CHAPTER II

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SPREAD-F ECHOES FROM THE IONOSPHERE OVER AHMEDABAD

I. INTRODUCTION

Often, vertical radio pulses sent up into the ionosphere are reflected to earth not as a sharp echo, but came back as a broad band of echoes consisting of a number of reflections of varying amplitudes. The broadness or the separation of such echoes depends upon the structure of the irregularities and their distribution. The problem is to relate the different types of scatter to the structure and distribution of irregularities. Some ionospheric h'-f records showing typical scattering of radio pulses are reproduced in later sections. They take the following forms:

(i) Forking of the cusp of the critical frequency,
(ii) slightly displaced parallel records with different critical frequencies,
(iii) diffuseness throughout the range of frequencies closely superposed on these parallel records,
(iv) spreading only near the end of the record or near the height of maximum electron density and
(v) completely diffused echoes with no sharp definition of the layer or cusp of critical frequency.

Examples of them are shown in the h'-f records of Figs. 1 and 2. Scattering of radio pulses occur in the F2 layer itself, but can also be observed in an ionospheric record if the
pulse first strikes an irregularity of the sporadic E layer slightly away from the vertical, is diverted to the F2 layer and is then reflected back to the ground. Such a mechanism will give a number of satellite echoes in scattered form over a range of frequencies of the F2 record and this mechanism was suggested by Eckersley (1940) - Dieminger (1951) dealt extensively with different types of F-scatter and came to the conclusion that the F2-scatter was mainly due to irregularities within that layer itself. The records reproduced in Figs. 1 and 2 on 12 May 1955 and 17 December 1956 show this.

Fig. 1: - h'f records of Ahmedabad on 12 May 1955, 3 April 1954 and 2 July 1957 showing different types of spread F.
Fig. 2: A sequence of hourly h'-f records of Ahmedabad from 00 to 07 hr on 17 December 1956 showing diffused parallel traces of spread F not due to Es.

Records in Fig. 3 taken on 4 September 1957 does not show any F2-scatter although sporadic E layer was recorded. In the records of 17 December 1956 in Fig. 2, F2-scatter echoes were present although Es was absent. These are clear evidences of F2-scatter primarily due to irregularities in the relevant layer (more records in Figs. 14 and 15). However, McNicol (1956), Netzer (1940) and Becker (1952) attribute some of the F2-scatter echoes to the presence of Es layer. Records in Fig. 1 taken at 0145 hr and 0500 hr on 2 July 1957 suggest
this type of scatter, but these are not common in Ahmedabad. There is also an $K$-scatter, evidence for which will be given in chapter VI.

Fig. 3: - $h'\cdot f$ records of Ahmedabad on 4 September 1957 showing absence of spread $F$ although $Es$ is recorded.

II. DAILY AND MONTHLY VARIATIONS IN SPREAD $F$

OCCURRENCE AT AHMEDABAD IN 1954 AND 1956

The occurrence of spread $F$ at Ahmedabad is mainly a night-time feature. It begins usually after 1900 hr. Various types of spread $F$ echoes have been observed of which $h'\cdot f$
traces running parallel to each other and traces closely superposed on each other are common. Totally diffused type of echoes occur only in summer of low sunspot years. Forked echoes are generally observed when scattering just begins or when it has just ended. In a study of F2-layer characteristics in 1953-54, it was found that F2-scatter was most frequent at 03 hr in summer.

**Monthly frequencies of occurrences of spread F in 1954 and 1956**

The percentage frequency of spread F echoes at a particular hour was calculated from the number of days of observation of spread F and the total number of days of usable records. Fig. 4 gives the total number of occurrences of all types of F2-scatter echoes; the frequency of each type is not shown separately. Figs. 4a and 4b show the diurnal variation of F2-scatter for each month of the low sunspot year 1954 and of the high sunspot year 1956 respectively. The time scale includes 1800 to 0800 hrs, since spread F during the rest of the hours was rarely observed. In these Figures, are included median values of foF2 and hpF2. The year 1957 had a still higher sunspot number, but the diurnal variation was the same as in 1956, though spread-F activity was a little less on the whole.

2.1 1954

It can be seen from Fig. 4a that in all the months of the year 1954, the spread F usually commenced at 20 hr and
Fig. 4a

Fig. 4b

Figs. 4 a & b : Diurnal variation of occurrence of spread F, foF2 and hpF2 at Ahmedabad in each month of 1954 and 1956.
ended at 06 hr. The rate of fall in spread F near sunrise was much sharper than the rate of increase after nightfall. Whatever may be the degree of F2-scatter during night hours, the h'-f trace became free from any spread F after sunrise. An interesting point about spread F is that corresponding to every fall of hpF2, there is an increase of spread F. When spread F was at a high level in 1954, hpF2 was generally between 275 and 325 km and in 1956 it was between 325 and 375 km. The double peak of spread F activity in winter months can be seen to be associated with two separate falls of hpF2. The occurrence of spread F echoes was very frequent in the summer months and it is seen that hpF2 remained in the 300 - 350 km range for a longer time than in other months.

