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 extra-ordinary-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 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 traces 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, foEs, fbEs or h'Es. 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 pp. 18-26] and other special experiments are also useful. It is recommended that each station builds its own library of difficult records, confirming their interpretation with INAG and draws 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, fbEs or h'Es. (Section 4.83).
(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 reading 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 difference 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. Timing: 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. General: The 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. A numerical value for foF2 should be scaled. The scattered traces are scaled in accordance with the rules of section 2.83.

2.22. Conventions for assigning the level of accuracy: The maximum reading unit Δ has been defined in the table of recommended reading values given above (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 20%, or 5 Δ, whichever is greater, of an observed boundary of 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 20%, or 5 Δ, whichever is greater, a descriptive letter only is tabulated without a numerical value. A descriptive letter used in this context is often termed a replacement letter (See Section 2.3).

The rules for frequencies are summarized in Fig.2.1a.

2.23. Accuracy rules in total range of uncertainty forms: Operators who prefer to consider the total range of uncertainty may use the following rules which are equivalent to those given above.

(a) If the total range of uncertainty does not exceed 4% or 2Δ, whichever is greater, then the numerical value is unqualified.

(b) If the total range of uncertainty exceeds 4% or 2Δ, whichever is greater, but does not exceed 10% or 4Δ, whichever is greater, the value is considered doubtful and the qualifying letter U is used with the most probable value 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 lies within 10% or 3Δ, 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 this value and the appropriate descriptive letter.

(d) When the total range of uncertainty exceeds that in paragraph (b) but is less than 20% or 5Δ, whichever is greater, of an observed boundary of possible positions of the principal echo trace, then this observed limit is tabulated with the qualifying letter D or E, whichever is applicable, and the appropriate descriptive letter.

(e) When the total range of uncertainty exceeds 20% or 5Δ, whichever is greater, a descriptive letter only is tabulated without a numerical value.

The application of these rules to F-region frequency parameters Δ = 0.1 MHz and E-region parameters with Δ = 0.05 MHz are shown graphically in Figs. 2.1 (a) and (b), respectively."

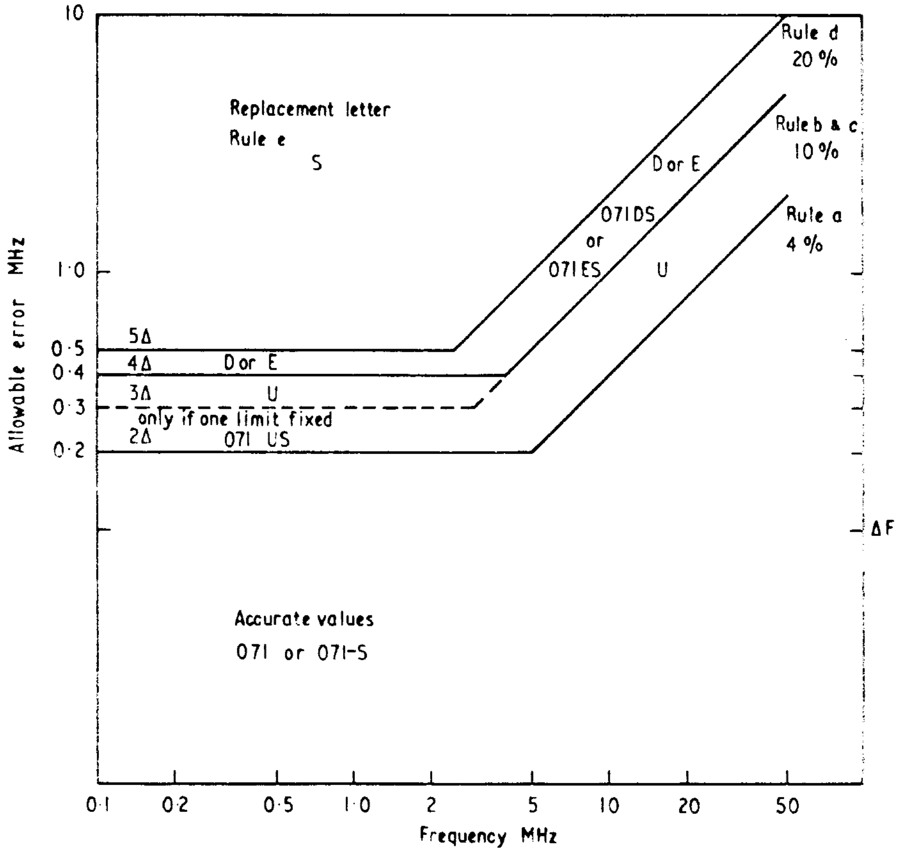


Fig. 2.1a Accuracy rules for F region frequencies Δ = 0.1 MHz in terms of total range of error.

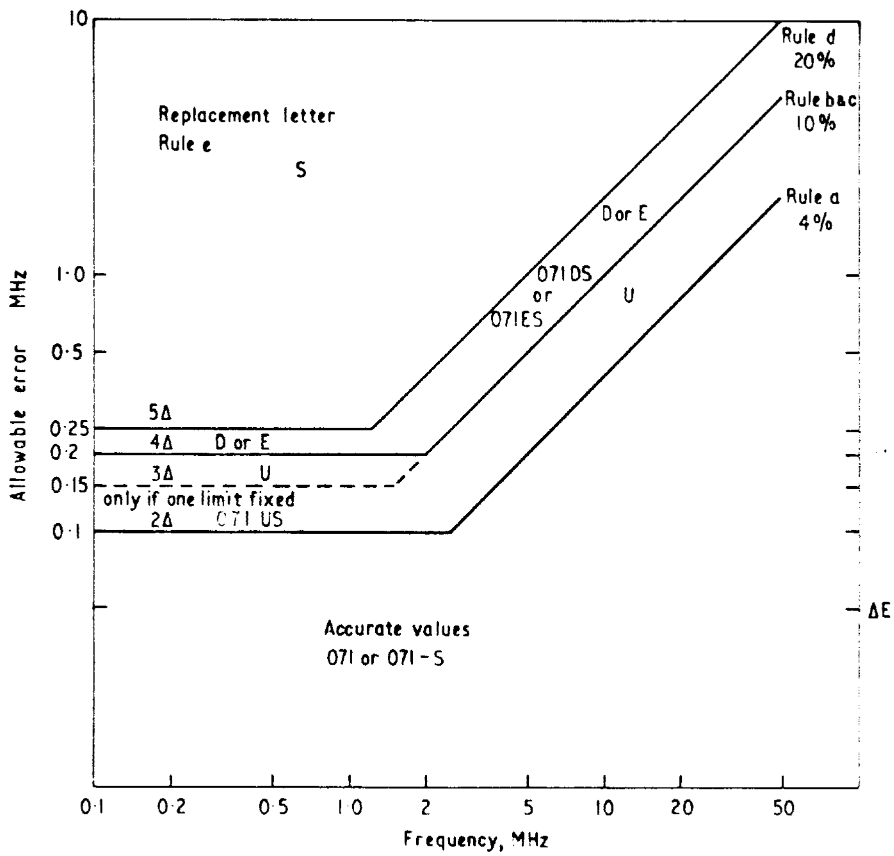


Fig. 2.1b Accuracy rules for E region frequencies Δ = 0.05 MHz in terms of total range of error.

2.24. Miscellaneous Notes

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 (Section 2.8).

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 may be used without qualifying letters in two ways:

(a) to denote the presence of a phenomenon which does not affect the scaling accuracy.

(b) to replace a numerical value when no measurement within the accuracy limits is impossible.

In case (b) the descriptive letter is called a replacement letter.

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 frequency spread.
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 - Particle E layer present.
L - Measurement influenced or impossible because the trace has no sufficiently definite cusp between layers. Mixed spread F present (see section 2.8.)

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.

P - Man-made perturbations of the observed parameter; or spur type spread F present (see section 2.8).

Q - Range spread present. (See also Section 2.8)
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 - Lacuna phenomena (also Section 2.75) or severe F-layer tilt present.
Z - Qualifying letter: Measurement deduced from the third magneto-electronic component.
Descriptive letter: Third magneto-electronic component present.

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

The following descriptive letters are used to show spread F types where spread F types are tabulated in the Standard F tables. They then take precedence over all other letters. (See section 3.2, p. 74).

F - Frequency spread present. foF2 and fxI tables only.
L - Mixed spread present. foF2 and fxI tables only.
P - Polar spur.fxI table only.
Q - Range spread present. h'F, h'F2 tables. Rarely in foF2 or fxI tables.

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.

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.

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(a). Extrapolation in height is also allowed, Figs. 2.3, 2.4.

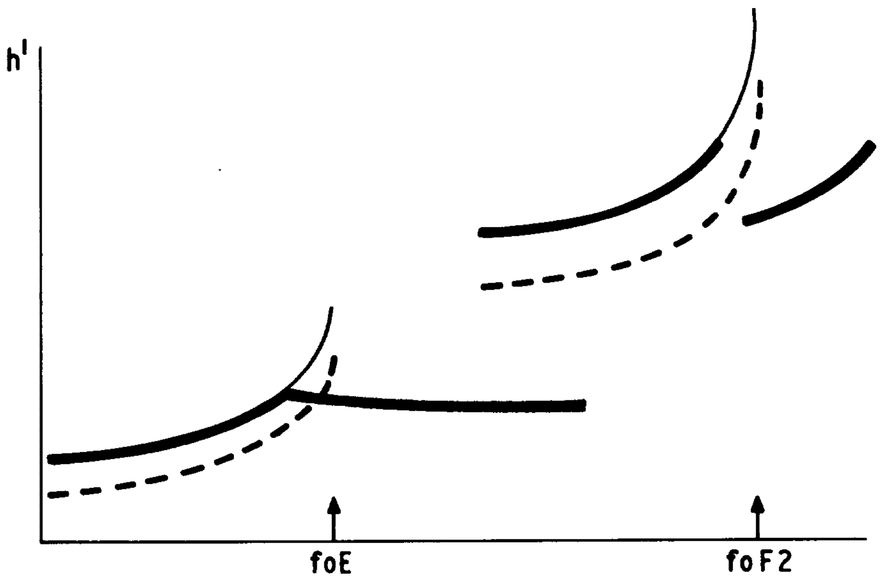


Fig. 2.2a Extrapolation to a critical frequency.

The shape of the normal trace (---) for similar conditions is traced and moved to fit the observed trace (thin line in Fig. 2.2a. By this means the ionogram traces (shown thick) are extrapolated to give the critical frequency.

Use accuracy rules to decide if qualifying letter needed. (section 2.2)
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.

The range of uncertainty due to extrapolation extends from the end of the observed trace to the deduced value of the critical frequency. This has the merits of simplicity and long use. However, this rule restricts the number of numerical values allowed by the accuracy rules. The convention shown in Fig. 2.2b is also permitted. This can be stated: The ranges of uncertainty allowed by the accuracy rules are to be compared with the ranges between the least and largest value of critical frequency permitted by the extrapolation process.

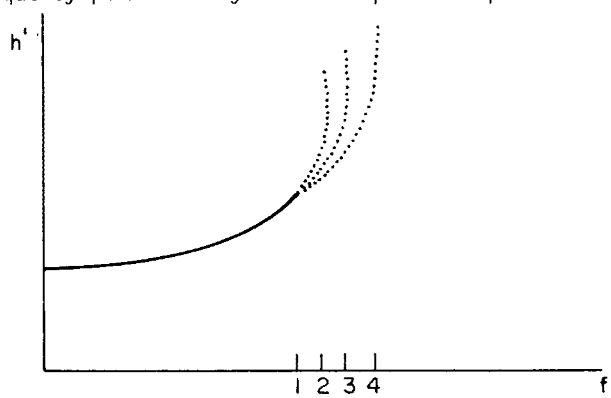


Fig. 2.2b Range of uncertainty when extrapolating to a critical frequency

The observed trace ends at frequency 1.
The most probable trace gives a critical frequency at frequency 3.
The least possible value of the critical frequency is 2.
The greatest possible value of the critical frequency is 4. The observed uncertainties, 2-3 and 3-4, or 2-3 are compared with the allowable uncertainties given in section 2.22 or 2.23 respectively, e.g., if 2-3 is less than Δ, no qualification is needed (rule a).
Note that the range of uncertainty is usually less than the range of extrapolation given by the difference 1-3.

