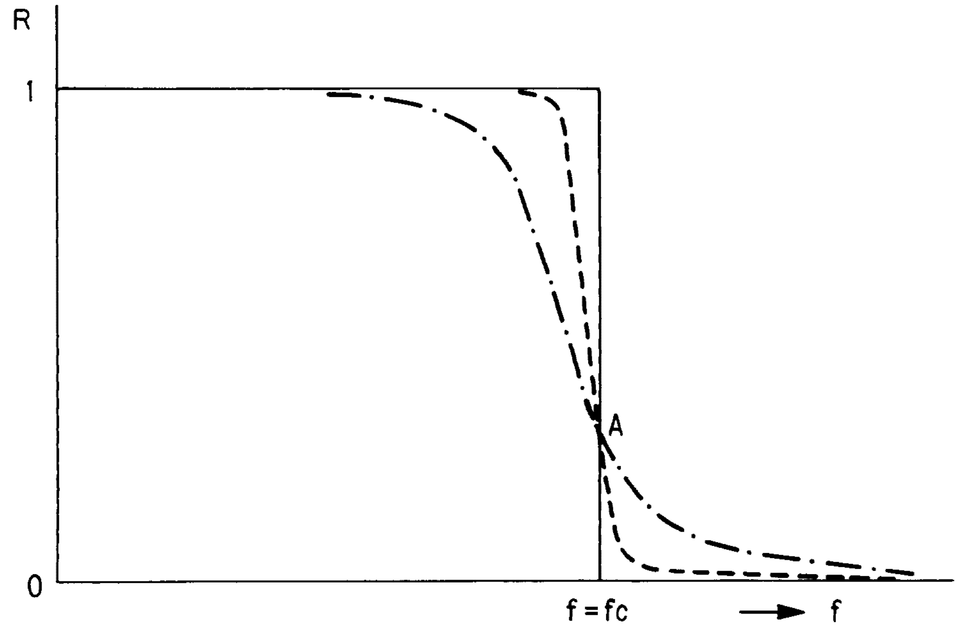

Fig. 1.2 Reflection coefficient, R, of a thin and thick layer as a function of frequency.

—— 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 having the higher critical frequency when above fB (Fig. 1.3). The magneto-electronic theory shows that the reflection levels of the two modes (o and x) depend on the ratio of the exploring frequency f to the gyrofrequency fB. These are given below, where $X = fN^2/f^2$ and $Y = fB/f$

If f < fB ordinary mode : X = 1 extraordinary mode : X = 1 + Y
If f > fB ordinary mode : X = 1 extraordinary mode : X = 1 - Y

For any set of circumstances, there can only be two characteristic modes but, because of coupling, there may be more than two characteristic traces.

For ionogram reduction it is more convenient to denote the traces according to the conditions of reflection:

Reflection at X = 1	o-trace
at X = 1 - Y	x-trace
at X = 1 + Y	z-trace (or third magneto-electronic component)

Near the gyrofrequency the x-mode trace shows a special type of retardation (Fig. 1.4(a) and Fig. 1.5) which does not correspond to a critical frequency. As the x mode is more strongly absorbed than the o mode, very rarely, a trace showing retardation at frequencies near but below fB is found. This is a z trace. fB is seen only when absorption is small. The patterns which would be expected as the ordinary wave critical frequency changes from fo >> fB to fo ≑ fB and fo < fB are shown schematically in Fig. 14.

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. N and B are directly related to the electron plasma frequency, fN, and the electron gyrofrequency, fB, respectively.

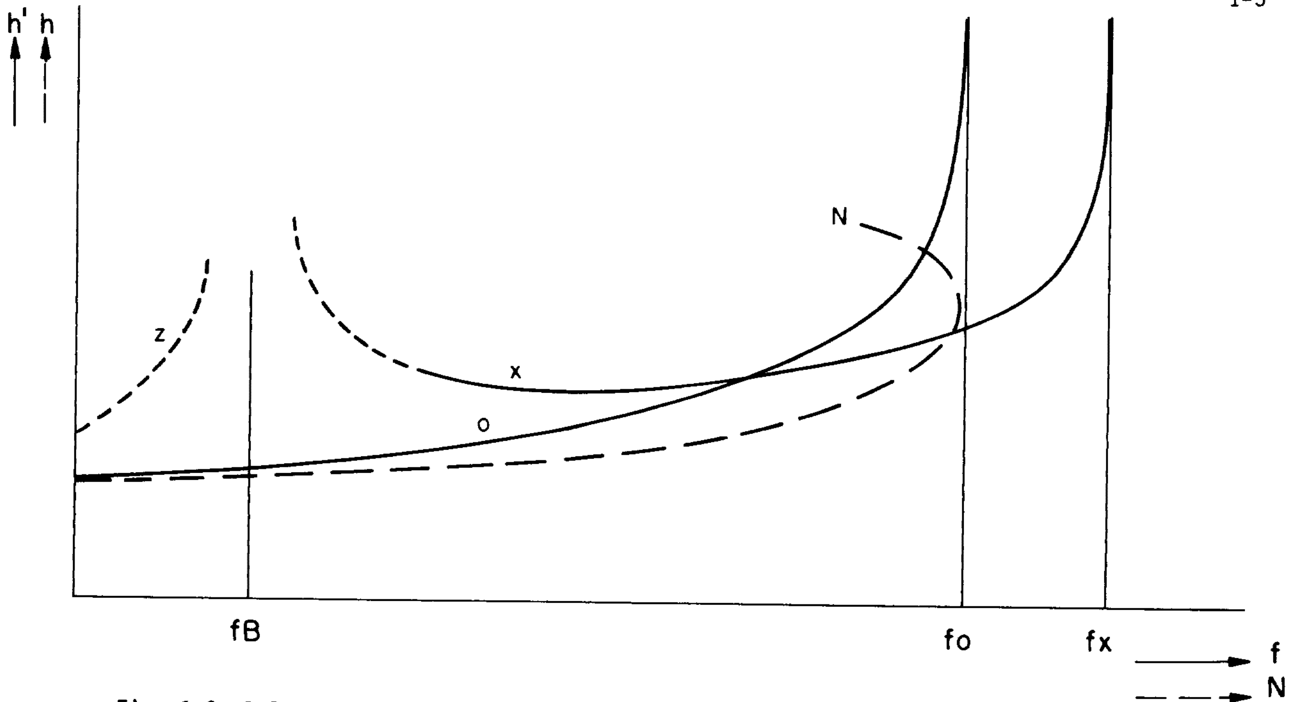

Fig. 1.3 Relations between virtual and true height with magnetic field.
-- electron density distribution — h'f pattern.

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

or $$fN/MHz = 8.98 \cdot 10^{-6}\ (N/m^{-3})^{1/2} \qquad (1.2)$$

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

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

In these equations the unit of magnetic induction is the Gauss (Gs). The corresponding MKS unit is the Tesla (T). $1T = 10^4 Gs$.

Note B and fB decrease with increase in height, h, above the surface. The gyrofrequency fB is the natural resonance frequency of the electrons about a magnetic field of strength B.