2.2 1956

If we look to Fig. 4b in which spread F is shown for the year 1956, it would be seen that some important changes in the characteristics took place after January 1956. The hour of peak of spread F receded from 03 hr to an hour or two before midnight, particularly in winter and equinoxes when the electron density was still at a high level. We had noted in Chapter I that a temporary increase in height at 20 hr was found in the winter months of 1954, but it was found in the equinoxes also in 1956-57. The occurrence of a peak of spread F at premidnight hours in these months is associated with a fall in hpF2 after 20 hr and particularly when its value lies between 300 and 350 km. The morning
peak in winter vanished at the end of 1956 and in the winter of 1957.

III - PROGRESSIVE CHANGES OF SPREAD F FROM 1954 TO 1957

3.1 A summary picture of spread F variations in different seasons through the half solar cycle 1954 - 1957 is presented in Fig. 5, where each year is divided into three seasons (viz. Winter: November, December, January and February; Equinox: March, April, September and October; Summer: May, June, July and August). Only November and December are taken as winter months for 1957, whereas in other years, winter includes the last two months of the year marked against the relevant picture plus the first two months of the next year. It is to be noted from the Figure that marked changes in spread F activity began in October 1955 when the sunspot number began to increase rapidly.

Winter:—On the whole, mean spread F activity in winter did not change much. The only important change from 1954 to 1957 was that the time of occurrence of peak receded from post-midnight hour to a pre-midnight hour.

Equinoxes:—In 1954-55, maximum spread F was observed at about 03 hr and in 1956-57 at about 21 hr.

Summer:—Great activity of spread F was observed in the summer months of 1954-55, the maximum being in the summer of 1955. The spread F activity in the summer of 1953 (not shown in the Fig.) was even greater than in the summer of 1954. It thus
appears that maximum scatter is observed in summer not quite at the sunspot minimum but on either side of the minimum of the sunspot cycle. At Huancayo also, the peak of spread F occurred in the local summer of 1945-46 in the last sunspot cycle. In 1956-57 summer, spread F at Ahmedabad was at the lowest level.

It is concluded that in high sunspot years, spread F over Ahmedabad has characteristics similar to those at other equatorial stations and differ from those at higher latitudes.

![Progressive changes in diurnal variation of spread F at Ahmedabad (1954-57).](image-url)
3.2 Change in time of maximum spread F

Fig. 6 shows the times of maximum F2-scatter in each month. The change from post-midnight hour in 1954-55 to pre-midnight and fluctuating hours in 1956-57 is clearly seen.

![Graph showing change in time of maximum spread F](image)

**Fig. 6:** Change in the time of maximum of spread F occurrence at Ahmedabad (1954-57).

3.3 Seasonal, annual and sunspot variations of spread F at Ahmedabad

Monthly mean values of spread F frequencies between 20 and 06 hours, monthly mean magnetic character figure Cp, monthly median midnight values of hpF2 and of foF2 are given in Fig. 7. The seasonal variation of spread F runs almost in opposite direction to that of Cp. The relationship is more clear in 1954 and 1955. In 1956 and 1957, the disturbances in Cp were so great that clear correlations cannot be seen. The records
of midnight foF2 and hpF2 do not make clear that any definite relation exists between these quantities and the variations of spread F. Figs. 8 - 11 which show mean nighttime frequencies of spread F on each day of the month at Ahmedabad brings out clearly the anti-correlation between magnetic activity and spread F occurrence.

Fig. 7: Variation of mean nighttime spread F, midnight hpF2, midnight foF2 at Ahmedabad and the mean International magnetic character figure Cp (1954-57).

IV - Correlation of spread F at different places

For comparing the F2-scatter at Ahmedabad (φ = 13.6°N) with that at other stations, viz. Yamagawa (φ = 21.2°N), Delhi (φ = 18.8°N), Kodaikanal (φ = 0.6°N) and Singapore (φ = 10°S)
the months January, March, July and October 1956 were chosen. The day-to-day changes in mean nighttime spread F at the above places are shown in Figs. 8 - 11. The times of observation at Indian stations are common but the time at Singapore is two hours ahead of Indian time and that at Yamagawa four hours ahead.