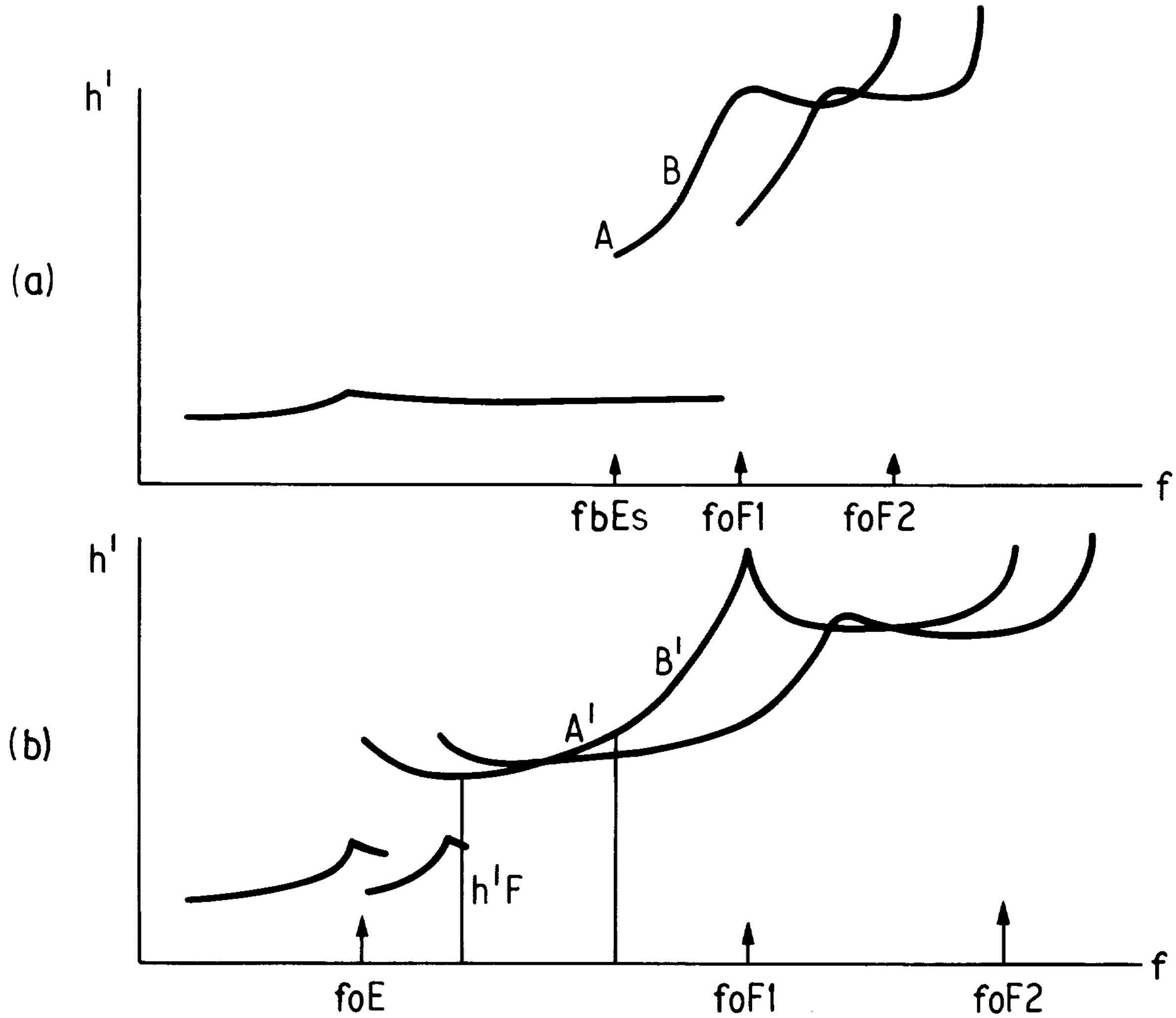


Fig. 2.3 Extrapolation in height

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).

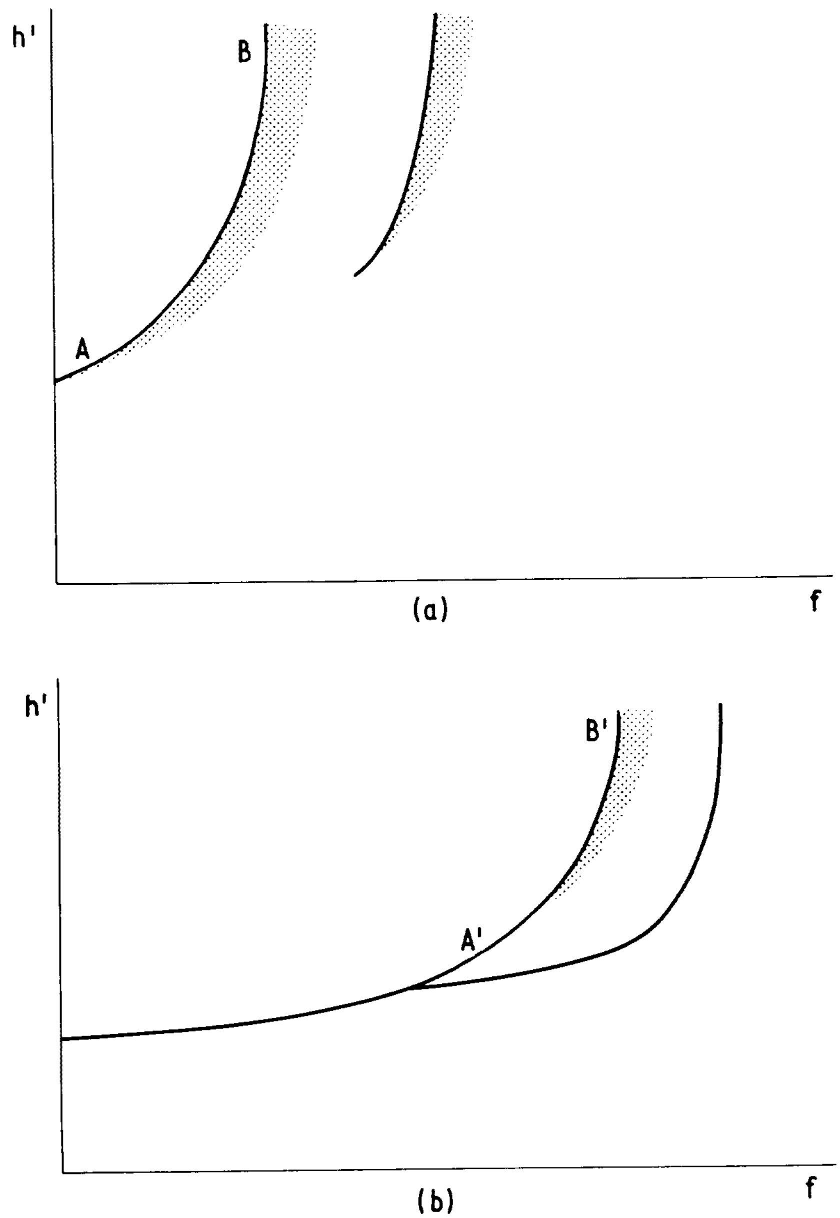


Fig. 2.4 (a)(b). Estimating error in minimum virtual height at night.

(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 if the frequency scale of the ionogram is logarithmic. Otherwise compare heights at A and A' where A' is chosen so that the frequency ratio B/A is equal to that for B'/A'.)

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.

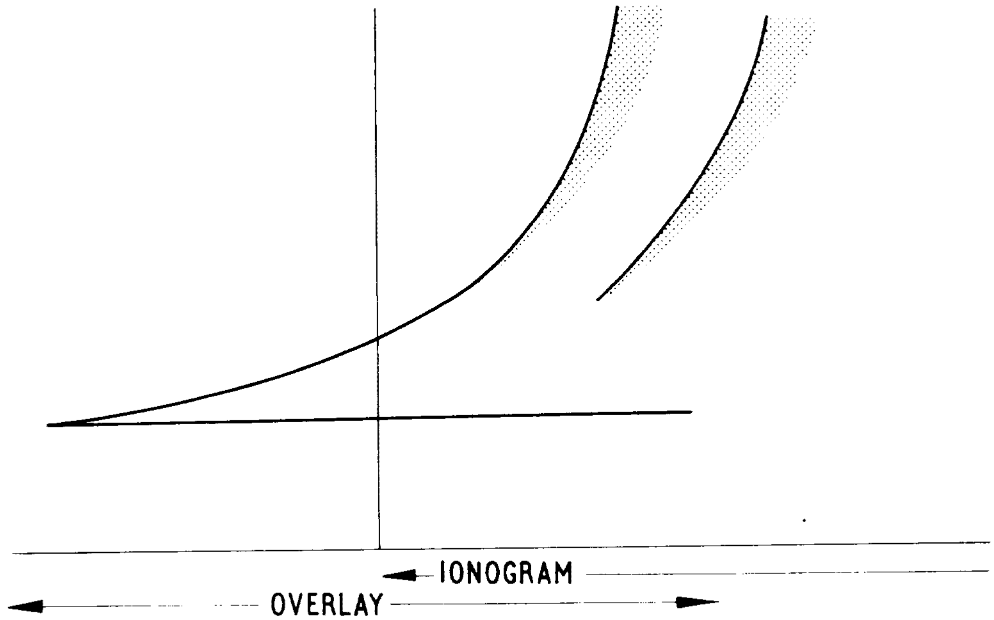


Fig. 2.4 (c). Estimating error in minimum virtual height at night or use of overlay based on Table 10.2

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 [A100I, 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 of Tilted Layers and Oblique or Spread 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 refers to oblique traces except when it is equal to fxF2, 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.

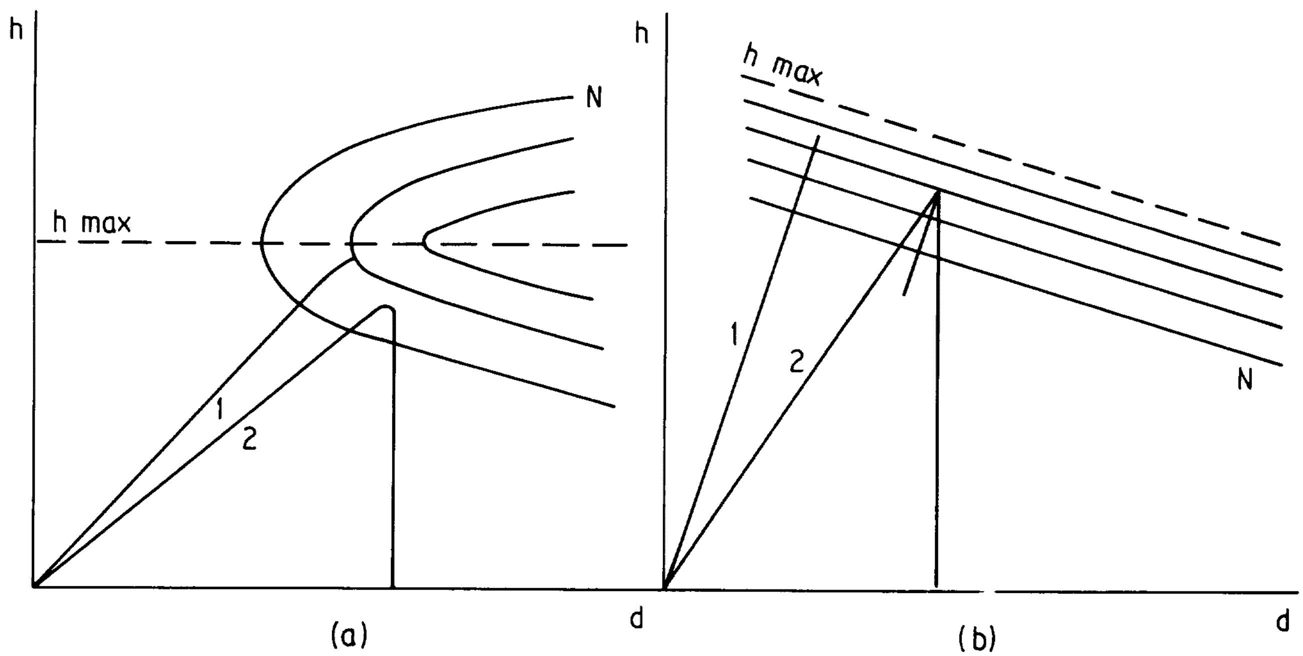
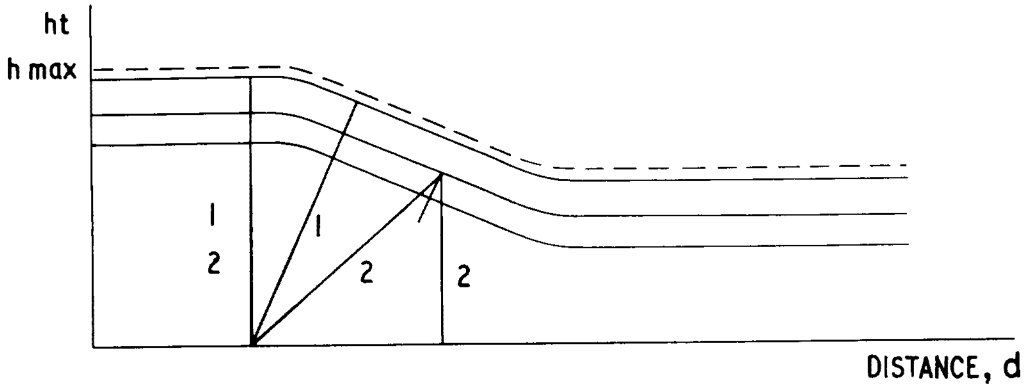


Fig. 2.5 Reflection from tilted layers.

