HIGH MULTIPLE RADIO REFLECTIONS FROM THE F_2 LAYER OF THE IONOSPHERE AT BRISBANE

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Summary

Continuous night-time records of multiple F_2 reflections at normal incidence have been made at a fixed frequency. The echo patterns have been classified, and qualitative explanations given in terms of humped ionization contours, extending the work of Pierce and Mimno (1940). These patterns have been studied also by a variable gain technique. It is concluded that accurate measurements of reflection coefficients cannot be made by this means. Statistical analyses of occurrences of up to the 10th multiple showed that: (*a*) if no account is taken of presence or absence of E_s, the frequency of occurrence increases towards dawn; (*b*) there is no correlation between the number of reflections observed and the virtual height of the region; (*c*) there is no correlation with " range duplications "; (*d*) inverse correlation between high multiple F reflections and presence of E_s occurs only when the lower region is blanketing; (*e*) there is no correlation between high multiples and the travelling disturbances described by Munro.

A study of the presence of very high multiples revealed maxima at the equinoxes. Oblique incidence recording gave no reflections beyond the fifth multiple.

I. INTRODUCTION

Part of this investigation is an extension of the work done by Pierce and Mimno (1940) on the reception of radio waves from distant ionospheric irregularities. Their work was carried out at a frequency of 3·5 Mc/s, and they proposed a plausible mechanism by which high multiple echo patterns could be formed.

The present work also includes a statistical study of the occurrences of high multiples, and of their correlation with other ionospheric phenomena, such as sporadic E region, range duplications,† and cellular waves.

II. EQUIPMENT

The equipment operated at a frequency of 2·28 Mc/s, using a pulse transmitter of peak output about 1 kW. Its pulse repetition frequency was 50 per second, and pulse width, 70 μsec. The receiver was a modified Loran A/APN4 type, of sensitivity requiring about 50 μV at the receiver input for recording of an echo. Since the aerial used was a half-wave dipole, this is equivalent to a field strength of about 2 μV/m.

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† A satellite echo above F_2, giving on $p'f$ records a trace approximately duplicating F_2, except in equivalent range (see Section X below).

The time base of the display system used for slightly more than half the investigation was adjusted to allow echoes of equivalent path up to 5600 km to be observed; for the remainder of the time, a path length up to 8000 km was recorded. Thus 16 reflections from a layer of virtual height 250 km could just be recorded in the latter case. All recording employed a camera using 35-mm film moving past the image of the 6-in. cathode-ray oscillograph screen at a rate of 5 in/hr.

As there is no F_2 reflection during the day at this frequency, the records are for night-time only, the equipment being run for up to 10 hr each night.

III. Echo Patterns Obtained

Examples of the various echo patterns obtained using vertical propagation, and simplified sketches of them, are shown in columns *A* and *B* of Plate 1. Time and height scales on the drawings are approximate only, as these are variable.

On examination of 200 nights' recording, the following numbers of the various patterns were observed:

(*a*) or (*b*) 155; (*c*) 2; (*d*) 1; (*e*) 2; (*f*) 5; (*g*) 3; (*h*) 2.

On a few occasions, somewhat similar patterns of multiple E_s reflections have been noticed, but the records have not been fully examined for such occurrences.

IV. Discussion of Echo Patterns

The assumption of one simple ionospheric irregularity, with minor variations, is sufficient to give a qualitative explanation of all the echo patterns of Plate 1 (*a*)–(*f*).

Following Pierce and Mimno (1940) suppose that a hump, such as shown in Figure 1 (*a*), moves over the transmitter-receiver site, where the angle α is about 1°, and the overall extent may be 200 km. This is an over-simplification, but at such small curvatures, straight-line sections are a reasonable approximation. Assuming geometrical optics to be applicable, a ray can retrace its path and be returned to the receiver only if it somewhere strikes a surface normally. Therefore only those rays leaving the transmitter at an angle $n\alpha$ (where n is an integer) to the normal can be returned. For in *AB* each reflection at the ionosphere or ground increases the angle between ray and normal by α, and in *BC* a corresponding decrease of angle α occurs at each reflection.