The value of fB can be calculated from the local ground value, fBo, using the inverse cube variation with height

$$fB = fBo \left(\frac{r_o + h}{r_o}\right)^{-3} \doteqdot fBo\left(1 - \frac{3h}{r_o}\right)$$

where r_o is the local radius of the earth.

If this is not available, use the dipole approximation (Section 14.32). By convention, h = 100 km is used for E layer, h = 300 km for F layer, h = 200 km when one value is used for both.

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

$$fx^2 - fxfB = fo^2 \qquad (1.5)$$

giving the well known rule

$$fx - fo \doteqdot fB/2 \qquad (1.6)$$

which holds provided fo >> fB;

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

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

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.

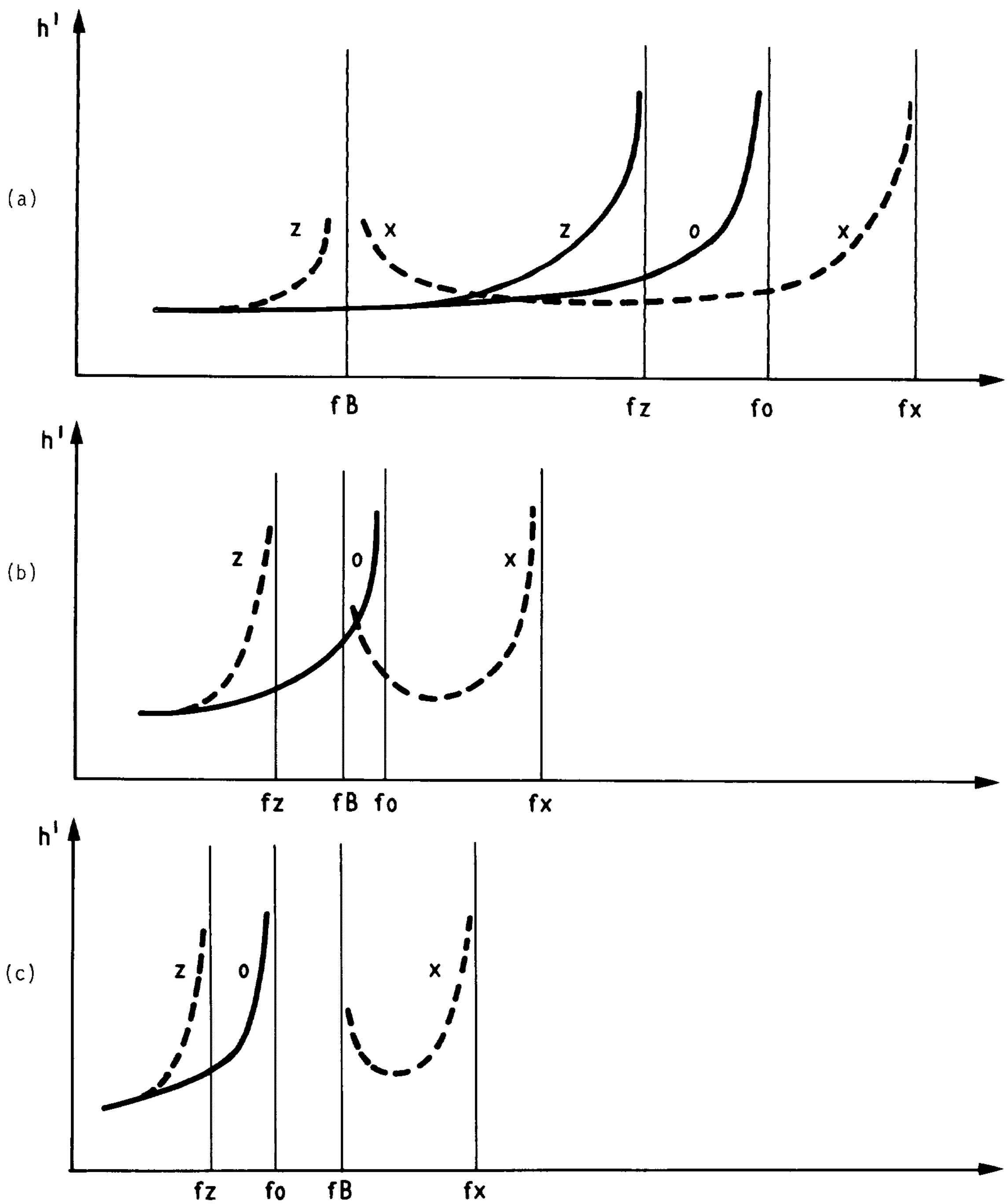

Fig. 1.4 Pattern of o- x- and z-mode traces as fo changes
(a) fo>>fB. (b) fo ≑ fB. (c) fo<fB.