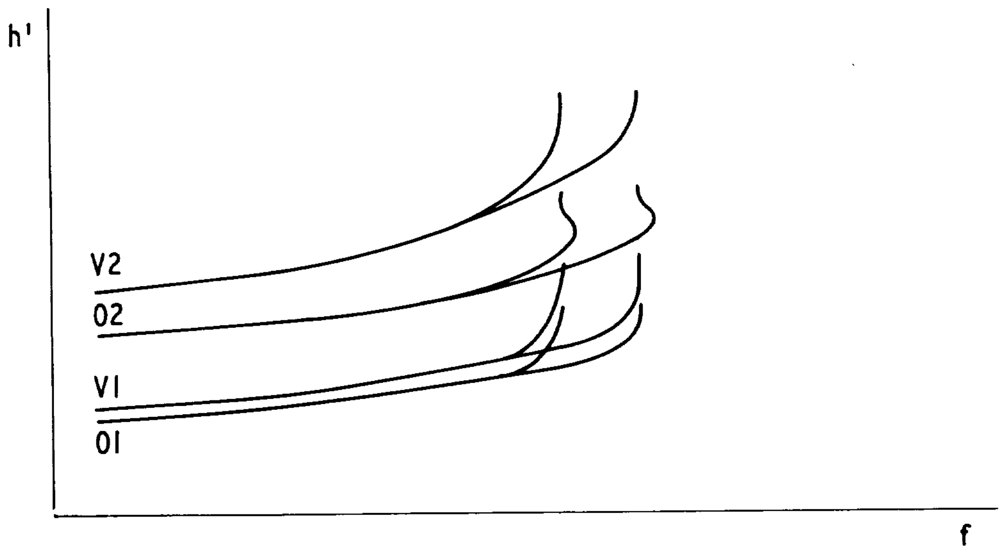
(a) electron density increasing with distance
(b) tilted layer-height changing, electron densities constant

—— 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.



(a)



(b)

Fig. 2.6 Simultaneous vertical and oblique reflection

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

$h'(V2) = 2\ h'(V1);\quad h'(02) \neq 2h'(01)$

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 (See also section 2.74)

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. See also spread F scaling rules in section 2.8.

2.71. Identification of large scale tilt: 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 large 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 5°.

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, and the rules in this section are used. Unless there is positive evidence of the existence of large tilts, they are assumed absent giving the normal analysis rules.

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, $h_2 - 2h_1 \doteq 0$.

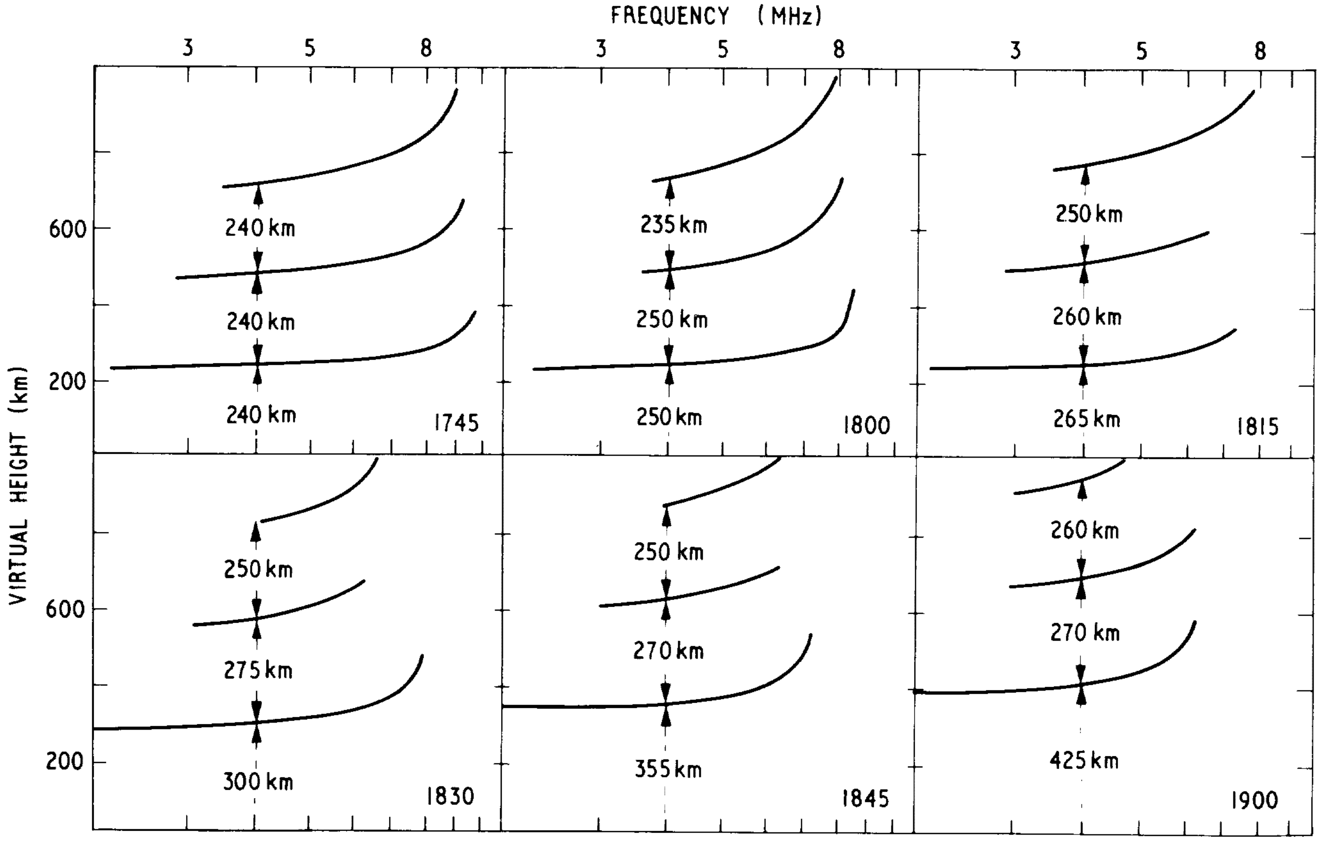


Fig. 2.7 Changes in pattern when large perturbation approaches station.

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).

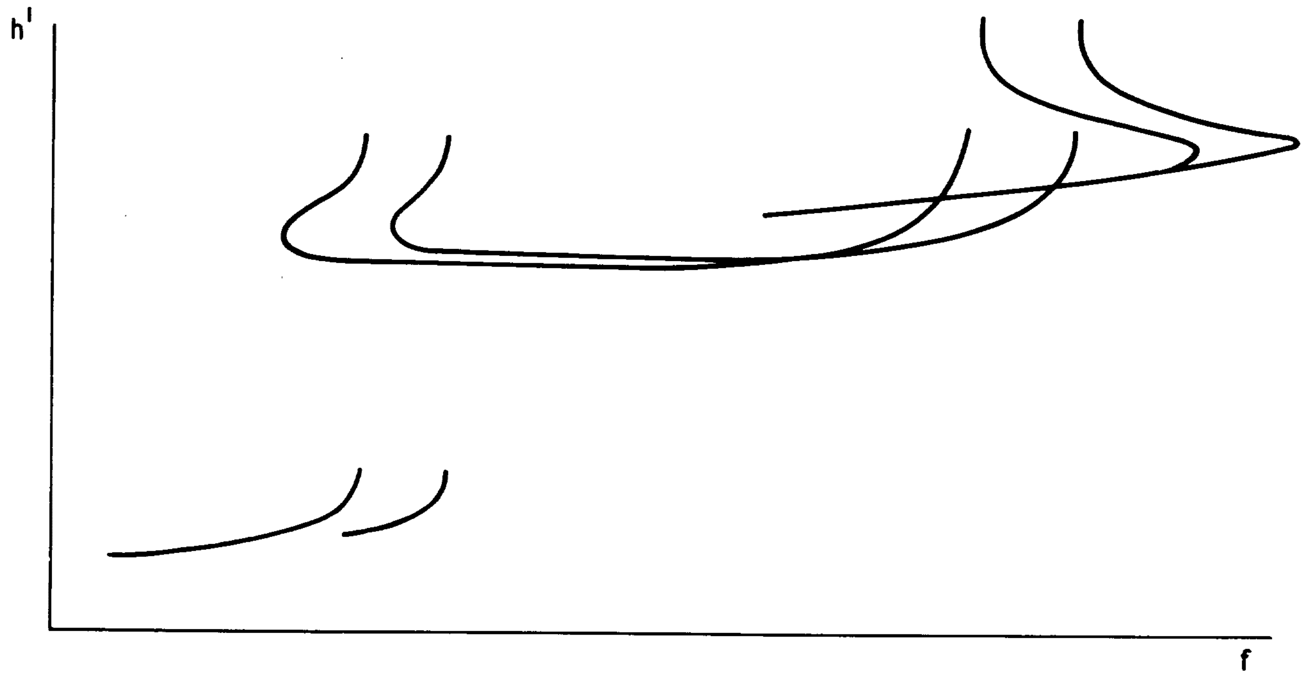


Fig. 2.8 Characteristic traces when tilts are large.

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.

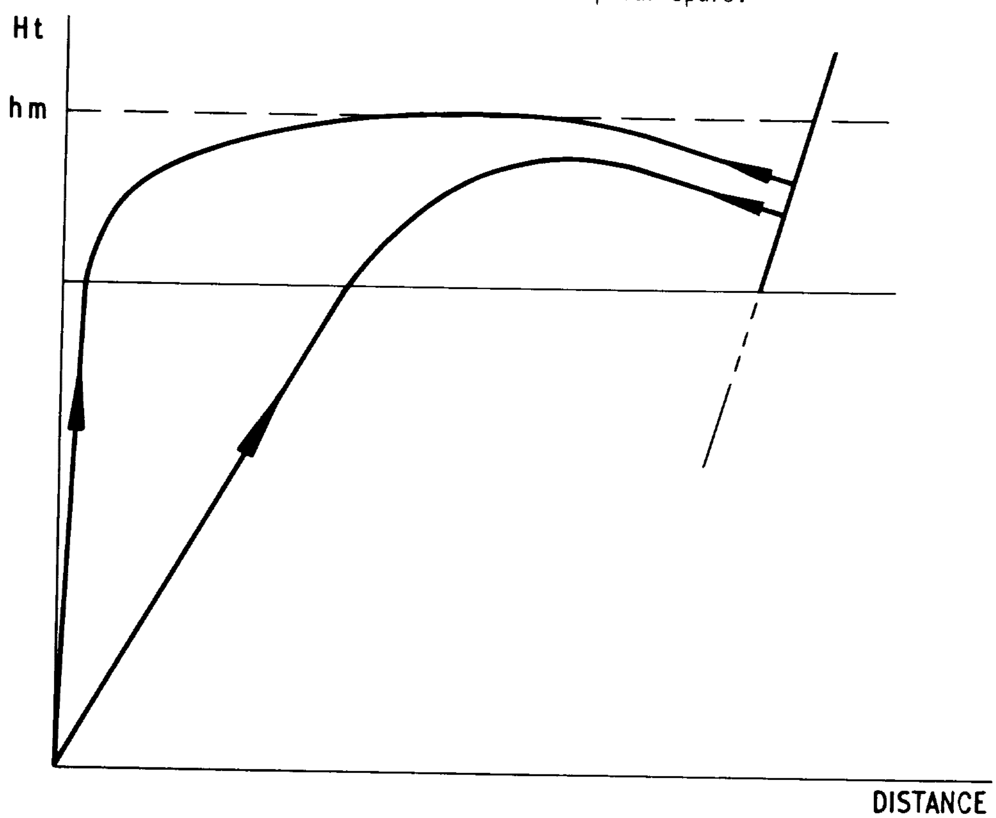


Fig. 2.9 Ray paths reflected from a field aligned irregularity showing high and low angle modes.

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 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 greater virtual heights than those for 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.