Fig. 8

Figs. 8 & 9: Day-to-day relation of spread F occurrence in low latitudes, March 1956 and October 1956.

From the Figures it is seen that

1) In March and October, spread F echoes are frequent in low latitudes and there is a fair to good correlation in the day-to-day occurrence of spread F at Ahmedabad, Kodaikanal and Singapore. Spread F activity decreases at
Delhi and becomes negligible at Yamagawa.

(2) In January and July, spread F is less frequently observed at Ahmedabad than in the equinoxes and the agreement between Ahmedabad and Kodaikanal is poorer. Even between the two equatorial stations, Kodaikanal and Singapore, the agreement is poor. At Yamagawa, spread F is more frequent in these months than in the equinoxes. The above observations imply that the irregularities which cause spread F in March and October are more widespread about the equator than in January and July.

**Fig. 10**  
Figs. 10 & 11: Day-to-day relation of spread F occurrence in low latitudes, January and July 1956.
It may be mentioned that Wright et al. (1956) were not able to obtain good correlation in solstices between spread F at Ibadan and radio star scintillations at Achimota 510 km away, although both lie in the equatorial zone. Wells (1954) failed to get any similarity in the seasonal variation of spread F at Huancayo (\( \Phi = 12^\circ S \)) and radio star scintillations at Cambridge (\( \Phi = 52^\circ N \)). From the observations of spread F at the five places considered here, it appears that Yamagawa falls in the middle latitude zone, while Ahmedabad is very nearly in the equatorial zone in years of high sunspots.

(3) In all these months, spread F was low on days of high magnetic activity at Indian stations and Singapore. There is no indication of a decrease or increase in spread F at Yamagawa on such days. In a recent note, Lyon and others (1958) have shown that a change-over in the correlation between spread F and \( \text{Cp} \) takes place somewhere about \( \Phi = 20^\circ S \) or \( I = 54^\circ S \). Possibly the change-over from low to middle latitude type of spread F is somewhere near Yamagawa (\( \Phi = 21.2^\circ N \)) in the north.

V - RELATION OF SPREAD F TO MAGNETIC CHARACTER OF DAY

5.1 Diurnal variation of spread F on quiet and disturbed days at Ahmedabad.

In view of the suggested anti-correlation between mean nighttime spread F activity and \( \text{Cp} \) (Section III), it was felt desirable to investigate more closely the relation
between spread $F$ and magnetic activity. For this, days having $\sum K \geq 25$ (Alibag Magnetic Observatory) were picked out and they were called disturbed days. Days with $\sum K < 15$ were called quiet days. 132 disturbed days and 118 quiet days were available during 1956 - 1957. Mean diurnal variation of spread $F$ occurrence was then calculated both for quiet and disturbed days at Ahmedabad and the results are shown in Fig. 12. The quiet day variation shows a broad maximum over 2100 - 0200 hrs and it is about 44%. The disturbed day variation shows also a broad maximum in the same interval of time, but its magnitude has come down to nearly $1/3$ of that on quiet days. The broad maximum is probably due to the averaging of spread $F$ for all months.

On days of $\sum K \geq 35$ (25 days only), further reduction in spread $F$ is obtained. A similar result was found by Wright et al (1956) at Ibadan, particularly in winter. They showed from the data of 1952 that the spread $F$ activity increased with magnetic activity at Slough. Bhargava (1958) showed that spread $F$ was less frequent during disturbed days at Kodaikanal.

5.2 **Superposed-epoch variation of spread $F$ at Ahmedabad, Kokubunji and Slough.**

Variation of spread $F$ with magnetic activity was further examined by superposed-epoch method at three places which normally show spread $F$ characteristics different from one another. These places are Ahmedabad ($\Phi = 13.6^0 N$),
Kokubunji (25.5°N) near the Sq. current focus and Slough (φ = 54°N). Data for Kokubunji were taken from "Ionospheric Data in Japan" published by the Radio Research Laboratories and those for Slough were taken from the Ionosphere bulletin of Radio Research Station, D.S.I.R. Data of magnetic K indices were published by the Alibag Magnetic Observatory in the Indian Journal of Meteorology and Geophysics. All days with $\sum K \geq 25$ were taken as 'zero' days. When there were two or three days consecutively with high value of $\sum K$, the day having highest value was taken as 'zero' day. Percentage frequency of spread $F$ on zero day and on each of three days.
Fig. 13 a: - Relation of spread F to magnetic K index by superposed-epoch method at Ahmedabad, Kokubunji and Slough.