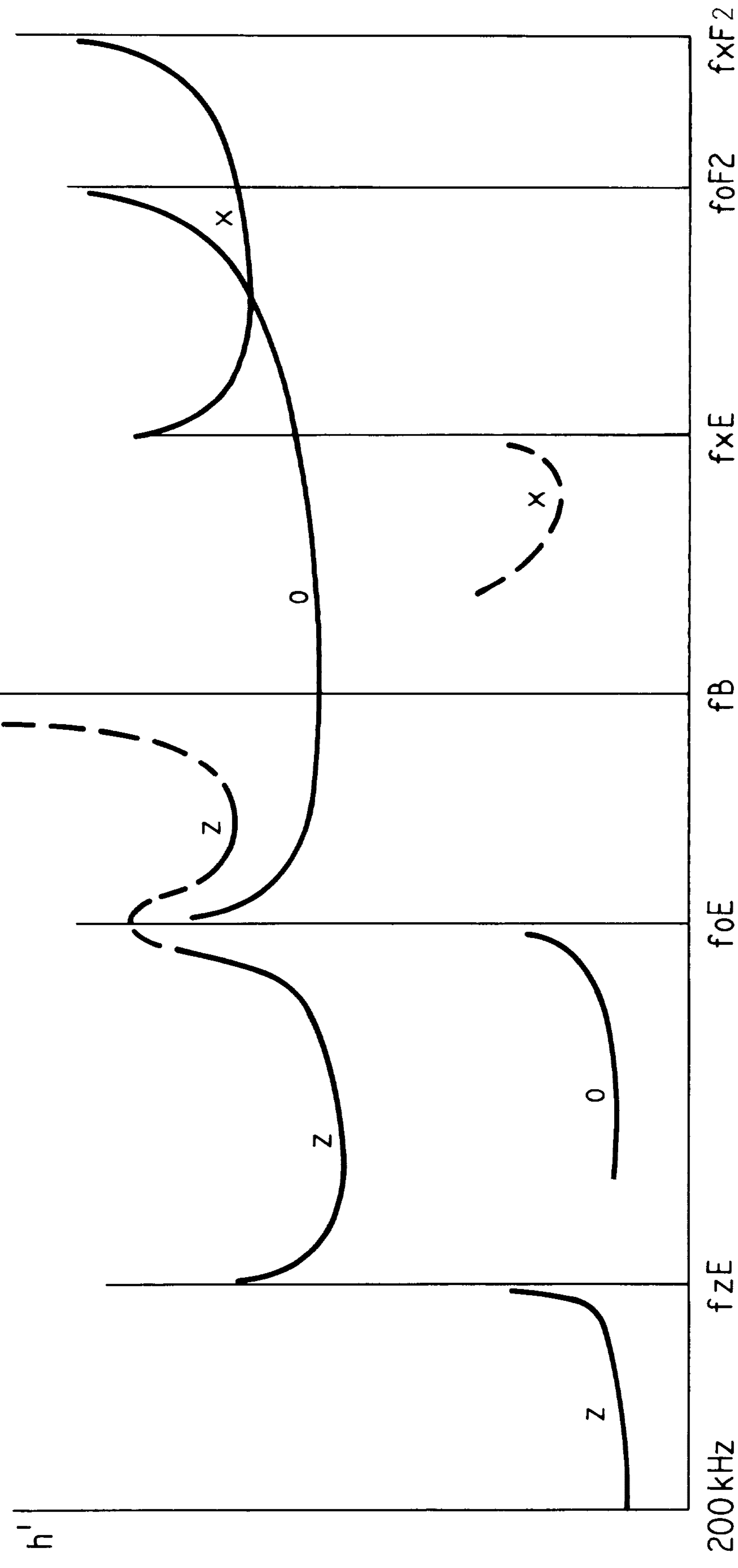

Fig. 1.5 Low frequency ionogram at night, normal E and F traces. No Es. Parts which are usually not seen shown dashed.

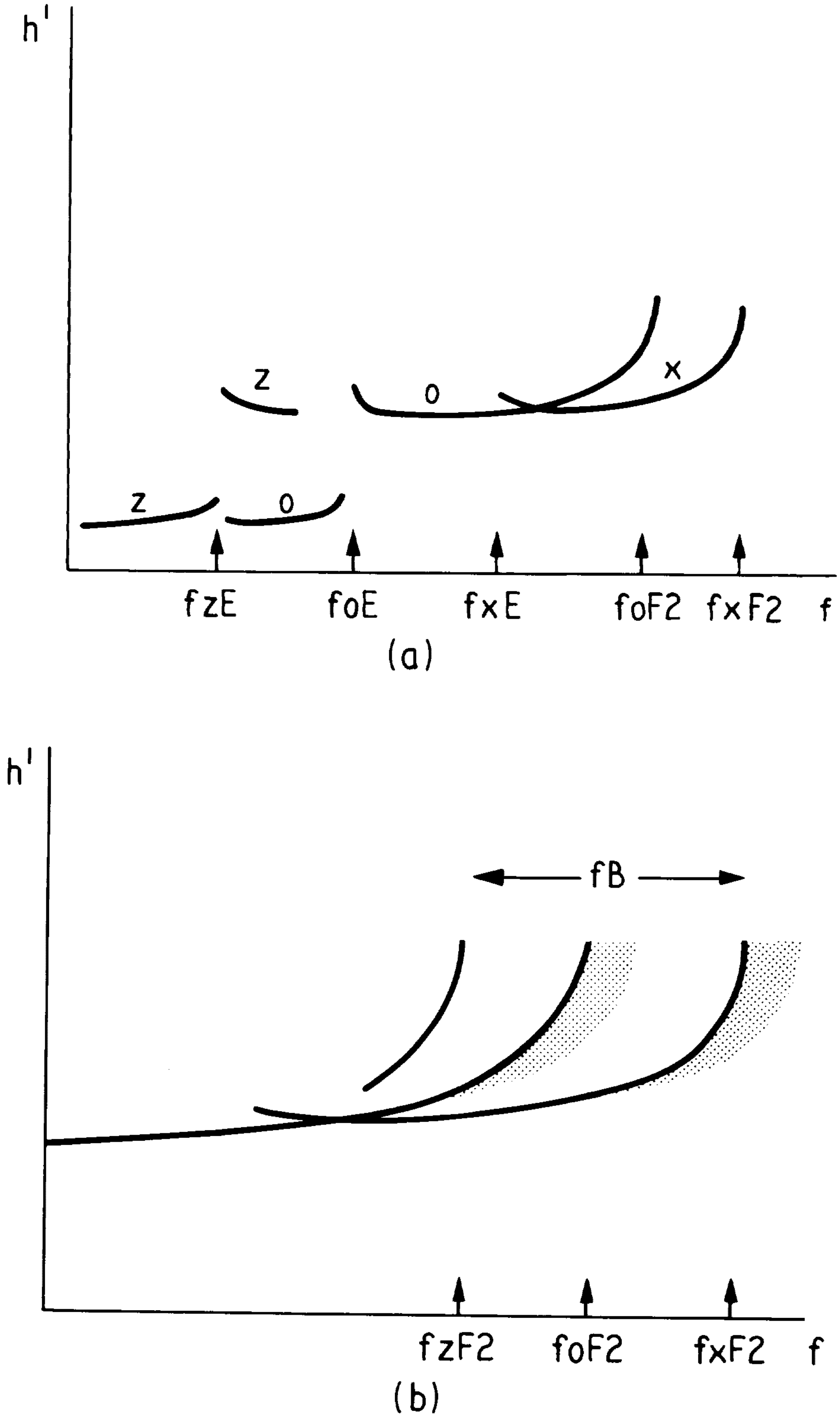

Fig. 1.6 z mode
(a) due to coupling
(b) due to scattering
(Note z trace is not scattered in (b)).

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 (Figs. 1.5, 1.6) 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 [A33I, Figs. 23, 24; A34F, Fig. 25], [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. 2.5) 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].

z-mode echoes are relatively common at observatories where the magnetic dip is greater than 65°. The difficulty of distinguishing a z-o mode pair from an o-x mode pair can be minimized using the following criteria:

(a) Interpolation from the sequence of ionograms between times when the components can be identified positively.

(b) The F layer z traces are better defined and show less spread than the corresponding o traces and are often weaker.

(c) The x trace is usually missing or, at best, is significantly weakened for about 0.5MHz above the gyrofrequency and not received below the gyrofrequency. Thus, x-mode critical frequencies are seldom observed below fB + 0.5MHz.

(d) When two critical frequencies occur below the gyrofrequency they must be a z-o pair.

At high magnetic 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.