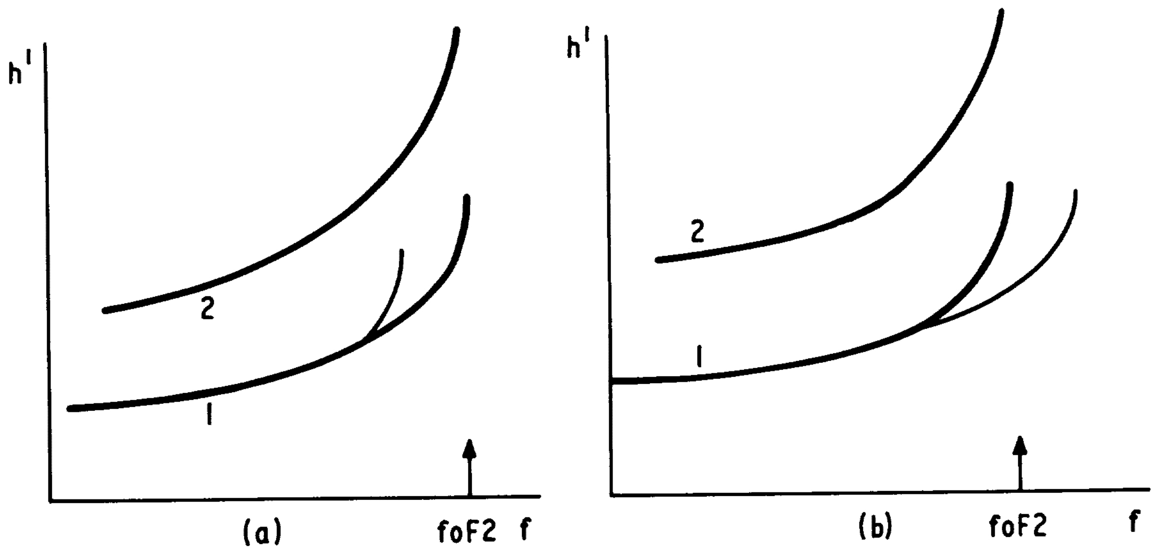


Fig. 2.10 Reflection from a cloud, o mode only

(a) Electron density (N) in cloud less than N in layer.
(b) Electron density (N) in cloud greater 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. Principal traces are normally more solid than those from clouds.

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, provided allowance is made for pulse width as in Fig. 3.14.

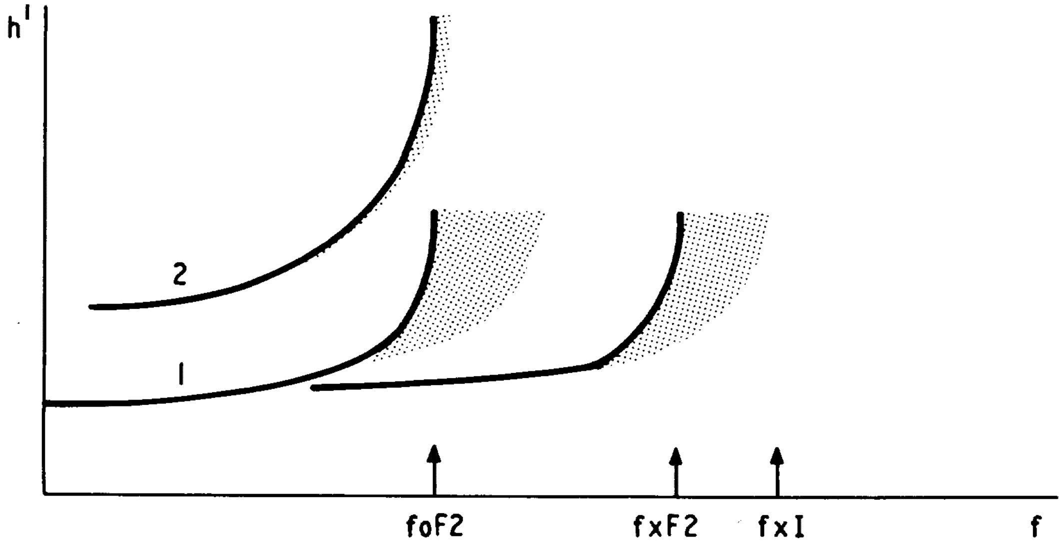


Fig. 2.11 Frequency spread

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 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.

A common cause of small tilts is the presence of travelling ionospheric disturbances. A travelling ionospheric disturbance (TID) is the name attributed to a pressure wave which propagates in the ionosphere. These can occur at any latitude at any time, but their effects on the ionogram are most obvious during daylight particularly when F1 is present.

Figure 2.12 illustrates the sequence of events produced by a TID. This first perturbs the upper F region, then F1 and finally E region. Not all the patterns in the sequence are observed as much depends on the vertical velocity component of the pressure wave and the interval between ionograms. For the sake of clarity, only the o-component is shown.

Although the descriptive letter H is most frequently used to denote the presence of a TID, the preferred scaling of each parameter is given in Table 1. Examples arise in which the o and x traces differ greatly and in such cases the appropriate letter is Y. Thus 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.

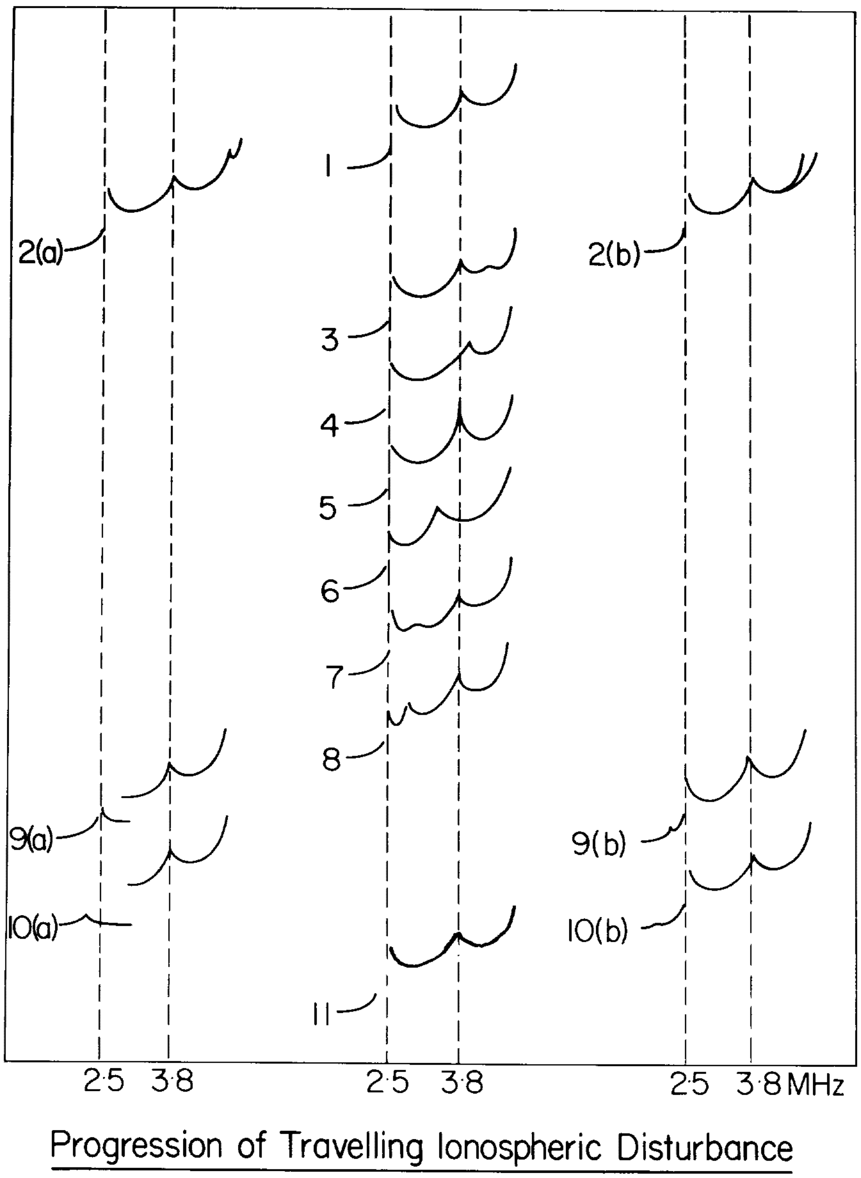


Fig. 2.12 Sequence of ionograms showing the progression of a Travelling Ionospheric Disturbance. Columns A and B show possible alternative patterns.

Table 1

Preferred Scaling of Ionograms shown in Fig. 2-12

	foF2	h'F2	foF1	h'F	foE	h'E
1	052	350	380	220	250	100
2A	056*H	350	380	220	250	100
2B	056*V	350	380	220	250	100
3	052	350*H	380	220	250	100
4	052	350-H	400*H	220	250	100
5	052	350	380-H	220	250	100
6	052	350	350*H	220	250	100
7	052	350	380	220*H	250	100
8	052	350	380	260*H	250	100
9A	052	350	380	220*A	250-A	100
9B	052	350	380	220	250-A	100
10A	052	350	380	220*A	250*A	100
10B	052	350	380	220	250	100*H
11	052	350	380	220	250	100

* Indicates that use of qualifying letter may be necessary.

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. 2.13. 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. 2.14 (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.

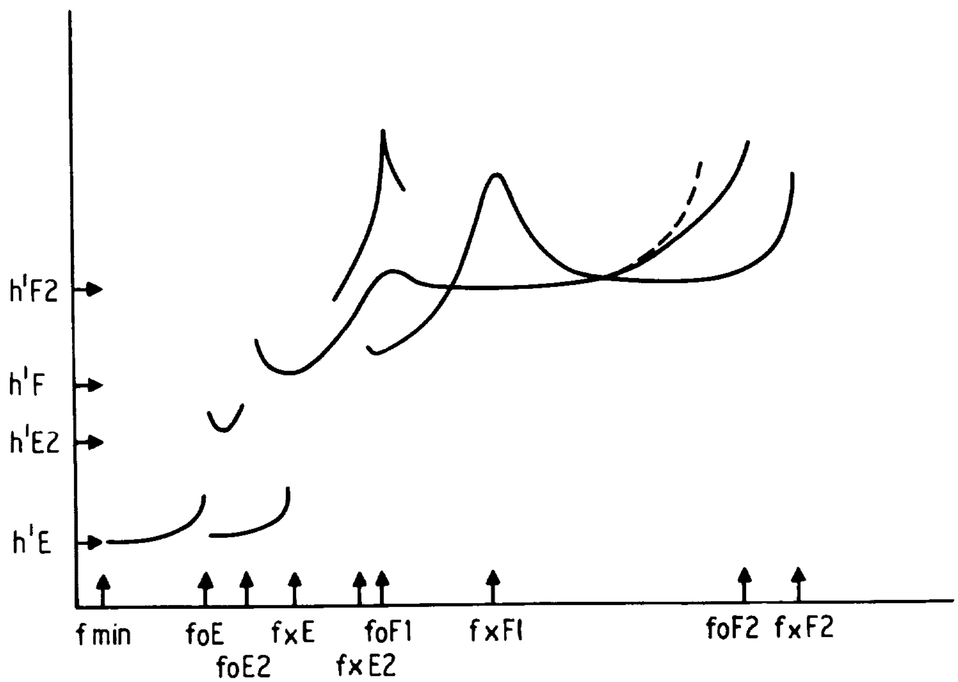


Fig. 2.13 North-South tilts showing distortion of traces

Caption Fig. 2.13.

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

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

2.73. Interpretation when large tilts are present: At high and low latitudes large tilts sometimes exceeding 45° can be quite common at certain times of day. 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 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). These and other examples were collected in a High Latitude Supplement to this Handbook published as UAG-50.

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].

The interpretation of some of these patterns by the use of aircraft is discussed, with examples in section 11.6 p 260-270. These patterns should correspond with those given in the Handbook Supplement on High Latitude Ionograms, Report UAG-50.

2.74. Range spreading: Range spreading, Fig. 2.15, is often 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. 2.16. 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. 2.17.