Fig. 13 b: - Spread F vs. $\Sigma K$ at Ahmedabad and Slough.
preceding and following were tabulated for each epoch. Total number of such epochs during 1956-57 for which data were available at Ahmedabad was 81. The averaged results on each day of these epochs are shown in Fig. 13a along with $\Sigma K$.

It is clear that spread F at Ahmedabad decreased with increase in $\Sigma K$ while at Slough spread F increased with increase in $\Sigma K$. For an increase in $\Sigma K$ by about 1$\frac{1}{2}$ times, the reduction in spread F at Ahmedabad and the increase in spread F at Slough were by about 2$\frac{1}{2}$ times. Kokubunji did not seem to be affected on quiet or disturbed days. It is concluded, therefore, that the change-over in the relation of spread F to magnetic activity takes place somewhere near Kokubunji.

The curves showing inverse variation of spread F with magnetic K index at Ahmedabad and direct relation at Slough are shown in Fig. 13b.

h'-f records in Fig. 3 taken during the night of 4-5 September 1957 (SWI) show no spread F. This was a night of magnetic storm and heights of F2 were raised.

Usually h'-f records are free from spread F after sunrise. h'-f records in the early morning hours of 22 January 1957 which was a period of severe magnetic disturbance showed absence of spread F (Fig. 14), increase of height to great levels and occurrence of spread F at 0600 hr when the height came down. Spread F at 0600 hr was unusual.
Fig. 14: h'–f records of Ahmedabad during the morning hours of 22 January 1957, a disturbed period, showing absence of spread F at great heights and its presence at 0600 hr when the layer descended.

Severe magnetic storms with much spread F are rare. But there was one such on the night of 29–30 September 1957. Records are reproduced in Fig. 15.

VI - SPREAD F AND F2–STRATIFICATION

Sometimes the h'–f record for F2 shows splitting into one or more cusps or ridges at the end or the trace may take a wavy shape with an intermediate inflection or its ends get straightened instead of rising sharply at the critical frequency. Such changes in h'–f records are denoted by letter 'H' meaning stratification within the layer. Munro (1953, 1956) has shown such splitting of h'–f record can take
place if a travelling wave disturbance passes over and causes changes in the vertical distribution of ionization. Whatever may be the cause of F2-stratification, it is found from the records so far taken at Ahmedabad that F2-scatter rarely accompanies F2-stratification. On the other hand, F2-scatter begins after the occurrence of F2-stratification. The former starts when the height falls while the latter is observed when the height is rising.

Fig. 15: - h'-f records of Ahmedabad during a magnetically disturbed night of 29-30 September 1956 showing spread F at great heights. Note also sporadic echoes at 170-200 km.
6.1 In Fig. 16 are shown the diurnal variations of spread F and F2-stratification for 1954 and 1955. It is found that F2-stratification has two peaks at 20 hr and 05-06 hr. These are also the times of temporary increases in height. On the other hand, F2-scatter begins after 20 hr and has a peak at 03 hr. It is falling down at 05-06 hr.

![Fig. 16: Comparison of mean diurnal variation of spread F and F2-stratification at Ahmedabad (1954-55)](image)

6.2 The inverse variation of F2-scatter and F2-stratification is further to be noticed from their seasonal variations. This is shown in Fig. 17. The mean percentages of F2-scatter cover the period 20-06 hr while those for F2-stratification cover the period 19-06 hr. It is seen that F2-stratification is maximum in equinoxes while F2-scatter is minimum in these seasons. The anti-correlation between these phenomena is clear. This result is consistent with the observations of McNicol and others (1956) at Brisbane who showed that spread
F was not due to stratification in F2.

Fig. 17: Seasonal changes of spread F in opposite direction to those of F2-stratification at Ahmedabad (1954-1955)

VII - CONCLUDING REMARKS

Let us now compare the characteristics of spread F at Ahmedabad with those observed at other latitudes.

7.1 In equatorial latitudes, Osborne (1951) at Singapore found that scatter echoes start when the height of the F2 layer (h'F2) begins to fall after reaching its maximum value. The frequency of occurrence is maximum at about 20 hr in equinoxes. At Ibadan, Wright and others (1956) reported the occurrence in summer of a peak around midnight near sunspot minimum. Wells (1954) at Huancayo found that F2-scatter echoes were frequent between 20 and 04 hrs with a peak at about 03 hr.
The occurrences were maximum in local summer but in low sunspot years, there was a secondary maximum in winter. The general trend was a decrease in occurrence with increase in sunspot number. Bhargava (1958) reported that F2-scatter variations at Kodaikanal in 1955-56 were similar to those at Singapore.