The limited extent of *AB* and *BC* imposes further conditions, so that for any particular starting point, reflection occurs only for certain values of n. The echo pattern shown in Figure 1 (*b*) was derived by calculating all the paths of the rays for a series of positions of the irregularity, displaced horizontally with respect to each other.

If we regard the two sections *AB* and *BC* of Figure 1 (*a*) as separate entities, and combine them in the manner indicated in column *C* of Plate 1, we obtain by similar means exactly the patterns shown in column *B*. Now, changes in the irregularity while passing overhead, asymmetry in the irregularity, changes in angle, height, extent, or speed of the movement will all cause modifications to the patterns considered; all the echo patterns shown in column *A* of Plate 1 (*a*)–(*f*) can thus be accounted for.

It was noted that on many nights, especially in midsummer, an echo pattern of type (*a*) of Plate 1 occurred just before dawn. (This occurrence causes a maximum at this time in the histograms of diurnal variation (Fig. 2).) The pattern obtained did not quite agree with those described by Pierce and Mimno, but was more often of the type here shown. This is exactly the type of formation which would be expected from a region of large extent having about 1° inclination to the horizontal, and moving towards the recording site. This is precisely the state of affairs at this time of day ; shortly afterwards, the F_2 reflection disappears altogether.

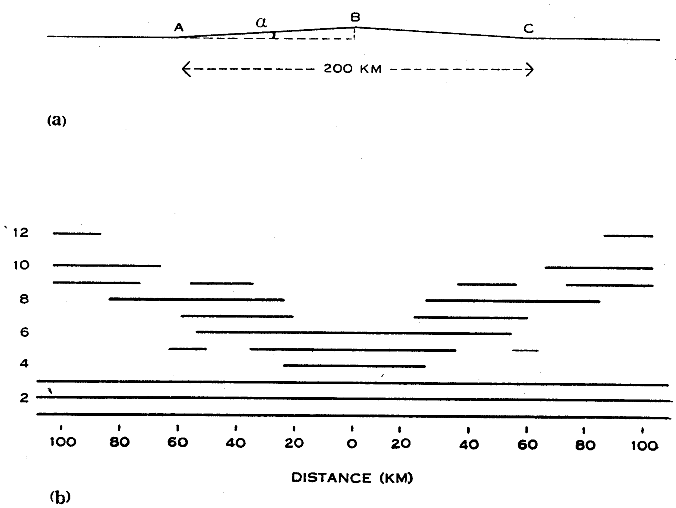


Fig. 1.—Echo pattern formed by ionospheric hump.
(*a*) Assumed irregularity in the F_2 region.
(*b*) Echo pattern calculated from (*a*).

It is worth noting that the very simple irregularity assumed in Figure 1 gives rise to a somewhat complex echo pattern—there are some orders missing, some are intermittent, while others appear very strongly. Thus it is to be expected that recorded echo patterns would often be very complex, considering the complicated horizontal distribution of electron density which certainly occurs in the F_2 region.

The pattern type (*g*) will be dealt with in Section IX.

The pattern (*h*) is quite different in appearance from (*a*)–(*f*). It can be explained along the following lines.

If the angle α (Fig. 1) is increased to about 3°, and the overall extent of the hump decreased to about 100 km, the geometry changes, and patterns such as those of Plate 1 (*a*)–(*f*) cannot be formed. However, with a configuration differing from this only by having smoothed corners, the number of multiples increases markedly as the centre of the irregularity approaches a position vertically above the transmitter-receiver site. An echo pattern of the type (*h*) can thus be produced. This hypothesis finds confirmation in the slight height rise shown in the records towards the centre of this pattern ; other high multiple

KK

patterns are not accompanied by observable height rises, probably because these are below the resolution of the equipment.

Type (*k*) occurs for some 2 or 3 hr at a time and, on a night when such a reflection is seen, the other reflection patterns mentioned above are absent. The simplest explanation of such an occurrence is in terms of a very " quiet " F_2 region, which remains parallel to the Earth's surface and highly reflecting for long periods.

Thus it appears that simple kinks in the F_2 region, of various angles and widths, are adequate for satisfactory explanations of all observed high multiple patterns.

