CHAPTER II

ON HIGH MULTIPLE REFLECTIONS AND OTHER
ABNORMALITIES OBSERVED IN THE
P'-F RECORDS

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THE OCCURRENCE OF HIGH MULTIPLE REFLECTIONS FROM THE F2 REGION OF THE IONOSPHERE BASED ON A STUDY OF THE AHMEDABAD RECORDS

BY

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THE OCCURRENCE OF HIGH MULTIPLE REFLECTIONS FROM THE F2 REGION OF THE IONOSPHERE BASED ON A STUDY OF THE AHMEDABAD RECORDS

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INTRODUCTION

Shortly after the installation of the automatic ionospheric recorder at Ahmedabad in January 1953, it was observed that on certain nights groups of pulses other than the regular ones moved swiftly across the time base on the monitor oscilloscope. On the P'-f records, they produced traces which started from below the ground pulse and crossed the various P'-f traces. Examples of such records are shown in Fig. 1. After the first three months of regular P'-f recording, the phenomenon was not observed for some months, but reappeared clearly in December 1953 and January 1954. A study of the phenomenon was then undertaken.

GENERAL FEATURES OF THE PHENOMENON

The following features were noticed about these abnormal traces: (1) They occurred only during night. (2) At any frequency the separation in height between two adjacent abnormal traces appeared to be the same as the virtual height of the first reflection trace at that frequency. (3) They ended at the ordinary critical frequency $f_0F_2$ of the $F_2$ layer, and on some occasions, there was another group of pulses ending at the extraordinary critical frequency $f_xF_2$ of the $F_2$ layer. (4) The ratio of the slope of an abnormal trace to that of the first reflection trace was found to be the same at any frequency and increased in steps of one from one trace to the next. It was therefore concluded that these abnormal traces represented high order reflections from the ionosphere.

The equipment at Ahmedabad is a British N.P.L. type automatic ionospheric recorder and the pulse repetition frequency is 50 per second. If the delay time of a high order multiple reflection is more than $1/50$ second, it will be recorded in the second sweep of the time base, and the equivalent height of the multiply reflected trace will exceed 3000 km. ($= 1/50$ second). The order of reflection can be determined by dividing the slope or the equivalent height of the trace at any frequency by the corresponding slope or height of the first reflection trace at that frequency.
During regular recording, the duration of the time base is usually adjusted to record echoes of equivalent height up to 1000 km only. However, the time base duration can be extended to record echoes of equivalent height up to about 2000 km. With such an extended time base, multiples up to the 17th order have been recorded. It was considered that it would be worthwhile to increase the height range still further and arrangements were made on a few occasions to record the echoes in two steps, first showing the reflections up to 1500 km, and then delaying the start of the time base so as to record heights between 1500 and 3000 km. Such a double record is shown in Fig. 2 where all multiple echoes from the first to the ninth can be seen.

An examination of the literature showed that high multiple reflections have been noticed by some previous workers on $P^\prime$-$t$ records (Pierce and Mimno, Baird). They attributed these to the curved shape of the ionosphere or humped ionisation contours in the ionosphere. These humps produce a mirror-like converging action on the reflected radio beam. Gipps, Gipps and Venton also explained some abnormal traces in $P^\prime$-$f$ records in terms of humps and concavities in the ionosphere. Munro described certain complexities observed on ionospheric records as the effects of the curvature of the ionospheric surface. Uyeda and Nakata have recently described similar abnormalities observed on $h^\prime$-$t$ and $fct$ records and explained them on an assumed inclination of the ionosphere and its movement.

**ANALYSIS OF AHMEDABAD RECORDS SHOWING HIGH ORDER MULTIPLE REFLECTIONS**

A detailed analysis was made of the records showing such abnormal traces and the present note contains a summary of the findings.

The parameters of the $F_2$ layers were determined by the method of Appleton and Beynon. The virtual heights of the layer at various frequencies were plotted against the corresponding values of Booker and Seaton's function:

$$\phi \left( \frac{f}{f_c} \right) = \frac{1}{2} \frac{f}{f_c} \log_e \left| \frac{f_c + f}{f_c - f} \right| - 1$$

where $f_c$ is the critical frequency of the layer and $f$ any frequency less than the critical frequency. It was found that a neat straight line could be drawn through the points showing that the distribution of electrons in the $F_2$ layer during the night time was approximately parabolic. The values of the virtual heights at $\phi = -1$ and $\phi = 0$ gave respectively the true height of the base $h_0 F_2$ and the height of the level of maximum ion density $h_p F_2$, the semi-thickness being given by $h_p - h_0$. 