Regarding F2-scatter occurrences at latitudes higher than Ahmedabad, Reber (1954 a, b) showed that at a number of middle latitude stations, there was a peak near 03 hr in winter and that their number decreased with increase in sunspot number. At Brisbane, Singleton (1957) found that F2-scatter had maximum occurrence in winter. All the above workers showed that F2-scatter was a night-time phenomenon. A table giving the comparative characteristics of spread F at various places is given below. The stations are arranged in order of their geomagnetic latitudes from north to south.

7.2 Table I - Occurrences of spread F at different places.

(See next page)
TABLE I - Occurrences of spread F at different places

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Place</th>
<th>Geomagnetic Latitude</th>
<th>Time of diurnal Peak, hr, LMT</th>
<th>Seasonal Variation</th>
<th>Increase or decrease with increase in sunspot number</th>
<th>Author</th>
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<tr>
<td>1</td>
<td>Winnipeg</td>
<td>59.5° N</td>
<td>03</td>
<td>Max. in winter</td>
<td>Increase</td>
<td>Grote Reber (Private comm'n with Meek, 1954)</td>
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<td>Slough</td>
<td>54° N</td>
<td>03</td>
<td>Max. in winter</td>
<td>Increase</td>
<td>Dagg (1957)</td>
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<td>Washington</td>
<td>50.3° N</td>
<td>03</td>
<td>No special preference</td>
<td>No special preference</td>
<td>Grote Reber (1954)</td>
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<td>43.6° N</td>
<td>03 (Winter) 00 (Summer)</td>
<td>Max. in winter</td>
<td>-</td>
<td>-do-</td>
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<td>5</td>
<td>Barton Rouge</td>
<td>41° N</td>
<td>Changes from 00 to 05 hr from summer to winter</td>
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<td>Decrease</td>
<td>-do-</td>
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<td>-do-</td>
<td>-do-</td>
<td>Decrease to 1/10 in winter and 1/2 in summer</td>
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<td>Ahmedabad</td>
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<td>03 (S.S.min)</td>
<td>Max. in Decrease</td>
<td>Kotadia and Ramanathan (1958)</td>
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<td>21-22(S.S.max. in winter &amp; equinoxes)</td>
<td>of S.S. min. Max. in Equinoxes of S.S.max.</td>
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<td>00</td>
<td>Max. in local summer</td>
<td>Wright, Koster &amp; Skinner (1956)</td>
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<td>Kodaikanal</td>
<td>0.6° N</td>
<td>20</td>
<td>Max. in equinoxes</td>
<td>Bhargava (1958)</td>
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<td>Huancayo</td>
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<td>03 &amp; 05(Winter)</td>
<td>Max. in local summer</td>
<td>Wells (1954)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>02 &amp; 04(Summer)</td>
<td>Decrease</td>
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<td>Singapore</td>
<td>10° S</td>
<td>20</td>
<td>Max. in equinoxes</td>
<td>Osborne (1951)</td>
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<td>Rarotonga</td>
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<td>02-04</td>
<td>No special preference</td>
<td>Grote Reber (1954)</td>
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<td>13</td>
<td>Brisbane</td>
<td>35.7° S</td>
<td>05 (Summer) flat over 21-05 (Winter)</td>
<td>Max. in Decrease winter</td>
<td>Singleton (1956)</td>
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<td>Watheroo</td>
<td>41.7° S</td>
<td>21, 00 &amp; 05</td>
<td>Max. in winter</td>
<td>Grote Reber (1954)</td>
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<td>03 (Summer)</td>
<td>Max. in winter</td>
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<td></td>
<td>21-02(Winter)</td>
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</table>

S.S.min. = Sunspot minimum; S.S.max. = Sunspot maximum.
7.3 It is seen from the above table that

(1) In low sunspot years, the seasonal variation of F2-scatter has a maximum in winter at middle latitudes but maximum in summer at Ahmedabad and equatorial stations. In high sunspot years, it is still a maximum in winter in middle latitudes, but at Ahmedabad and equatorial stations, it is maximum in equinoxes instead of summer. At latitudes higher than $\phi = 22^\circ$, the maximum F2-scatter occurs in winter both in low as well as in high sunspot years.

(2) With change in sunspot number, maximum F2-scatter occurs at or near the minimum of the sunspot cycle at Ahmedabad and equatorial stations.

(3) From the correlation of magnetic activity with F2-scatter, a change-over of disturbance variation from low to middle latitude type was found to take place near Kokubunj (\( \phi = 25.5^\circ \) N) or Yamagawa (\( \phi = 21.2^\circ \) N).
References