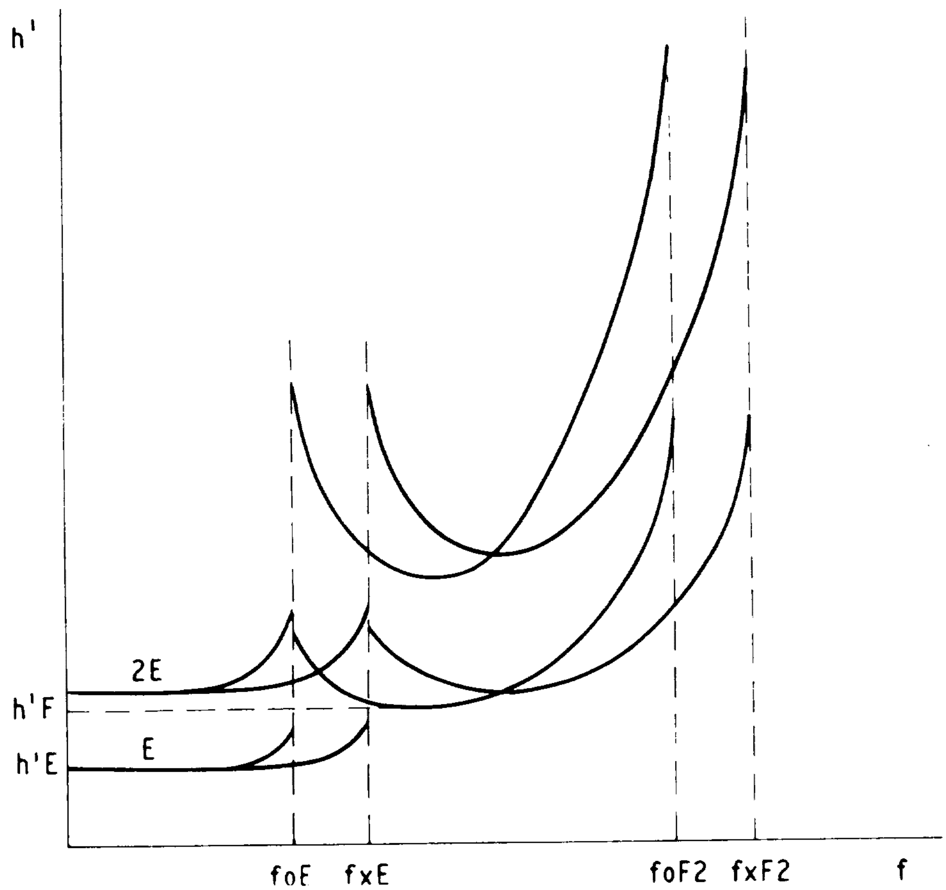

Fig. 1.7 Idealized ionogram when two layers are present.

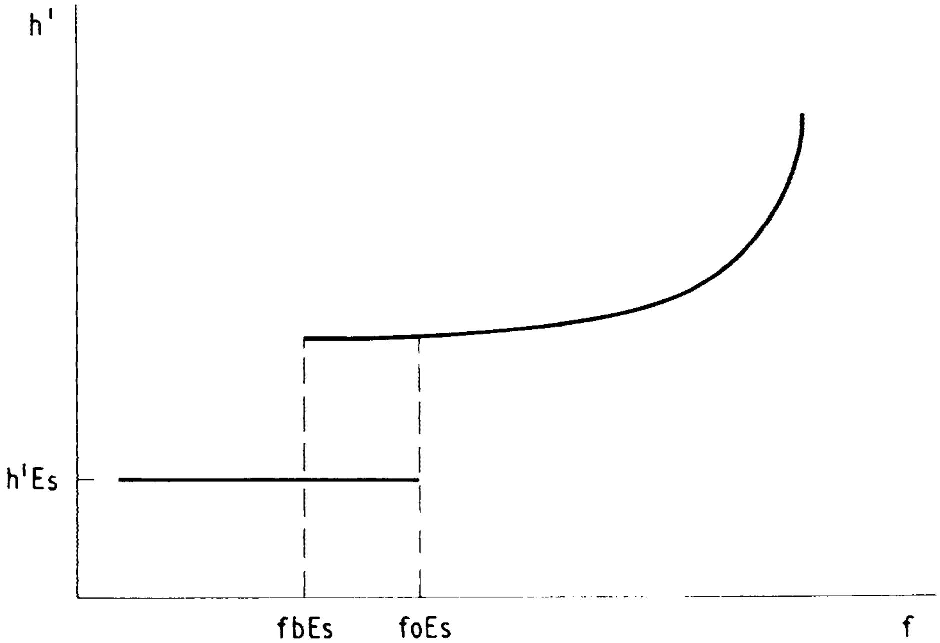

Fig. 1.8 Idealized ordinary ray pattern when a thin layer is present. Note that the quantity corresponding to the critical frequency of a thick layer always lies between foEs and fbEs. (Section 1.07(c))

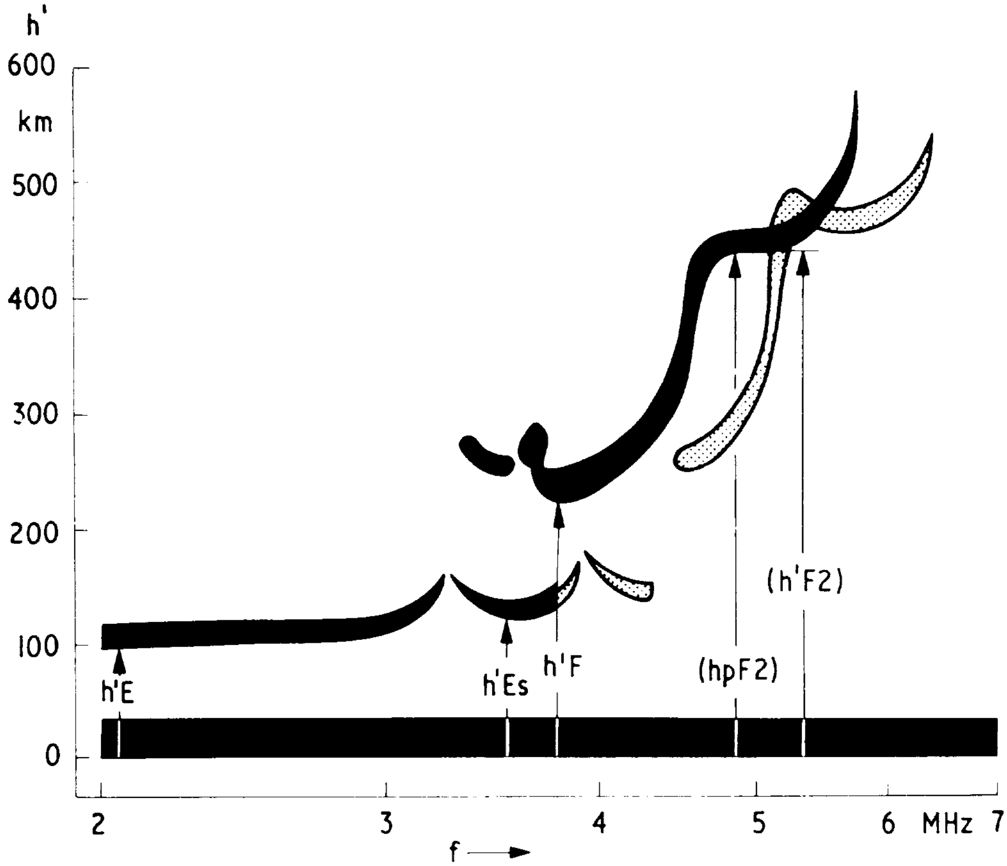

Fig. 1.9(a) Typical day time ionogram with minimum virtual heights h'E, h'Es, h'F, h'F2, and the "parabolic height" h_pF2. These are all read from the o trace (black).

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.

Ionograms frequently show multiple and mixed reflections.

A multiple reflection is the name given to a trace which has been reflected from the ionosphere more than once. An echo which results from two reflections from the same layer, with an intermediate reflection from the ground, is called a second order; three reflections give a third order, and so on. Orders as high as fifteen or more occasionally occur when absorption is extremely low. These very high orders are still being reflected between the ground and the ionosphere after a time greater than that of the time base period and consequently appear on the ionogram. Fig. 1.9(b) shows a typical example of these 'round-the-time-base' traces, orders 8 to 11 are visible.