<table>
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<tr>
<th>f (Mc/s)</th>
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<th>( h_2 ) (km)</th>
<th>( h_2/2 = h_1 ) (km)</th>
<th>( h(n_1) ) (km)</th>
<th>( h(n_2) ) (km)</th>
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The analysis of a typical record (Fig. 1 b) is given in the following table. The value of $f_0F_2$ was 3·0 Mc/s. $h(n_1)$, $h(n_2)$, $h(n_3)$ and $h(n_4)$ are the virtual heights of observed multiples and are found to be nearly equal to 11, 12, 13 and 14 times $h_1$. $h_pF_2$ was found to be 250 km, $h_0F_2$ to be equal to 198 km, and the semi-thickness of the layer was 52 km.

With a view to find out what ionospheric features were associated with high multiples, the parameters $h_0$, $h_p$ and $T$ obtained from the hourly ionospheric records during the occurrence of the phenomenon were examined.

![Graph](image)

**Fig. 3.** (a) Mean minimum virtual height of the $F_2$-layer (January 1953 to December 1954). (b) Average hour to hour change in $hF_2$ (January 1953 to December 1954). (c) Total number of occurrences of high multiples (January 1953 to December 1954).
In the records of the period January 1953 to December 1954 there were 256 such occurrences. It was found that in general high multiple reflections were associated with a hump in the ionospheric surface over the place of observation. High multiples occurred more or less continuously for many hours in certain periods of the night in some months. Near the critical frequency the multiples are generally weaker, due no doubt to increased absorption as well as to increased slope of the $P' - f$ traces.

The distribution of the occurrence of high multiples with the hour of the night is shown in Fig. 3 (c). In Fig. 3 (a) and 3 (b) are shown the mean

![Graphs showing variation of $h_0F_2$ and occurrence of high multiples on selected nights.]

**Fig. 4.** Variation of $h_0F_2$ and the occurrence of high multiples on a few nights.
virtual height ($h'F_2$) and the average hour-to-hour change in virtual height ($h'F_2$) during the period January 1953 to December 1954.

It will be seen that the hour of maximum occurrence of high multiples are round about 21 hours, 01 hour and 04 hour. The times of maximum frequency of occurrence of high multiples nearly coincide with or precede the times of maximum rate of change of $h'F_2$. The strength of the peak at 01 hour in Fig. 3(c) is abnormal due to the large number of occurrences of high multiples at that hour in one month only, namely in November 1954.

Figure 4 gives the analysis of the heights of the $F_2$ layer on a number of individual nights at times when high multiples were observed. The circles represent the times at which high multiples were observed.

Observations at short period intervals taken on a few nights showed fair correlation between the highest order multiple and the curvature of the

![Graph showing variation of total number of multiple reflections and height of base of the $F_2$ layer on the night of 10 to 11 March 1955.](image)
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ionospheric surface. Figure 5 shows the results of observations taken on the night of 10-11 March 1955.

It was found that sporadic E does not affect the high multiples except when it blankets the normal reflections. Sometimes high multiples of \textit{F}_2 and sporadic \textit{E} can be seen simultaneously recorded over the same frequency range (Fig. 1b).

1 F scatter usually reduces the number of multiple reflections but there are some exceptions to this also (Fig. 1c).

\textbf{SEASONAL VARIATION OF MULTIPLE REFLECTIONS}

It appears from Fig. 6 that high multiples are least frequent in the summer months May to July and most frequent in November to March or

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig6.png}
\caption{Fig. 6. Percentage of nights on which high multiple reflections were recorded in various months January 1953 to December 1954.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig7.png}
\caption{Fig. 7. Variation of $\textit{h'}F_2$ during night time in different months of the year.}
\end{figure}
April. This accords with the fact that the daily variations of $h'F_2$ are least pronounced in the summer months and most pronounced in autumn and spring. During summer, $E_s$ and $F$—scatter are rather more frequent and these no doubt contribute partly to the rarity of high multiples in that season.