V. Measurement of Absorption

Some observations were made using a variable gain technique,* in which the receiver gain was varied from a maximum to a minimum once every minute. The total attenuation from one limit to the other was about 100 db. As before, the records are on 35-mm film which moved continuously past the image of the cathode-ray oscillograph screen at about 5 in/hr. The gaps between short sections of the trace are caused by the receiver running at minimum gain for a few seconds before returning to the maximum value. An example of the records is shown in Plate 2, Figure 1.

The lengths of the traces in any small segment indicate directly the relative intensity of an echo in decibels above the limit of recording. Owing to fading and the limitations of the recording technique, an accuracy in determination of the attenuation per reflection better than ± 5 per cent. for small attenuation, and ± 10 per cent. for large attenuation, cannot be achieved.

Table 1 (*a*) shows some readings obtained by this method, at random times during " steady " conditions when none of the echo patterns (*a*)–(*g*) of Plate 1 was occurring. This set of results illustrates the errors incurred in measuring absorption losses by taking the relative strengths of consecutive echoes without careful selection of data ; for in several cases an echo of high order is stronger than those immediately below it. This would lead to a reflection coefficient greater than unity.

However, this difficulty seldom occurs in the lower orders, and a good indication of the reflection losses can be obtained by taking account of the relative strengths of the first three or four echoes. Allowing for the attenuation suffered because of increase in path length, it is found that, when high multiples are occurring, the loss per reflection is about 1–2 db.

Table 1 (*b*) shows a continuous set of results during an echo pattern of type (*a*) of Plate 1, readings being taken at 3-min intervals, as shown. The variations in intensity are fully consistent with the explanation outlined in Section IV.

* Suggested by Webster, and developed by McNicol, for another purpose.

VI. Diurnal Variation

The diurnal variation of high multiple occurrence has been studied in two ways.

(*a*) Each night was divided into 10-min periods. When a multiple above the eighth (as an arbitrary standard) appeared, a single occurrence was recorded. For multiples between fourth and eighth, only a half was noted. Figure 2 shows the resulting histogram.

Table 1

VALUES OF ATTENUATION OF RECEIVED ECHOES, MEASURED FROM HIGH MULTIPLE RECORDS OF VARIABLE GAIN TYPE

(*a*) *Values at random times*

Multiple No.	Attenuation (db)						
11	—	—	—	—	—	—	—
10	—	—	56	41	63	71	63
9	—	—	50	50	68	61	63
8	—	70	42	57	70	59	51
7	—	88	52	69	72	63	51
6	69	76	48	66	70	73	51
5	67	70	44	48	63	71	49
4	59	52	42	50	59	60	44
3	49	61	38	41	53	54	41
2	44	55	30	41	53	44	34
1	34	36	33	41	31	35	39

(*b*) *Consecutive values during a period of* 54 *min*

Multiple No.	Attenuation (db)																		
16	60	50	40	60	60	70	70	70	70	75	—	—	—	—	—	—	—	—	—
15	70	50	50	50	60	60	60	60	60	70	70	—	—	—	—	—	—	—	—
14	—	50	50	50	60	50	60	60	50	60	60	—	—	—	—	—	—	—	—
13	—	—	50	60	50	50	50	40	40	50	50	70	—	—	—	—	—	—	—
12	—	—	60	60	60	40	40	40	40	30	40	60	—	—	—	—	—	—	—
11	—	—	—	75	70	40	40	35	30	25	40	50	75	75	—	—	—	—	—
10	—	—	—	—	75	75	60	40	30	30	40	40	70	70	75	75	—	—	—
9	—	—	—	—	—	—	70	60	30	25	40	40	70	70	70	70	75	—	—
8	—	—	75	75	75	75	70	60	40	40	40	40	70	60	50	60	70	70	75
7	—	—	70	75	75	75	60	50	40	40	40	40	60	30	40	50	60	60	70
6	70	60	60	60	60	60	60	40	40	30	30	30	40	40	40	40	40	50	50
5	50	40	50	50	50	50	50	35	40	30	30	30	30	30	30	40	30	40	40
4	35	40	40	40	40	40	40	25	35	25	25	30	40	25	25	30	15	30	30
3	35	25	25	30	30	35	25	25	25	15	15	15	25	25	15	25	25	25	25
2	25	20	15	25	25	25	15	25	15	10	10	10	15	15	15	15	10	15	15
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Time	0507	0510	0513	0516	0519	0522	0525	0528	0531	0534	0537	0540	0543	0546	0549	0552	0555	0558	0601

There is a tendency for the number of occurrences to be fewer earlier in the night. This may be due to more frequent blanketing by E_s between 1900 and 2400 hr, often preventing any F_2 reflection at all.