It is possible for mixed reflections between the E and F layers to occur when sporadic E is present. The most common of these is a second order reflection from the top of a sporadic E layer - the M reflection at a height (2h'F-h'Es). The mixed mode F reflection followed by Es reflection, or vice versa, are also common at a height (h'F + h'Es). Both are shown in Fig. 1.9(c). The M reflection often gives a stronger trace than the 2F normal mode when absorption is present, as it has only passed through the absorbing D region twice instead of four times. Higher multiples also occur and can be easily identified by noting that the M and N traces are a constant distance (h'Es) from the 2F and 1F traces, respectively. Higher modes 2F + E, 3F - E, etc., are identified similarly. A typical ionogram showing E, F and mixed mode multiple reflection is shown in Fig. 1.9(d) together with the mode identifications.

Under normal circumstances, M and N reflections are not scaled but can be used occasionally to give a numerical value of foF2 when the layer is tilted so that the normal F traces are missing.

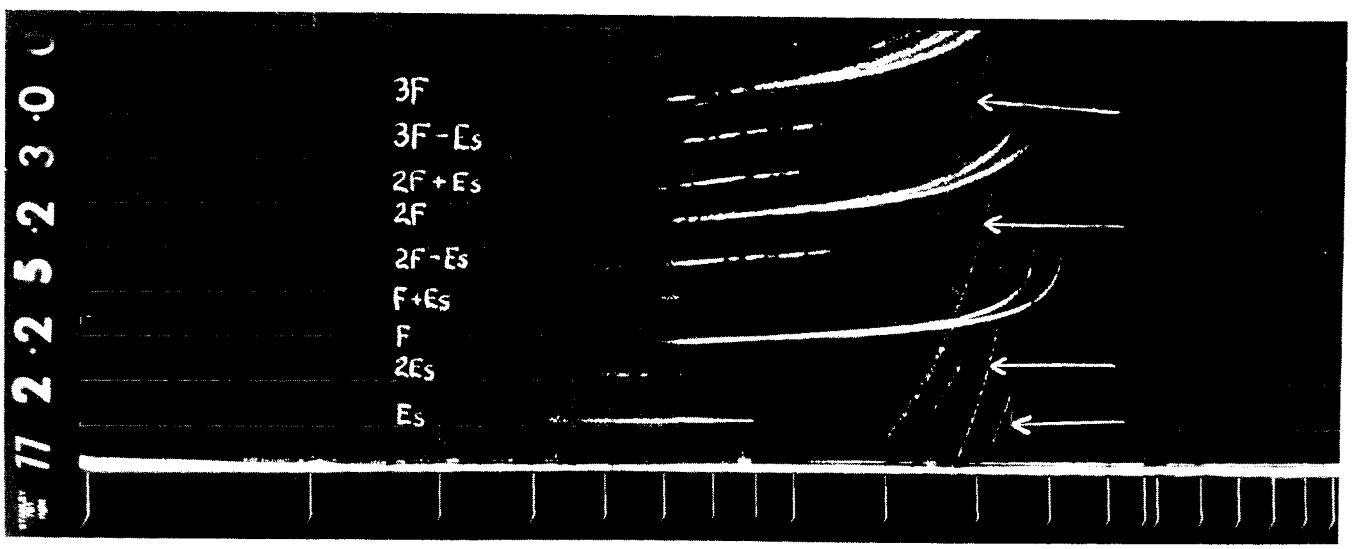

Fig. 1.9(b) Ionogram showing very high order F region reflections, also multiple reflections. Arrows indicate 'round-the-time-base' traces.

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(a).

The following definitions, selection rules and measurement conventions can be applied to any magneto-electronic 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 height.

(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.

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

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

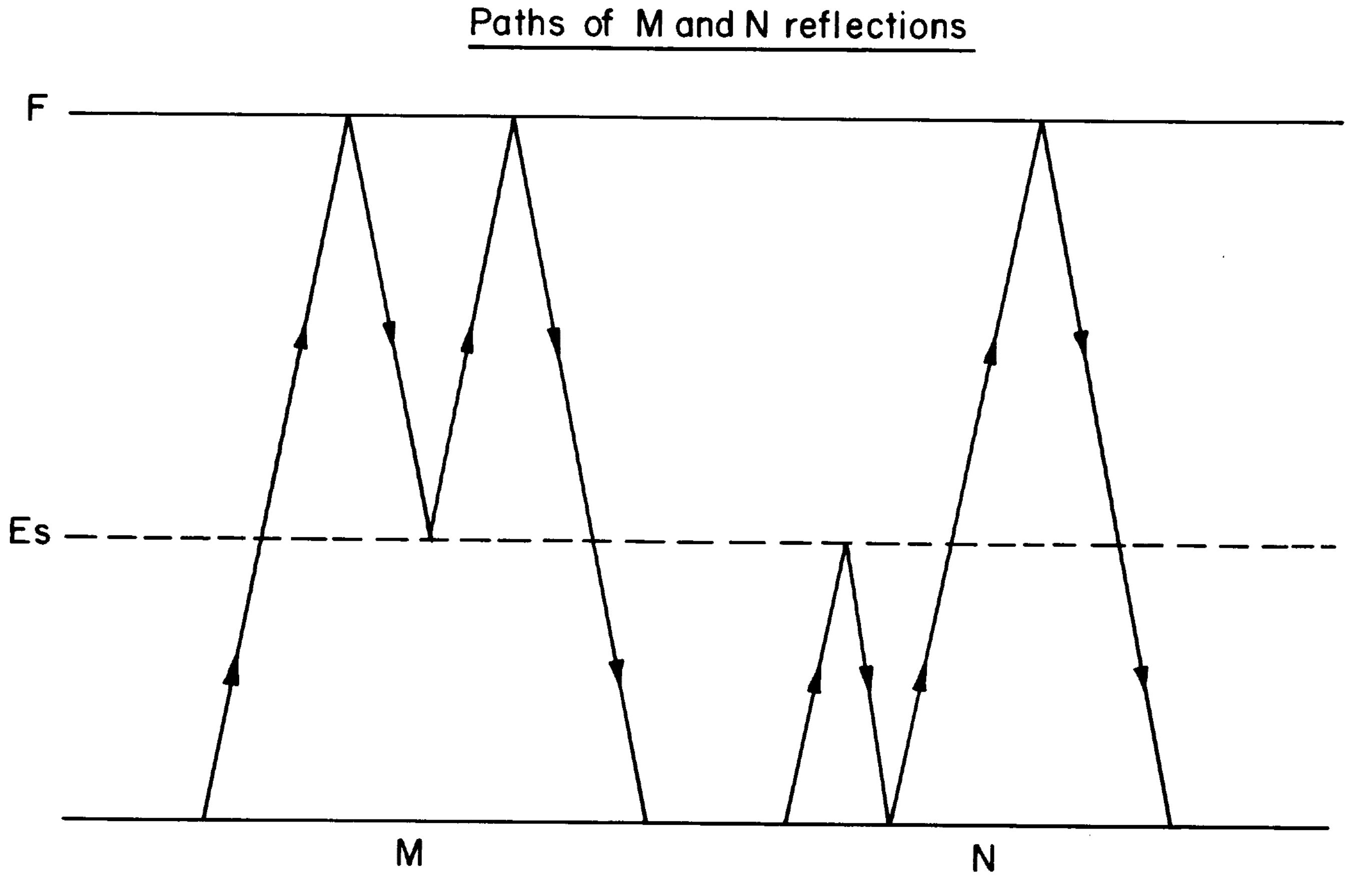

Fig. 1.9(c) Virtual height of M reflection 2F-Es, N reflection F + Es.