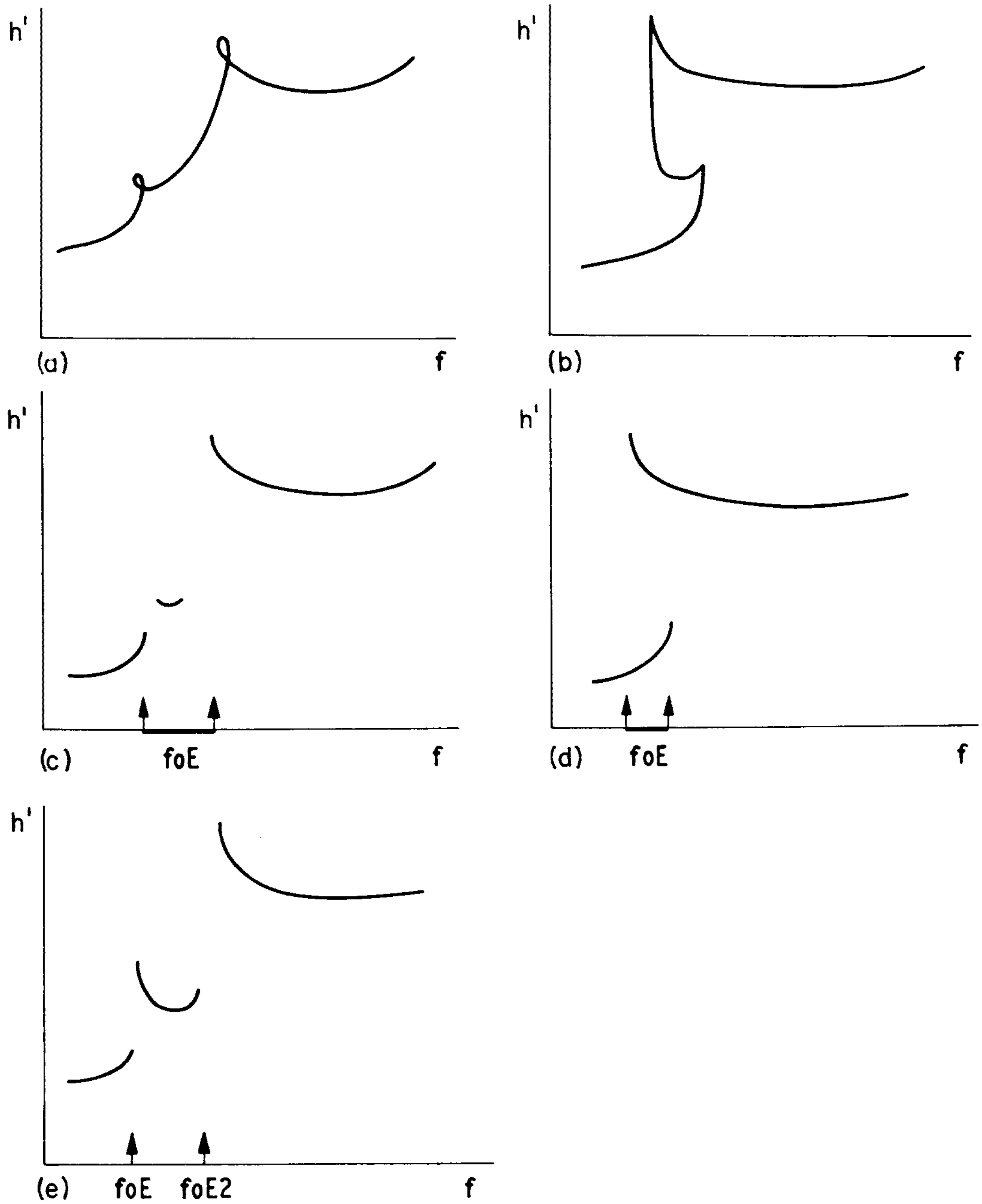


Fig. 2.14 Distinction between effects of layer tilt and intermediate thick E layer
(a)(b) The critical forms of o- or x-mode traces when tilts are present near hmE.
(c)(d) Traces after allowing for focus phenomena.
(e) Thick E2 layer.

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 intermediate trace in case (c) may be missing.

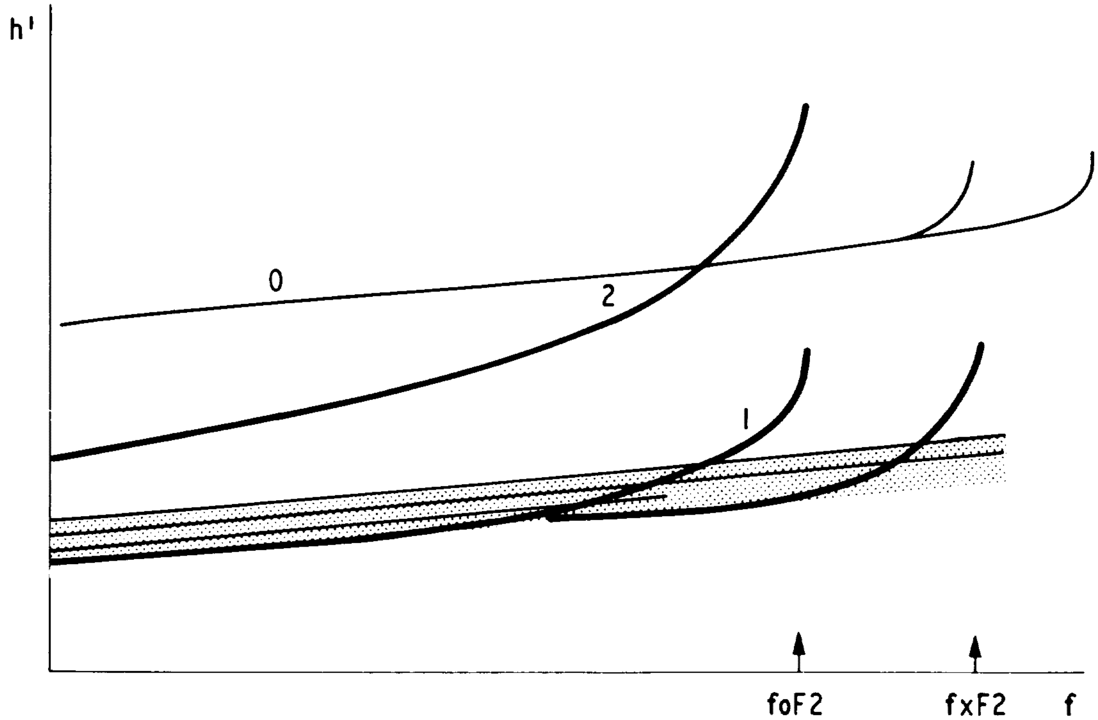


Fig. 2.15 Range spreading

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).
(iii) Range spread indicated by dotted structure and satellite traces. The latter may be absent.

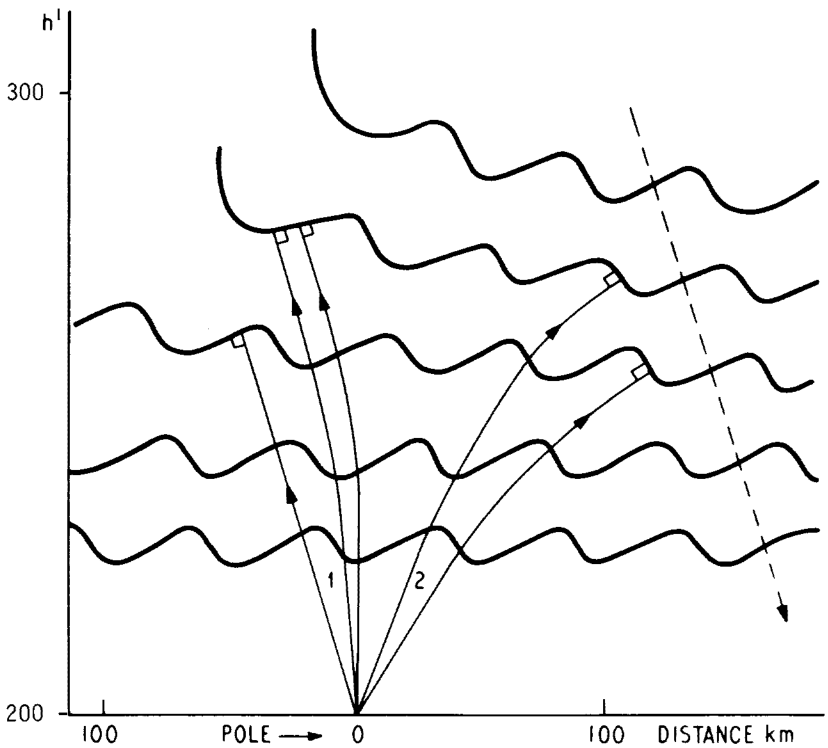


Fig. 2.16 Reflection from irregular ionosphere

Note: Electron density increasing towards pole.

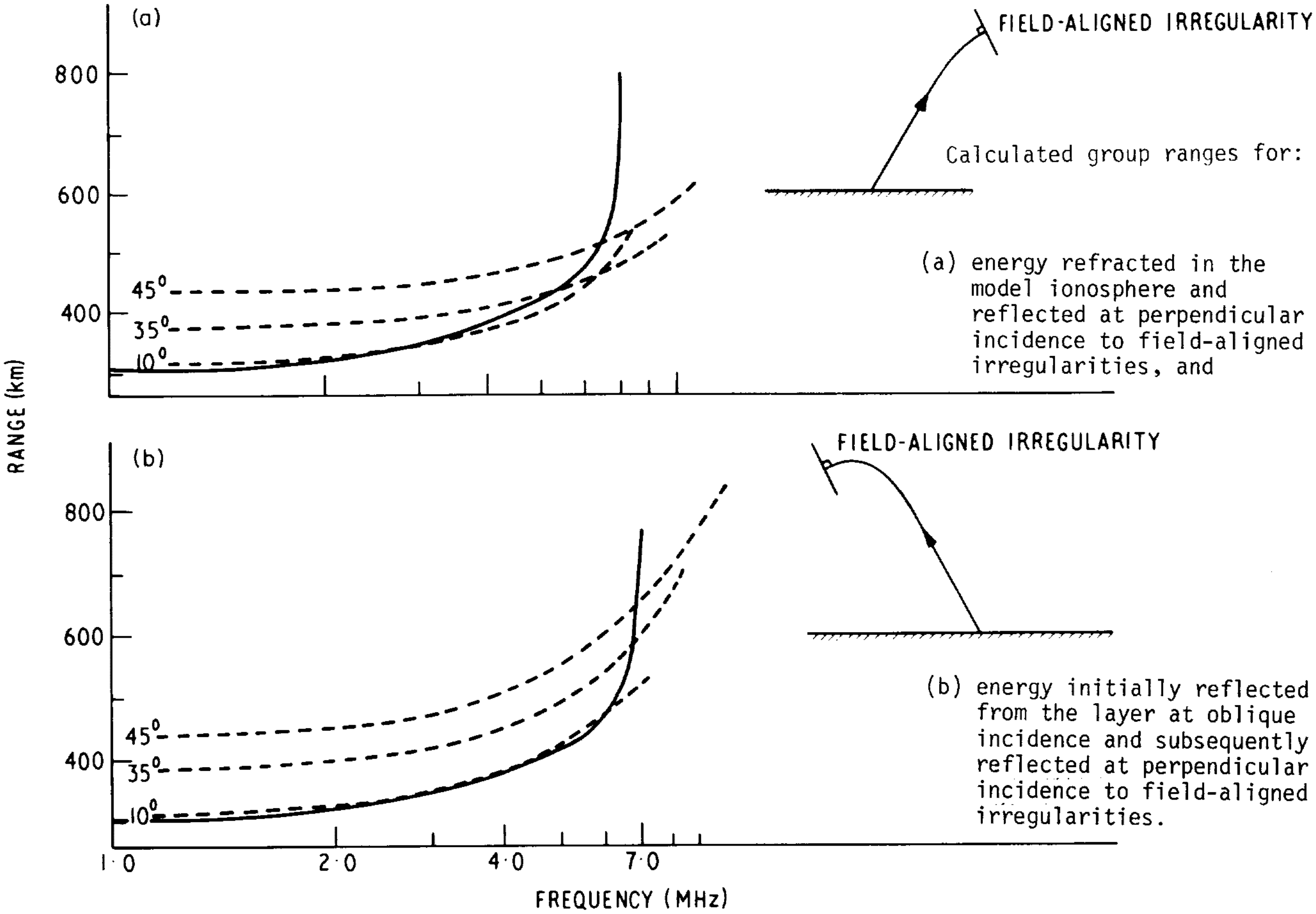


Fig. 2.17

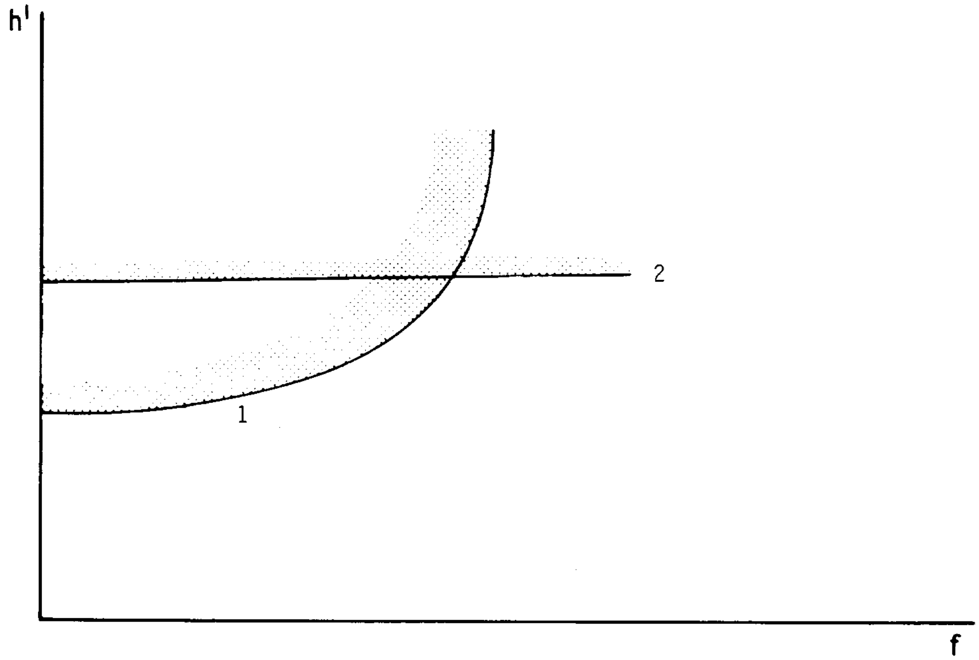


Fig. 2.18 Traces reflected in mode 1 (parallel to field) and mode 2 (perpendicular to field) in Fig. 2.15.