(*b*) For each hour of the night, the highest multiple showing on the records* was noted. The numbers were averaged for each hour of the night over a period of 30 days. The results are given in Table 2 ; they show no consistent trend.

VII. Occurrence of Very High Multiples from $p'f$ Records

Very high multiple reflections occasionally produce records on the third time base sweep of the standard variable frequency records† made at 10 min. intervals. The equivalent range is therefore somewhere over 6000 km. The order of reflection is about 20, depending on the virtual height of the region.

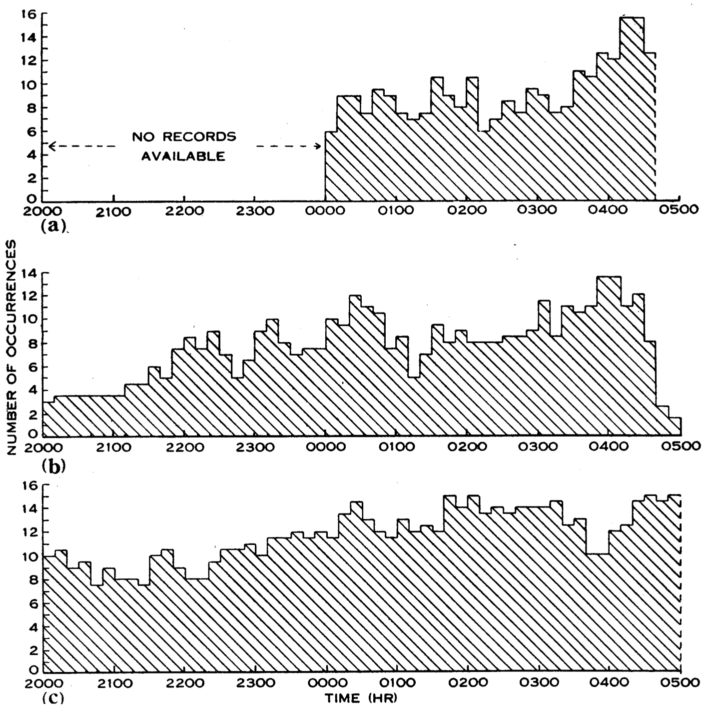


Fig. 2.—Diurnal variation of high multiple occurrences: one for multiples over the eighth, one-half for multiples between fourth and eighth.

(*a*) For 30 days ; October 1951.

(*b*) For 60 days ; November, December 1951 and January 1952.

(*c*) For 38 days ; March 1952 and some of April 1952.