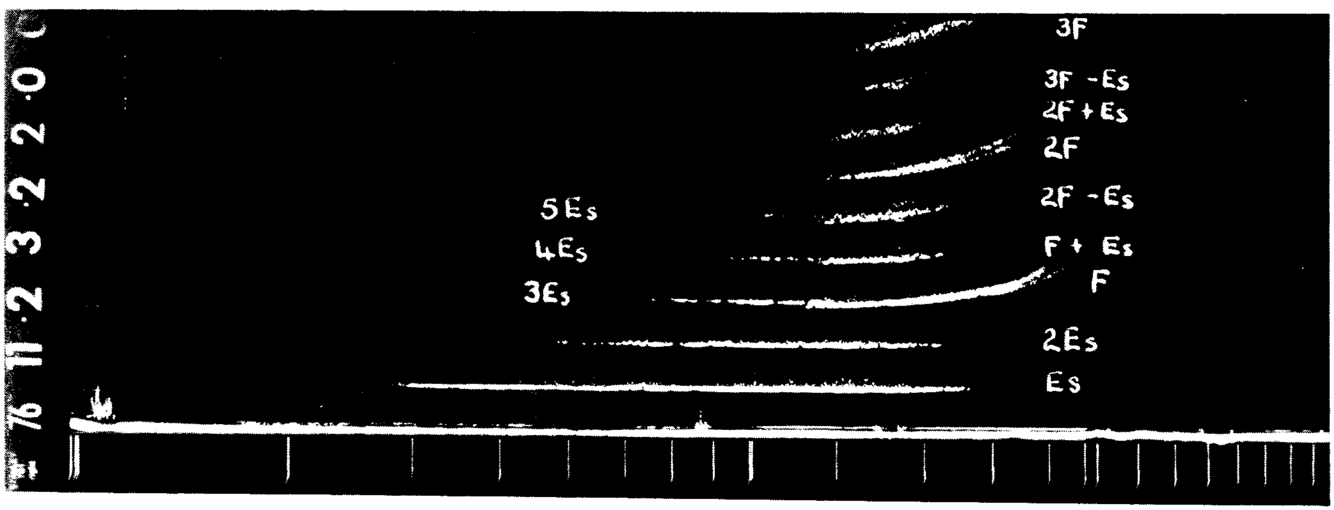

Fig. 1.9(d) Ionogram showing multiple reflections. Note 3Es is superposed on 1F as is 4Es on (F + Es).

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.

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 1.41).

CCIR* $\quad hpF2 = -176 + 1490/M(3000)F2 \qquad (1.9)$

40°N-40°S** $\quad hpF2 = -225 + 1650/M(3000)F2 \qquad (1.10)$

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.***

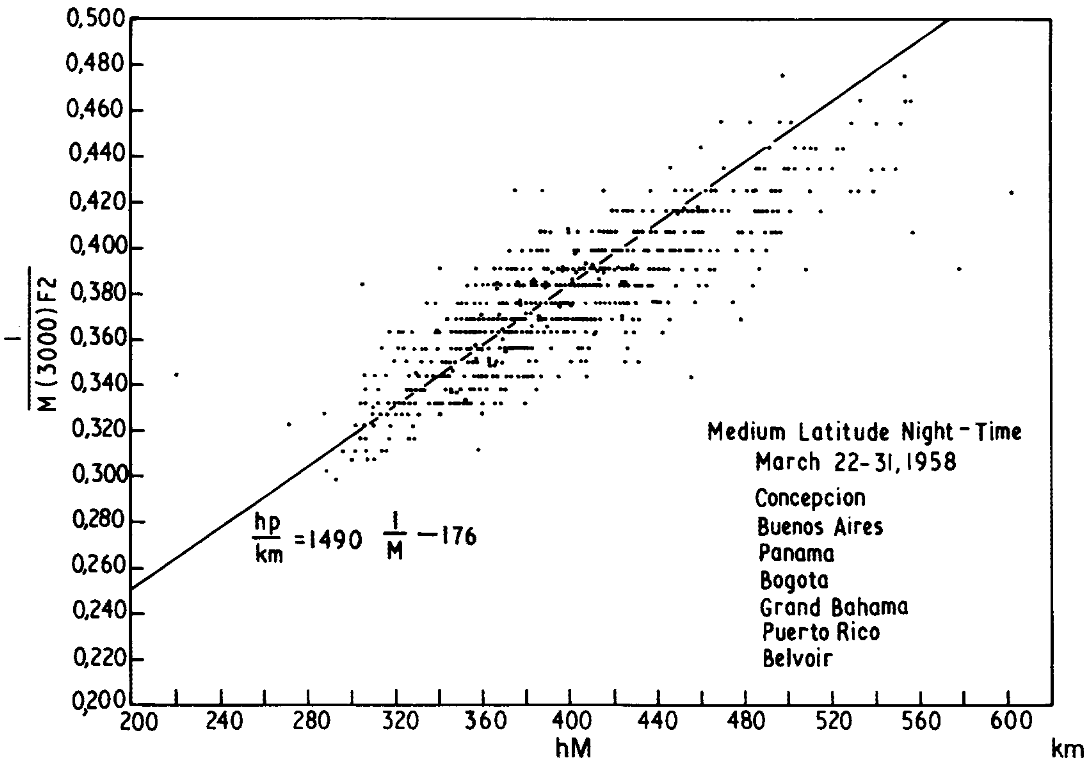

Fig. 1.10 Correlation between 1/M(3000)F2 and hM(km) for night hours, medium latitude.

* 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

1.09. 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 CCIR.

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

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 150 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 extra-ordinary 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. By convention entries of foE are omitted at hours when normal E is not normally observed, which is usually because foE is below the minimum frequency of the ionosonde.

1.15 Particle E: The ionogram shows the presence of a thick layer in the E region with a critical frequency significantly greater than that of normal E (1.14). In most cases particle E can be attributed to direct or indirect ionization by particle activity. Particle E always causes group retardation in any traces from higher layers, and this retardation near foE is sufficient to identify the critical frequency. Traditionally this trace was called night E as the critical frequency of the normal E was below the lowest recordable frequency at night. Fortunately, in almost all practical cases, the difference between the critical frequency of the particle E and of normal E is large -- much larger than the differences between foE and foE2 (1.16). Thus at night when foE for normal E is between 300 kHz and 500 kHz particle E usually gives foE above 1MHz -- often up to about 5 MHz. Particle E is often preceded or followed by retardation type Es (Es-r) or auroral type Es (Es-a); in such cases foE usually varies rapidly with time. When particle E is present, as indicated by retardation of the traces from higher layers or by the character of the E trace (see section 3.2 letter K and section 4.24) it is identified in the tabulations by descriptive letter K (foE, foEs, fbEs, h'E, h'Es and Es type tables). Note retardation of a higher trace is enough to identify particle E (foE)-K if it obeys the definition given above. Particle E normally blankets normal E but is sometimes seen at greater heights up to about 170 km.