When the perturbations due to the field-aligned structure are small as in Fig. 2.16, 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 small tilt condition), Fig. 2.18. 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 from 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.

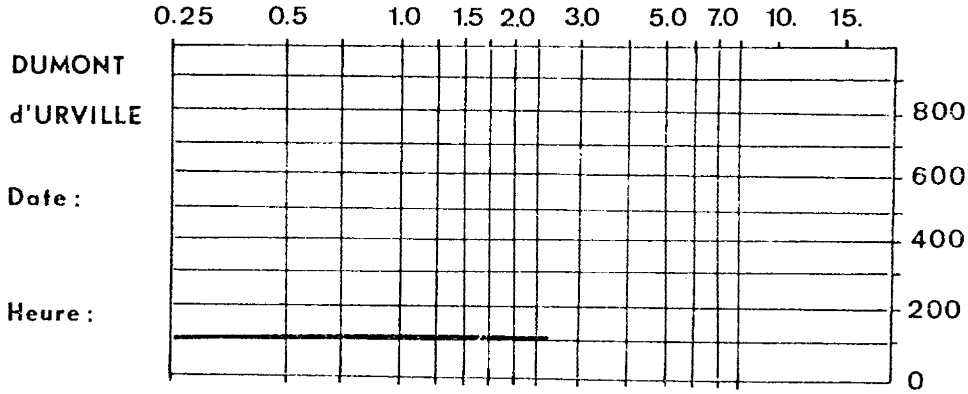
2.75. Lacuna phenomena. Under certain circumstances, the traces on ionograms which are reflected from a certain range of true height disappear although the remaining traces show that the absorption is either normal or only slightly increased. The name Lacuna (lacune in French) has been proposed for this phenomenon, Lacuna being the Latin word for "gap". When the equipment sensitivity is high or the phenomenon weak, it is possible to see weak reflections spread in frequency and height over part or all of the range where the normal traces have disappeared. Lacuna are most often seen during daytime in summer months.

The immediate cause of the loss of trace is a change in the mechanism of reflection so that the normal strong reflected wave is replaced by an extremely weak incoherent reflection from the same height. This is believed to be due to the presence of strong plasma instabilities in the layer, probably associated with the local ion-acoustic waves. The trace disappears suddenly when the height of reflection first reaches the anomalous zone and normal reflections appear suddenly when the height of reflection reaches the top of the zone. Thus when Lacuna starts a portion of the ionogram traces suddenly disappears. The zone affected most frequently starts in the normal E layer and extends to the height of maximum of the F1 layer--the F1 Lacuna. Sometimes the whole F layer is affected--total Lacuna, and it is clear that the phenomena can sometimes effect the F2 layer alone--F2 Lacuna. The immediate cause is the same in all three cases but it is likely that the generating physical forces are different for F2 and F1 Lacuna.

At stations where Lacuna phenomena are common, experts have little difficulty in recognizing F2 Lacuna and distinguishing it from the G condition (foF2 less than foF1), the main criterion being that the time variation of foF2 is normal, the trace suddenly disappearing without change in foF2, whereas for a G condition, foF2 decreases to below foF1 and eventually reappears and increases relative to it. Where F2 Lacuna is uncommon, e.g., only seen in exceptionally active magnetic storms, unskilled staff should ignore the possibility that it can occur. The original INAG rules did not allow for F2 Lacuna as the distinction is difficult where Lacuna are rare.

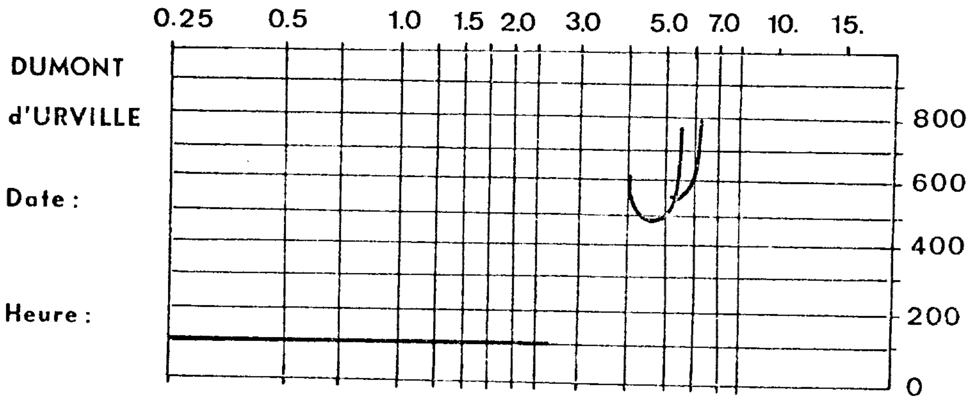
Lacuna appears to be closely associated with activity along the auroral oval and is also found at the magnetic poles. It may therefore prove to be a useful tool for studying activity in these zones. It is also closely associated with slant Es seen at high latitudes and has been discussed under the title Slant E condition (J. K. Olesen, AGARD CP97, 1972, pp. 22.1-27.19, NATO Paris; INAG 12, p. 14-19).

The distinguishing feature of Lacuna is that the amplitude of signals reflected from a certain range of heights is abnormally small, whereas outside this range the traces are consistent with the presence of normal or slightly enhanced absorption. In contrast an increase in absorption would cause fmin to increase, the x-mode traces to weaken relative to the o-mode traces and the multiple traces to weaken or disappear, these effects being greatest at the lowest frequencies and least at the highest. Lacuna often extends too close to foE and foF1. In these cases the trace suddenly disappears or reappears as the frequency changes. If the phenomenon were due to absorption, it would gradually weaken or reappear over a band of frequencies. The detailed rules for analyzing Lacuna are given in Chapter 3, letter Y. Some examples of all the cases of Lacuna seen at Terre Adelie are shown in Figs. A-F below. The phenomenon is very common at this station and the distinctions Y, G, i.e., whether parameters ought to be present, are solved by comparison with ionograms taken before and after the event. These figures show the preferred interpretation to be used by experts, the rules for nonexperts are given in Chapter 3. For example, there is little difficulty in distinguishing between the very weak Lacuna scatter, Y, and spread F, F, when many examples of both have been compared but the distinction cannot be made reliably at stations where the phenomena are rare.



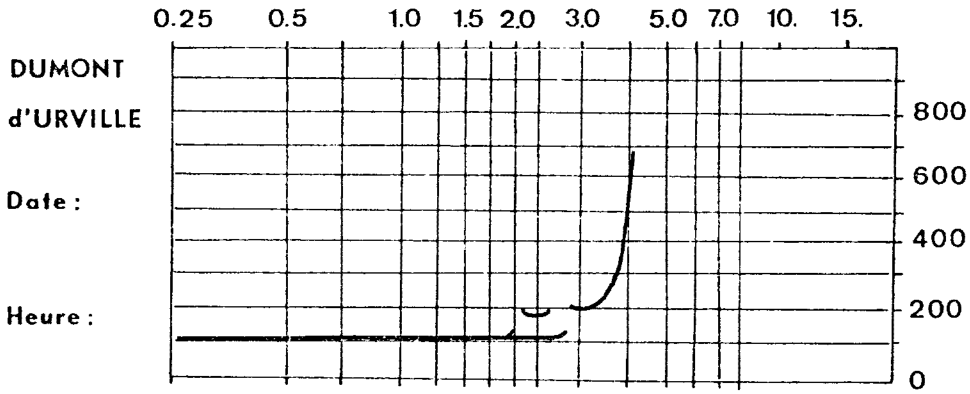
f min	h'E	fo E	h' Es	fo Es	fb Es	type Es
E		Y	G	G	G	
h'F	fo F_1	M3000F_1	h'F_2	fo F_2	M3000F_2	fx I
Y	Y	Y	Y	Y	Y	

Fig. A. "Total F Lacuna"
Observations: All F region parameters and foE are replaced by Y.



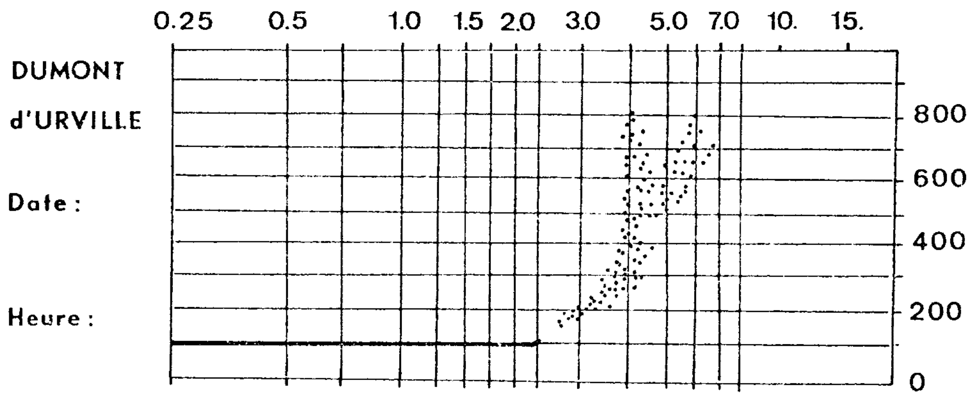
f min	h'E	fo E	h' Es	fo Es	fb Es	type Es
E	100	Y	G	G	G	
h'F	fo F_1	M3000F_1	h'F_2	fo F_2	M3000F_2	fx I
Y	U_{40}^{Y}	Y	485	56	245	

Fig. B. "F1 Lacuna"
Observations: foE, h'F and M3000F2 are replaced by Y. foF1 can be deduced from the retardation of the F2 trace but is doubtful, hence qualify by U and describe by Y.



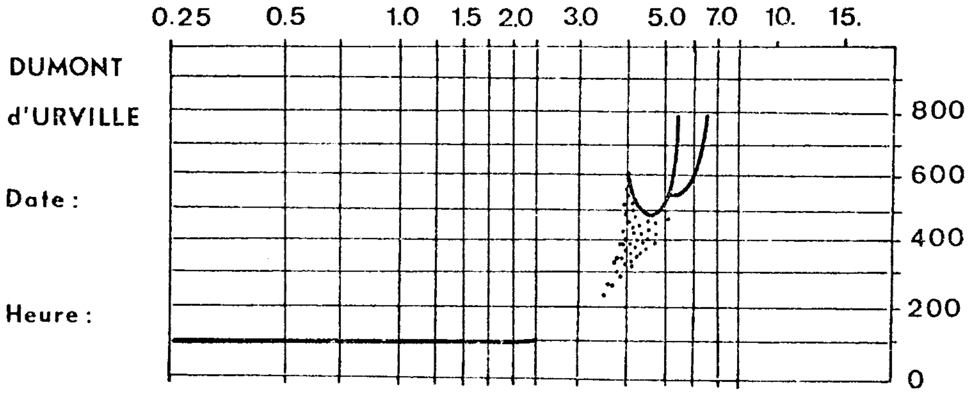
fmin	h'E	foE	h'Es	foEs	fbEs	type Es
E	100^Z	280	G	G	G	
h'F	foF_1	$M3000F_1$	$h'F_2$	foF_2	$M3000F_2$	fxI
195^Z	40^Y	350	Y	Y	Y	

Fig. C. "F2 Lacuna"
Observations: All F2 parameters are replaced by Y. It is important to distinguish between the proper use of Y and that of G in this type of pattern. The value of foF1 is described by Y and qualified or not by U depending on the doubt in the reliability of foF1. (Apply accuracy rules and compare with normal patterns for similar time.) If in doubt, use U. Note F1 x trace may be present or absent, as shown here.