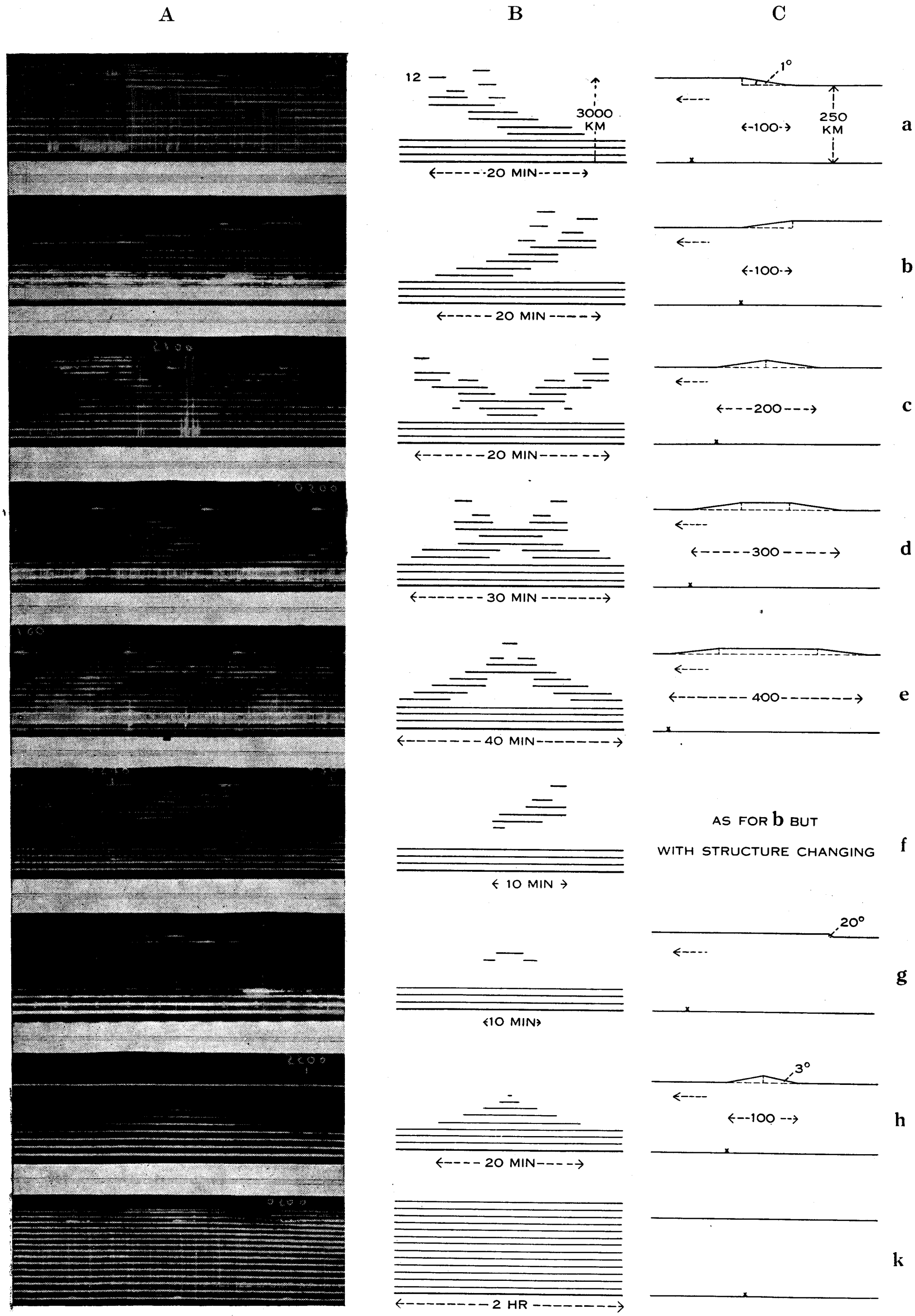
The actual order for a particular record was calculated in two ways:

(*a*) by comparing the tangents of the angles which the first reflection trace and the *n*th reflection trace make with the horizontal ;

* Since the display system eliminated echoes above about the 15th, these numbers were in some instances under-estimates.

† For a description of the recorder see Higgs (1945).

REFLECTIONS FROM THE F_2 LAYER OF THE IONOSPHERE



Echo patterns and their interpretations. *A*, Actual records ; *B*, calculated patterns ; *C*, corresponding ionospheric irregularities assumed for calculation of *B*.

REFLECTIONS FROM THE F_2 LAYER OF THE IONOSPHERE

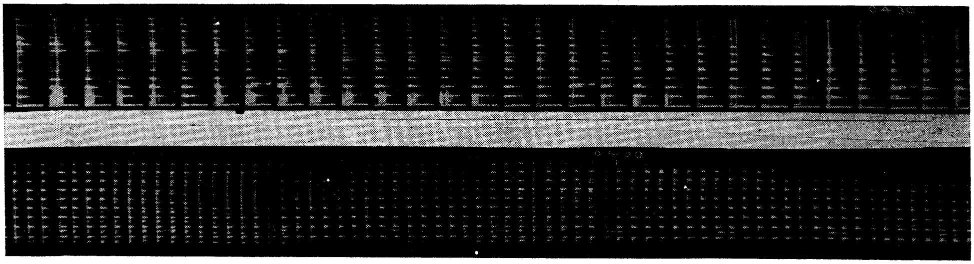


Fig. 1.—Records obtained with variable gain technique.