* For explanation of letter symbols see Chapter 3.

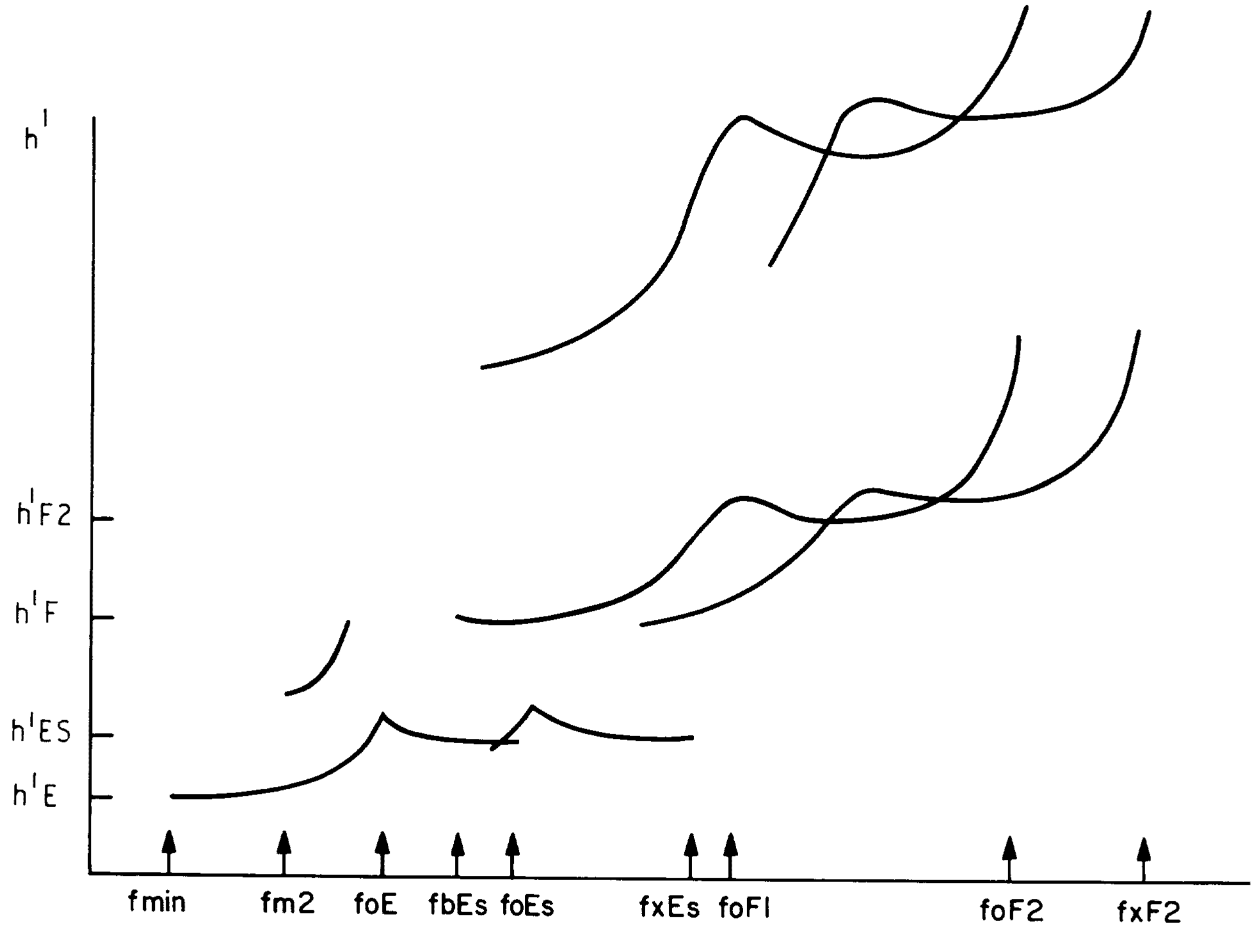

Fig. 1.11 Standard height and frequency parameters.

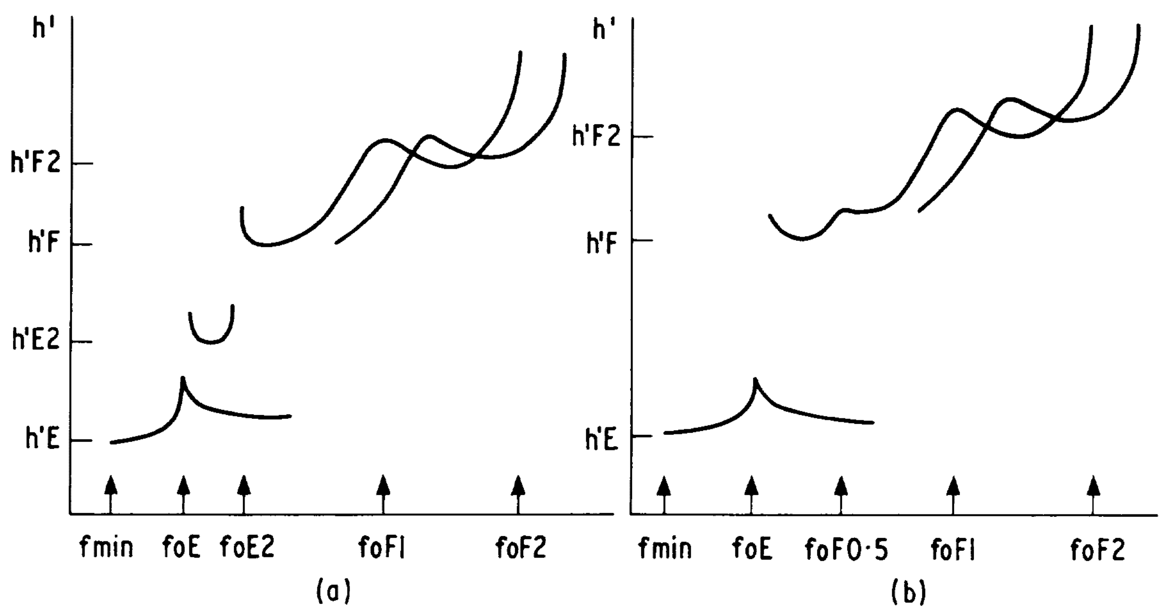

Fig. 1.12 Distinction between E2 and F0.5. In (b) h'F should be written (h'F)UH

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).

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).

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. Spread F rules are given in Section 2-8.

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) which seems to have fallen out of use and may be ignored.

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) With some high sensitivity types of ionosonde fmin seldom shows changes of absorption except during very large events. For such equipments, fm2 should be reduced and circulated instead of or in addition to fmin. Note when fmin is not tabulated, the appropriate value of fmin should always be shown in tables of other parameters when the parameter is below fmin, i.e., . . . 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: 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 foF1.5 (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. See also Section 1.08).