IRREGULARITIES IN THE INTENSITIES OF THE MULTIPLE REFLECTIONS

A phenomenon related to the above is the anomalous and varying distribution of intensity of multiple echoes. This phenomenon can be seen clearly on many occasions on the monitor oscilloscope and generally occurs on multiples higher than the third. It is difficult to determine quantitatively intensity ratios of the various multiples from the $P'P$ records but approximate estimates of their intensity can be obtained in some cases.

At times, depending upon the position of the hump with respect to the place of observation, a higher multiple may be formed by combination of waves leaving the transmitter at different angles and arriving at the receiver after being reflected from off-vertical points in the ionosphere. The intensity of some particular multiple may then be greater than that of the lower ones depending upon the curvature, height, and reflection coefficient of the $F_2$ layer, as well as on the radiation patterns of the transmitting and receiving antennae.

CONCLUSION

These observations show clearly that even at night, the $F_2$ layer cannot by no means be considered as a simple plane reflecting surface and that there are dynamic changes going on in it most of the time. Determination of the reflection coefficient of the layer and of the absorption of the atmosphere below it is rendered particularly difficult because of these changes.

ACKNOWLEDGEMENT

The author is indebted to Prof. K. R. Ramanathan for his keen interest and guidance in the work. The Council of Scientific and Industrial Research (India) is supporting the ionospheric station with financial assistance.

REFERENCES

FIG. 1(a). P' record at 01 hr. on 28-10-1954.

FIG. 1(b). P' record at 02 hr. on 31-1-1953.

FIG. 1(c). P' record at 00 hr. on 17-3-1953.

Fig. 1. P' records showing abnormal traces crossing the lower order reflection traces.
FIG. 2. $P'$ record at 22 hr. on 10-3-1955 recorded in two steps, one recording echoes up to 1500 km. and the second immediately after, from 1500 km. to 3000 km,
FIG. (a) P' record at 00 hr. on 18-3-1954.

FIG. (b) Photo at 2230 hr. on 28-3-1955.

FIG. 8. Records showing second order reflection stronger than the first order reflection
FIG. 9. Multiple echoes at intervals of one minute on 24-3-1955.
On high multiple reflections and other
abnormalities observed in the F'-f records.

(Supplement to the paper attached herewith)

1. High multiple reflections.

Further example of high multiple reflections similar to those shown in Fig. 1 are shown in Fig. 10. Fig. 11 shows some records taken at intervals of ten minutes each during the occurrence of high multiples. The variation of $h_0F2$ and $h_pF2$ during the period are shown in Fig. 12. High multiples were observed at 0520, 0530 and 0540 hr. when there was a hump in the ionospheric surface over the station.

Fig. 13 shows some records taken at intervals of 15 minutes on 7 November 1954. These records were extended duration of time base, thereby the recording reflections from heights upto 2000 km. One can see that at 0000 hr there were only three weak $x$-components reflections from $F2$, but at 0015 their number had increased and they were also stronger. High multiples were recorded between 0030 and 0300 hr. These records will be discussed at a later stage.

Figs. 14 and 15 show two more examples of records taken in two steps similar to that shown in Fig. 2. Such recording enables one to observe all the multiples.
Figs. 16 and 17 (see also Fig. 5) show the variation of the highest order of multiple reflections and of $h_0F_2$. These figures show that there is an increased number of multiples when the ionospheric surface presents a concave surface towards the station.

Echizenya et al have described the occurrence of high multiples from F2 layer at Akita.

2. Anomalous intensity distribution of the multiple reflections.

It was mentioned in the previous paper that the intensities of the multiple reflections did not on some occasions decrease with increasing order. Fig. 18 shows a few examples of such a phenomena.

The focusing effect of particular orders of reflection can be referred from the minimum frequencies of reflection of different order multiples. The minimum frequency of reflection is indicative of the reflection coefficient and normally $f_{\text{min}}F_2$ increases with increasing order of multiple. An anomalous distribution of $f_{\text{min}}F_2$ with increasing order of multiple can be seen in the records at 0200 and 0300 hr on 7 November 1954. (Fig. 13). At 0200 hr $f_{\text{min}}F_2$ for the 5th order was less than that for the 3rd or 4th order reflections. At 0300 hr $f_{\text{min}}F_2$ for the 4th and 5th order reflections were smaller than that
for the 3rd order.