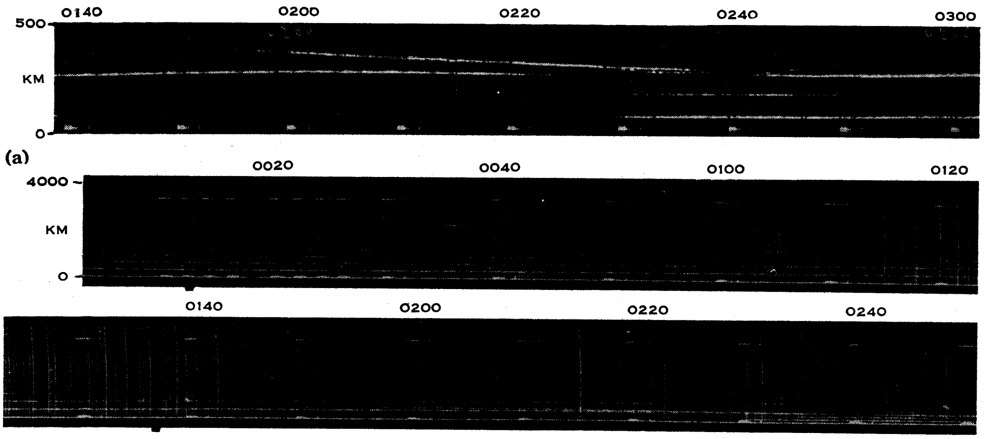


Fig. 2.—The fixed frequency records during a range duplication. (*a*) 0–500 km film, (*b*) 0–4000 km high multiple film. (The periodic marks near the bottom of film (*a*) and near the top of film (*b*) occur at 10-min intervals, and are caused by the standard variable-frequency recorder.)

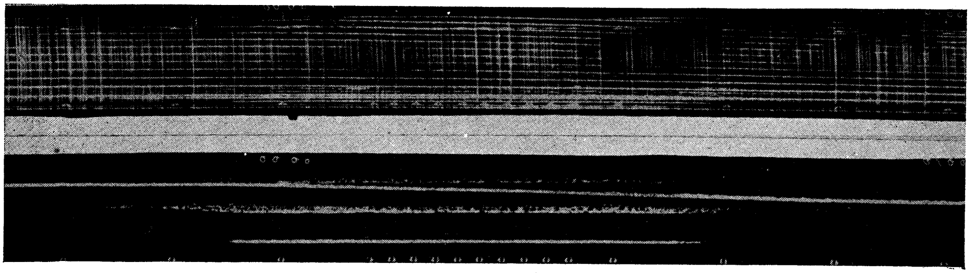


Fig. 3.—High multiple and 0–500 km records during E_s movement. (As in Figure 2, the $p'f$ marks occur at 10-min intervals.)

(*b*) by dividing (6000 + the height of the *n*th reflection as shown on the record) by the height of the first reflection at that frequency.

These two methods should agree.

Records were examined for every night during 1951 and 1952, this period containing some 40,000 individual records. Extra-high multiples showed on

TABLE 2

THE MAXIMUM NUMBER OF MULTIPLES OCCURRING IN EACH HOUR OF THE NIGHT, AVERAGED FOR 30 DAYS AT A TIME

Period \ Time	1900	2000	2100	2200	2300	0000	0100	0200	0300	0400	0500
October 1951 ..	—	—	—	—	—	7	7·5	7·5	6·5	7·5	
January 1952	5	4·5	5	6	6·5	6	6	5·5	6·5	6·5	
March 1952 ..	9	8	9	9	9	10	10	10	9	9	

only 35 occasions. (For comparison, it should be pointed out that high multiples of approximately the 10th order were recorded, on an average, several times each night. This agrees with the frequency of occurrence of such multiples on the fixed frequency records.) The number of occurrences is plotted as a function of