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 foF2.

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. 1.15). 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.

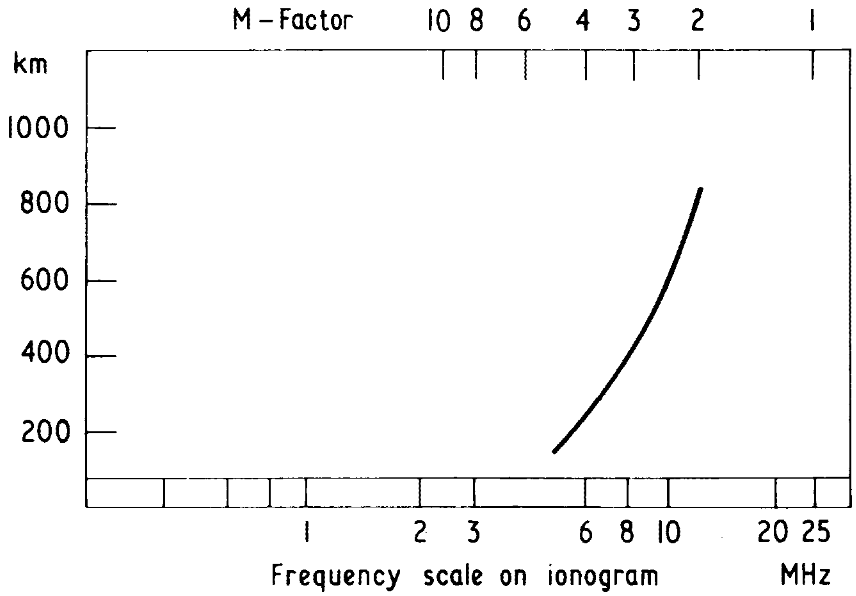

Fig. 1.13 MUF factor slider.

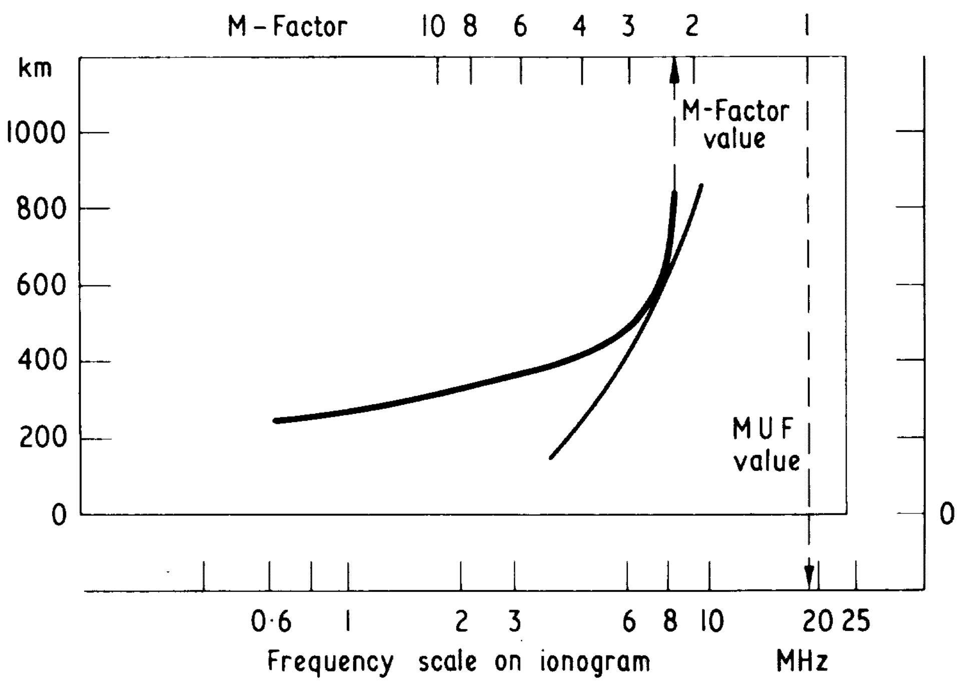

Fig. 1.14 Use of MUF factor slider.

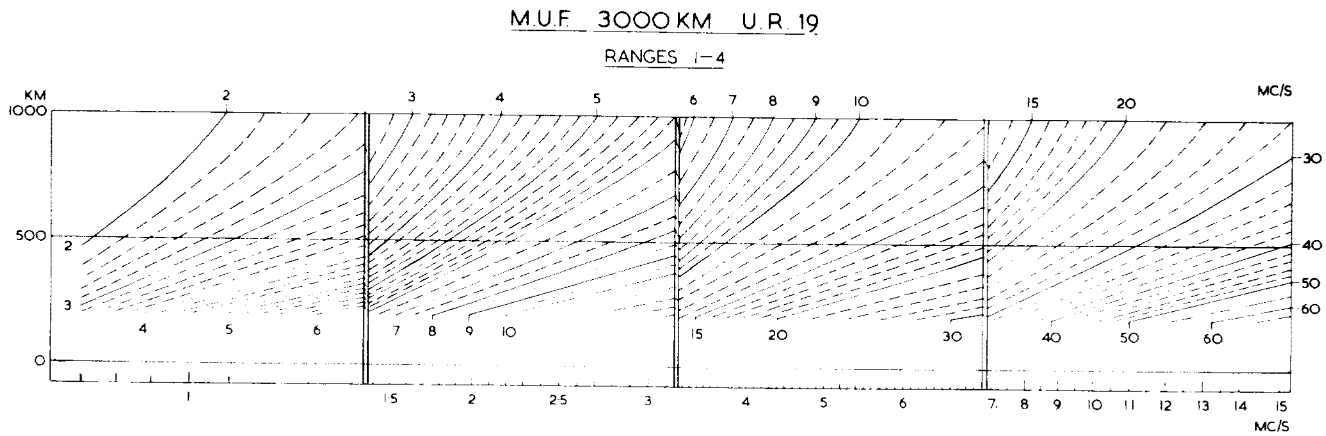

Fig. 1.15 Typical overlay for finding MUF's and MUF factors for ionograms with non-logarithmic frequency scales.

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 (See Section 1.19 and 1.24) are also particularly significant both as an index of the behavior 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.

1.9 Computer Output

Parameters reproduced in computer form are usually identified by the standard characteristic codes given in section 7.3. These may be supplemented or replaced if desired by the corresponding parameters in computer printout form, e.g., FOF2 for foF2, FMIN for fmin, etc. All lower case symbols are replaced by capitals for computer reproduction and are regarded as equivalent to the international conventions. Other use of the capital letter forms is permitted on a voluntary basis.

The use of capitals rather than lower case symbols for Es types was adopted in 1975 because in practice the lower case symbols are often difficult to read on worksheets. The original convention Es-a, Es-c etc. is preferred in texts. It is probable that, as more computers become available with lower case symbols, the parameters in computer form will also revert to the original form.

Originally lower case symbols were devised for Es types so as to avoid confusion with letter symbols which have quite different meanings. This is important to trainees but not important to fully trained operators who easily recognize the different context.

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