fmin	h'E	foE	h'Es	foEs	fbEs	type Es
E		$D225^Y$	G	G	G	
h'F	foF_1	$M3000F_1$	$h'F_2$	foF_2	$M3000F_2$	fxI
	$U40^F$	Y	Y	$U60^F$	Y	68

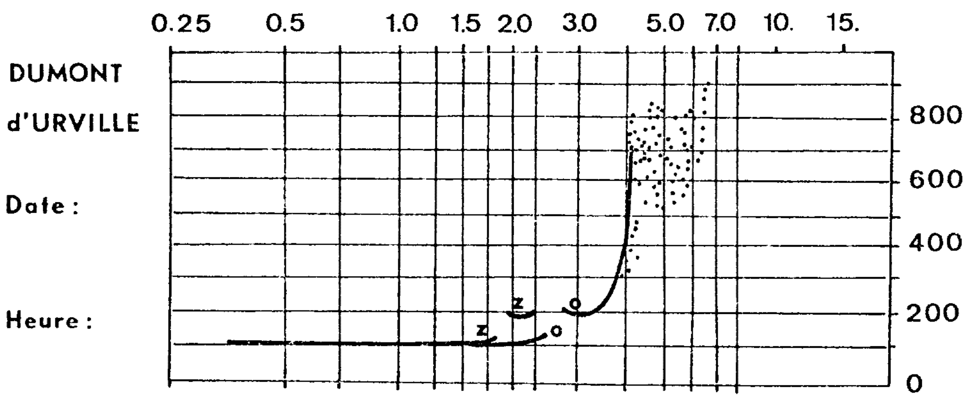
Fig. D. "Quasi-total F Lacuna"
Observations: Use of Y and F to indicate weakening (Y) and spread (F) of the traces.



fmin	h'E	foE	h'Es	foEs	fb Es	type Es
E	100	Y	G	G	G	
h'F	foF1	M3000F1	h'F2	foF2	M3000F2	fxI
Y	U40 Y	F	485	55	240	

Fig. E. "Quasi-F1 Lacuna"

Observations: Note the presence of clean F2 traces makes the identification of partial Lacuna F1 certain. M3000F1 could be replaced by F or by Y, the former is slightly preferable as the immediate cause is the spread, Y could imply no trace present.



fmin	h'E	foE	h'Es	foEs	fb Es	type Es
E	100Z	260	G	G	G	
h'F	foF1	M3000F1	h'F2	foF2	M3000F2	fxI
195Z	40Y	350	Y	Y	F	65

Fig. F. 'Quasi-F2 Lacuna"

Many examples of ionograms showing Lacuna and Slant Es condition will be found in the High Latitude Supplement (e.g., Fig. 2.45, 2.46, 2.51, 3.5, 5.26 and section 12).

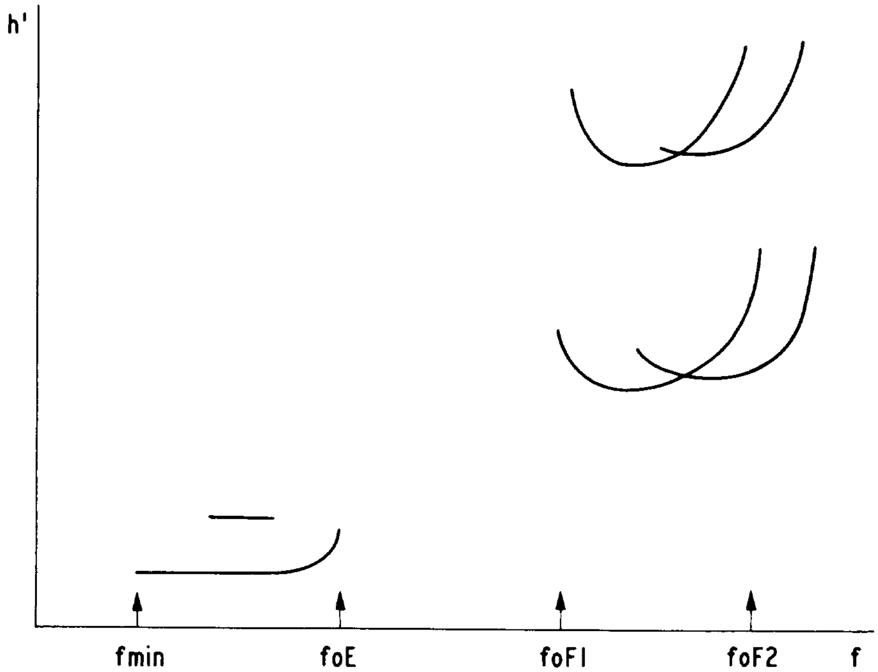


Fig. 2.19(a) Fl Lacuna

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 Fl trace when sensitivity is high or the lacuna is weak. It is usually strongest near foFl.
(e) At some stations the second order trace is not seen during Lacuna conditions.

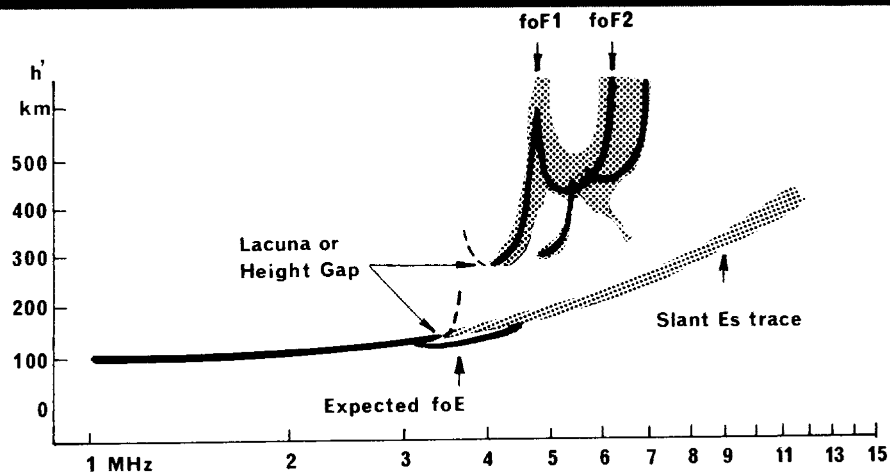


Fig. 2.19(b) Typical daytime ionogram with Slant Es phenomenon at an auroral zone station illustrating the main characteristics: Slant Es trace, Lacuna or Height Gap, F-spreadiness even in low part of Fl-trace, and obliques. Narssarssuaq, June 15, 1969 at 1559 hr. LT.

2.8. Spread F types

2.80. Historical: After considerable discussion INAG decided at Lima 1975 to adopt a simplified form of spread F typing and to recommend it for general use. The original proposals in section 12.34 were used as a basis. Many examples of spread F typing are given in the High Latitude Supplement (Report UAG-50).

While all agreed that the ideal solution would be to provide a spread F-type table similar to the Es-type table section 4.8, it was felt that this would cause too much work at stations for general use. INAG recommends that a separate spread F-type table be produced where possible, section 2.82.

In order to obtain widespread use and avoid additional work at the stations a compromise scheme was developed, see sections 2.83, 2.84.

2.81. Definition of spread F types:

(a) Frequency spread; letter symbol F.

The traces near the critical frequencies are broadened in frequency and may show additional traces similar to a normal critical frequency trace. This is the most common type of spread F at most latitudes, Figure 2.20. Other examples are shown in Figures 2.11, 2.18 trace z, 2.19, 3.8, 3.11, 3.12, 3.14, 3.28, 3.35, 3.39 a,b, 3.40 a,c,d; and for f-plot presentation 6.4, 6.5, 6.6, 6.7, 6.8. Frequency spread from a tilted F layer, Fig. 2.21 is also included in this classification. (See also 6.10e). Letter F should be used whenever the frequency range of the spread exceeds 0.3 MHz.

(b) Range spread; letter symbol Q.

The traces away from the critical frequency show broadening in range or the presence of satellite traces or both Figure 2.22. Other examples are shown in Figures 2.13, 2.17, 2.18 trace 1, 3.13, 6.10. For uniformity Q is used when the range spread exceeds 30 km in virtual height. When broad pulses are used so that the normal trace is wider than this limit use Q when the additional broadening of the trace exceeds 15 km.

(c) Mixed spread; letter symbol L.

The traces are broadened in both range and frequency and do not show the presence of distinct F and Q types. Figure 2.23. This classification shows a physical phenomenon distinct from those given by F and Q and INAG wishes to encourage its use on a voluntary basis.

(d) Spur (historically polar spur, equatorial spur); letter symbol P.

This class includes all types of spread F not classifiable under F, Q or L. It indicates the presence of traces from an oblique reflecting region which usually reflects to a considerably higher frequency than the F layer nearest overhead. When as the structure moves in time it may move overhead in which case the classification changes to F or Q as appropriate. Figure 2.24. Other examples are shown in Figures 3.39 c, 6.10 c,d.

2.82. Rules for use with a spread F type table.

When a spread F type table is made the following rules should be used.

(a) First entry Spread F type used to give fxI.

(b) Second entry Spread F type present at expected value of foF2.

(c) Third entry Range spread if present.

Note in most cases fxI is given by a frequency spread trace type F or by a range spread trace from near overhead, type Q, and only one entry is needed.

(d) When L is not used mixed type should be shown by entries of F, Q.

(e) Some possible entries are:

Single entry	F; Q; L.
Double entry	F, Q; P, F; P, L.
Treble entry	P, F, Q; P, L, Q.

(f)* X may be used to show the absence of spread F at times when it would normally be expected in the spread F type table.

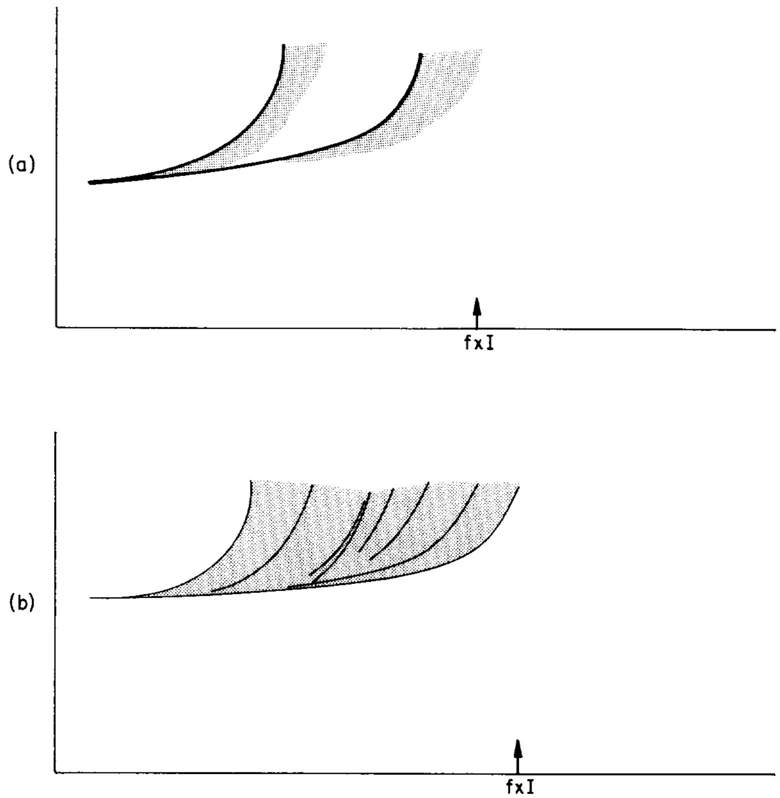


Fig. 2.20 Frequency spread. Type F

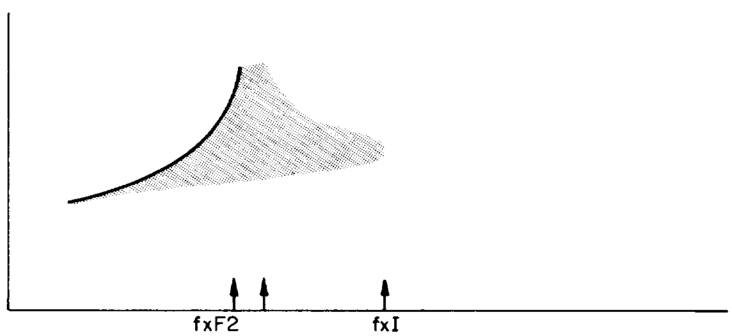


Fig. 2.21. Frequency spread. Type F

Note: In logic fxI should be read at the middle arrow but the standard fxI rule (read the highest frequency of spread visible) is easier and more useful.