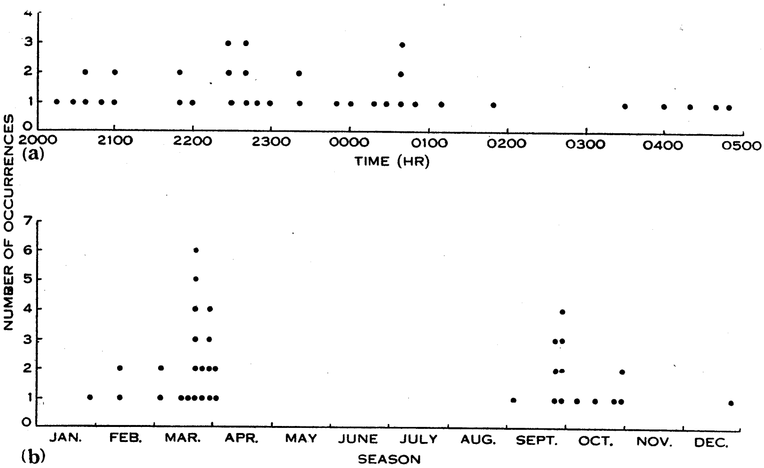


Fig. 3.—Distribution of very high multiple occurrences for 2 years, 1951 and 1952.

(*a*) Diurnal, (*b*) seasonal.

local time in Figure 3 (*a*). Considering the small number involved, it can be said only that extra-high multiples are more likely to occur before 0100 hr than between then and sunrise.

Their seasonal distribution, irrespective of the hour of occurrence, is shown in Figure 3 (*b*). The small number again precludes any definite conclusion, but the grouping suggests marked maxima at the equinoxes.

VIII. Correlation between Virtual Height of the Layer and Number of Multiples

The results of seven nights' observations were examined in two ways :

(*a*) plotting the layer height and multiple number individually as functions of time throughout the night, and comparing the graphs ;

(*b*) plotting the number of multiples as a function of layer height, irrespective of time.

Both methods indicated that the number of multiple reflections is quite independent of layer height.

IX. Correlation between Range Duplications and High Multiples

The term " range duplication " has been introduced by McNicol (personal communication 1952) to describe the phenomenon in which the F_2 echo is accompanied by a satellite,* this satellite persisting and changing in range in the same way as the main F_2 echo, as the transmitter frequency is changed. The critical frequency of the satellite trace on the $p'f$ record is normally (but not always) the same as for the principal trace. Echoes such as $F+E_s$ and $2F-E_s$ are, of course, excluded.

On fixed frequency records, the trace of lower range is always the continuous one ; the higher range trace may persist for periods up to 2 hr. Three general types of satellite are recognized :

(*a*) " Outgoing." The satellite starts at the same virtual range as the principal echo and gradually increases in separation. See Figure 4 (*a*).

(*b*) " Incoming." The satellite starts above the main trace and decreases in virtual range until it joins (or nearly joins) the principal trace, as in Figure 4 (*b*).

(*c*) " Bilateral." The satellite exhibits both (*b*) and (*a*) characteristics. See Figure 4 (*c*).

In connexion with the extensive work being carried out at Brisbane on this phenomenon, the records for 22 definite range duplications were investigated in two ways :

(*a*) the maximum number of high multiple reflections in a 10-min interval was plotted as a function of the time for 2 hr before and after the bifurcation point of the range duplication ;

(*b*) the hourly average numbers of multiples for 2 hr before and after the bifurcation were tabulated.

Neither method revealed any consistent feature. It therefore appears that the ionospheric configuration causing range duplications does not normally give rise to high multiple reflections, probably because range duplications are produced by an irregularity having a small extent (a few kilometres only) and a large inclination to the horizontal, while the patterns previously discussed require smaller inclinations.

* See also Gipps, Gipps, and Venton (1948).

Calculations by the methods outlined in Section IV indicate, however, that such a small kink in the F_2 region, while it would not lead to any high multiples when close to the recording site, would, as it approaches from a large distance, pass through one short section in which it could return an isolated high multiple echo, as pictured in Plate 1 (*g*).

A search for such isolated high multiples at appropriate times before and after the bifurcation of a range duplication was successful in one instance. This is pictured in Plate 2, Figure 2. In this case the eighth multiple appears

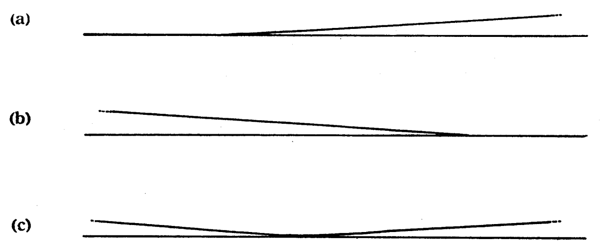


Fig. 4.—Idealized appearance of range duplications on fixed frequency records.
(*a*) " Outgoing ", (*b*) " incoming ", (*c*) " bilateral ".