3. Anomalous height distribution of multiple reflection

Another phenomenon connected with the irregularities in the ionosphere is that sometimes the virtual heights of multiple reflections are not integral multiples of the heights of the first order echo. A few examples of the phenomenon are shown in Fig. 19 (a) and (b). In Fig. 19 (a) both o and x component traces for second order reflection have virtual height less than twice those of first order. In Fig. 19(b) the virtual height of x component F2 reflections at 5 Mc/s, is 430 km for the first order, 710 for second order and only 910 km for the third order reflection. Two more examples of such a phenomenon are shown in Fig. 20 and 21. The phenomenon can be explained in terms of reflection from an inclined ionosphere, the different order multiple reflections are received from directions off the vertical. The first order reflection would be more inclined to the vertical and so will have a greater virtual height. Successive reflections will approach the vertical and the separation between successive traces will get smaller with increasing order of reflection.

Uyeda and Nakata\(^9\) have discussed similar phenomenon observed on sweep frequency records.

Records of this type are observed at Ahmedabad in the early and late portions of the night when the height of
F2 changes rapidly.

4. **Echoes with split-height.**

Referring to Fig. 13 we see that at 0245 hr the x component reflections are split and two simultaneous parallel traces are recorded in the second, third and fourth order reflections. Similar splitting in the heights of the multiple reflections can be seen in the records between 0130 to 0230 hr. Note that at 0245 hr the separation between the split-height echoes increased with increasing order of the multiple, whereas in Fig. 2 the separation decreased with increasing order. A good example of height splitting in higher multiple reflections is shown in Fig. 22. At 0300 high multiples were recorded but without any height splitting. Split-height multiples were recorded at 0400 hr when there was a sudden change in the heights of the F2 layer and so the ionospheric surface was inclined. At 0500 hr, the lower order multiples were not equally spaced. When the surface is inclined or there is a bulge in the ionospheric surface, the higher reflections may arise from two or more directions and give rise to parallel traces slightly displaced in height.

On some occasions split-height echoes may be seen in low order multiples as shown in Fig. 23. Note that the first order F2 trace is single, whereas second and higher order traces are duplicated.
On some occasions, even the first order reflection may be duplicated; two examples of the phenomenon are shown in Fig. 24. Note that all the reflection traces have duplicates.

On some occasions the duplicate traces may merge giving a broad diffuse trace resembling scattered or spread F traces as shown in Fig. 25.

The duplicate traces may have same critical frequencies or their apparent critical frequencies may be different as shown in Figs. 26 and 27.

References

(References 1 to 7 and Figs. 1 to 9 in the reprint.)
Fig. 10

Examples of high multiple reflections crossing the lower order reflections.
Fig. 11
Occurrence of high multiples due to a hump passing over the station.

Fig. 12
Showing the occurrence of high multiples during the passage of a hump on the ionospheric surface.
Fig. 13

P'-f records on 7 November 1954 showing the effects of the curvature of the ionospheric surface e.g. (1) high multiple at 0030 to 0145, (2) anomalous intensity distribution of multiple reflections at 0200, 0300 and (3) height split echoes at 0230 and 0245.
Fig. 14

P'-f records taken in two steps to record all the echoes from the ionosphere.

Fig. 15
Fig. 16

Fig. 17

Variation of the number of multiples reflections with the curvature of the ionospheric surface.
Fig. 18 (b)
P'-f records showing 4th order trace stronger than 2nd or 3rd order one.

Fig. 18 (a)
P'-f record showing 3rd order trace stronger than 2nd order one.

Fig. 18 (c)
P'-f record showing 5, 6 and 7th order reflections stronger than the lower ones.
Fig. 19 (b)

Fig. 19 (a)

$P_f$ records showing 2nd order $F_2$ trace at heights less than twice the 1st order heights.
Fig. 20

P'-f records showing anomolous height distribution of the different order traces.
Fig. 21

P'-f records showing the anomalous distribution of virtual heights of multiple reflections.
Fig. 22

P'-f record showing the height split echoes on the high multiple reflections.

Fig. 23

P'-f records showing single first order traces in whereas higher order ones are duplicated.
Fig. 24

P'-f records showing duplicate traces on first as well as on higher order traces.
Fig. 25

P' = f records showing broad traces due to the duplicate traces having merged.
Fig. 26

P'-f records showing different critical frequencies for the duplicate traces.
Fig. 27

P'-f record showing multiple critical frequencies of the F2 layer.