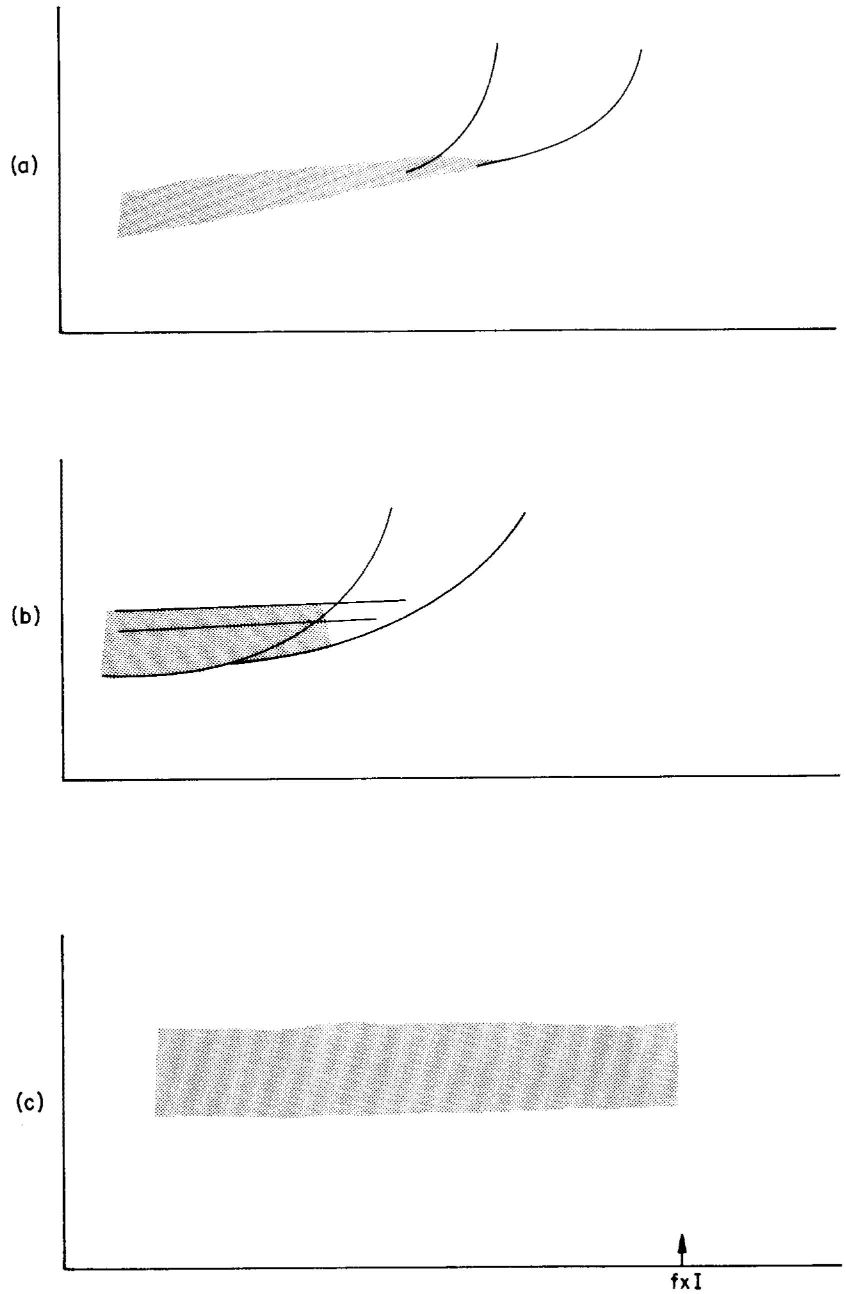


Fig. 2.22 Range spread. Type Q

(a) Shows an unresolved range spread Q in h'F table.
(b) Shows resolved range spread Q in h'F table.
(c) Shows fxI determined by a range spread pattern Q in h'F and fxI (or foF2 table).

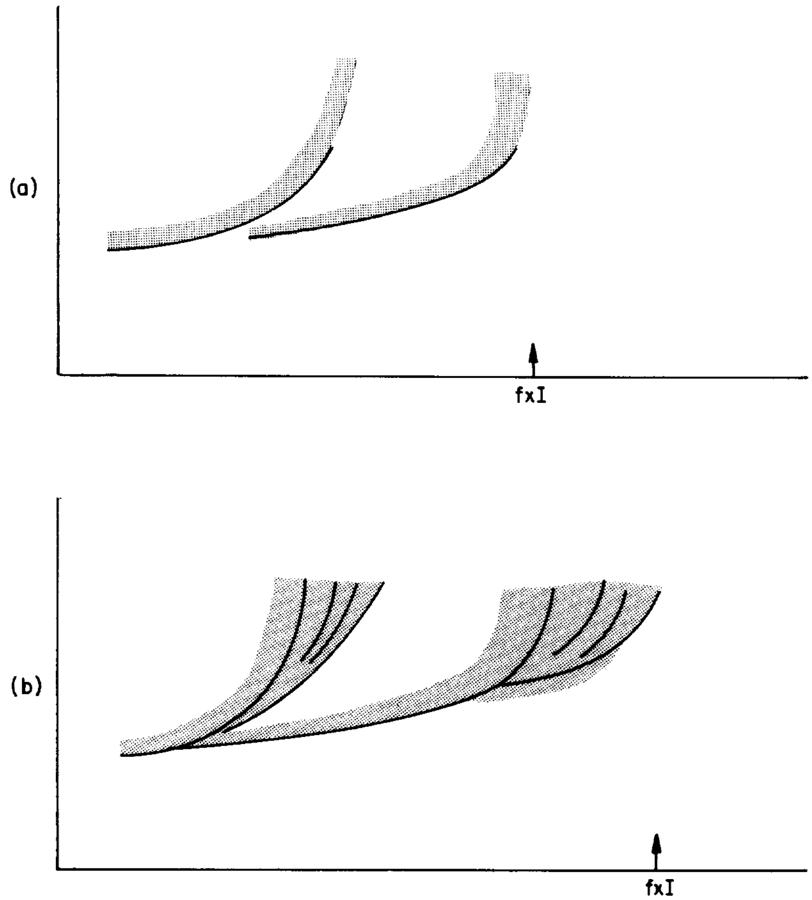


Fig. 2.23 Typical mixed. Type L

Note no structure in horizontal parts of trace. Usually no structure in frequency spread as in (a).

Structured frequency spread (b) superposed on pattern (a): Use F in fxI, L in h'F to give exact description. (Voluntary.)

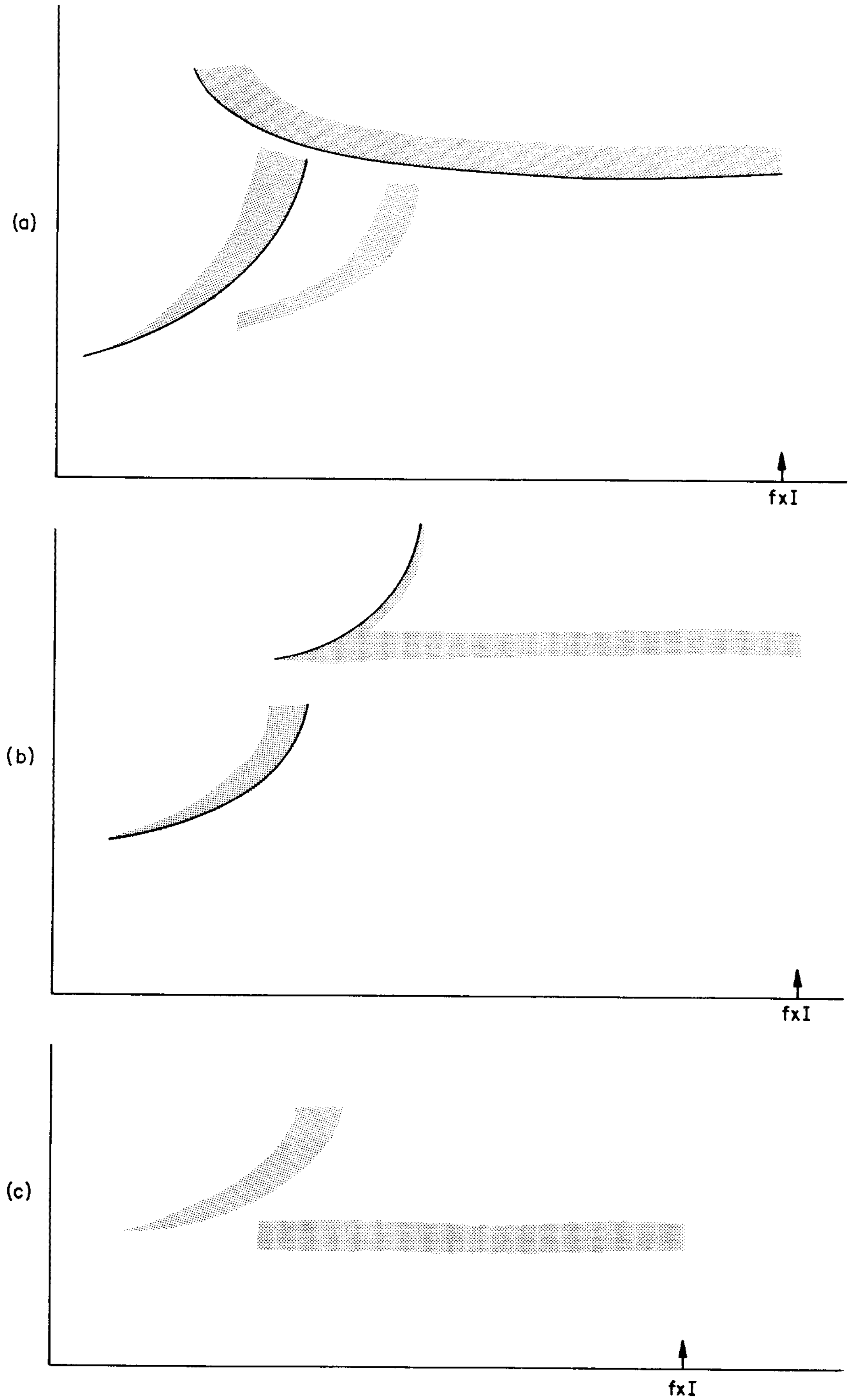


Fig. 2.24 Spur. Type P

Note the P traces may be above or below the main traces and may start at lower or higher frequencies than shown.

2.83. Rules for typing spread F in standard parameter tables.

Where a separate spread F table is not used, spread F types should be shown in the numerical tables using the following rules:

(a) Descriptive letters representing spread F types F, L, P, Q take priority over other descriptive letters in the tables to which they apply. (See table below.) In the remaining tables, the appropriate descriptive letter is determined by the usual rules (Section 3.2).

(b) The type of spread F used to evaluate fxI is shown in the fxI table. Absence of spread is shown by descriptive letter X (see fxI rules section 3.3).

(c) Frequency spread, F, is shown in the foF2 table. If fxI is also given by F and has been tabulated in the fxI table, letter symbols denoting reason for doubt may be used in preference to F in the foF2 table.

(d) Range spread, Q, is shown in the h'F table.

(e) When frequency spread or spur are absent and fxI is determined by a range spread trace, Q is used in the fxI table.

(f) Mixed spread, L, is shown in both h'F and foF2 tables unless structured traces Q or F are also present in which case these take priority in their appropriate tables.

(g) When L is not used, mixed type traces are shown by F in the foF2 table, Q in the h'F table.

Typical Cases

Present	fxI	foF2	h'F
No spread	X	-	-
Spur, F	P	F	-
F Q	F	(F)	Q
L	L	(L)	L
P F Q	P	F	Q

( ) without priority.

2.84. Rules when fxI tables are not available.

(a) Descriptive letters representing spread F types take priority over other descriptive letters in the tables to which they apply only. In the remaining tables, the appropriate descriptive letter is determined by the usual rules (Section 3.2).

(b) The type of spread F which would be used to evaluate fxI (see fxI rules section 3.3) is denoted by its descriptive letter symbol in the foF2 table (possible symbols F, P, Q or L).

(c) The presence of range spread is shown in the h'F table (possible symbols Q, L). Note in this case it is impossible to describe fully the ionogram and a priority system has to be used. In this fxI greater than fxF2 is more important than denoting frequency spread.

(d) Structured traces of types F or Q are always shown in preference to L when superposed.

2.85. Difficulties.

The main difficulty in practice is to distinguish between spur traces and Es-a traces seen at very oblique incidence. When a close sequence is available, e.g. three gain ionograms at the hour, it will be seen that the Es traces vary considerably in a space of a minute whereas spurs change more slowly. Spurs and high Es-a traces tend to occur together so possibly a unique solution is not essential. Spur patterns tend to recur on different nights at similar levels of magnetic activity, showing similar patterns whereas Es-a is less regular.

Certain types of spur appear to identify the movement of the auroral oval over the station (see High Latitude Supplement, Report UAG-50).

NOTES