for a brief period about 2 hr prior to the junction of the satellite trace and the principal trace. In this instance, all the facts can be fitted by a kink having an inclination of 20° to the horizontal, and an extent of 3–4 km in the direction of travel. For such a kink, the vertical extent would be at most 1·5 km so that the height change would not be detectable in the records. Calculation of the

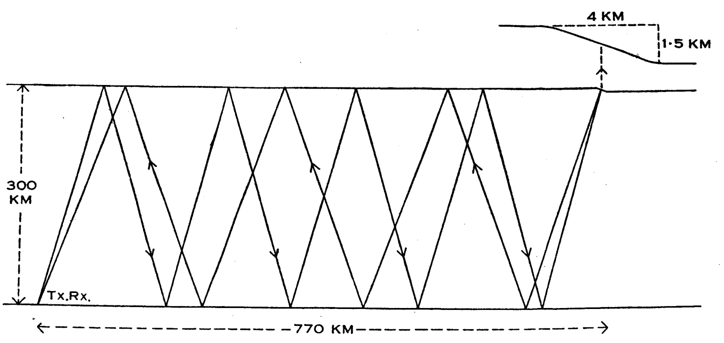


Fig. 5.—Mechanism of formation of a high multiple from a kink producing a range duplication.

velocity from the range duplication permits the placing of the kink 2 hr before the junction at 770 km horizontal displacement. At this distance (and with an angle of 20°) the eighth multiple reflection should appear, as in Figure 5.

On this view, the failure of an isolated multiple to appear near other range duplications can be ascribed to the limited stability of the ionospheric configuration. However, it is surprising that records of type (*g*) appear so rarely.

X. High Multiple F Reflection and Sporadic E

The occurrence of high multiple reflections is affected by the presence of E_s only when it is blanketing the upper layer, either totally or partially. In this case the strength of all F reflections is reduced by attenuation in the lower layer.

At other times, reflections from the E_s can appear in or disappear from the records without causing any noticeable change in the high multiples. An example of this is given in Plate 2, Figure 3, together with the 0–500 km record showing details of the E_s movement.

XI. Correlation between High Multiples and Travelling Disturbances

Munro (1950) has described a type of disturbance in $p'f$ records which Martyn (1950) has explained in terms of cellular waves in the ionosphere. Each occurrence of a disturbance of this type is noted by the observer scaling the Brisbane $p'f$ records.

The criterion taken for such a disturbance is the appearance of an upward kink in the height of the trace, appearing first at the higher frequency end. This then moves towards lower frequencies, causing a rise in minimum height. Also the o and x rays are separated to a much lower frequency than in the normal records preceding and following. The magnitude of the height rise is 50–60 km, and the duration, about 30 min.

Seventeen occurred during the currency of high multiple records. As for range duplications, plots were made of numbers of multiples for 2 hr before and after the passage of the disturbance, and the hourly averages for 2 hr before and after the disturbances were recorded. These show no consistent feature, indicating that the high multiples and Munro disturbances do not arise simultaneously from a given irregularity.

XII. Oblique Incidence

For a short period, simultaneous records were made at Brisbane of echoes arising from two transmitters, one located at the same site, and the other at Toowoomba, 100 km away. In the latter case the calculated angle of incidence at the F_2 layer, for a single hop, was about 10°.

In 25 nights' useful recording at oblique incidence, the highest multiple recorded was the fifth, which persisted for a few minutes on three occasions. The fourth was observed on 10 nights, the third and second much more frequently. During this period the normal incidence recording frequently showed multiples above the 10th reflection. This absence of oblique incidence high multiple reflections agrees with the statement made by Pierce and Mimno (1940).

There is a general correspondence between the normal and oblique records, however, the latter showing its higher multiple reflection at times when the former exhibited highest multiples and strongest echoes.

XIII. Acknowledgments

The author is deeply indebted to Professor H. C. Webster, who suggested the project and maintained a very active interest in it; and to Mr. R. W. E. McNicol, without whose guidance and many helpful ideas the work could not have been accomplished.

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