CHAPTER VI

ON THE SPECIAL FEATURES OF THE IONOSPHERIC DRIFTS

6.1 Height gradient of the horizontal drift and anisotropy parameters in \( E \) and \( F \) regions of the Ionosphere at Thumba

The height gradient of the apparent drift speed during day and night times for the \( F \)-region are described in paper attached at the end of this section. Some of these records were also subjected to full correlation analysis and these results are shown in table I. All the drift speed parameters, namely \( V_e, V', V \) and \( V_c \) are seen to decrease significantly with height. The drift directions \( \phi_a \) and \( \phi \) do not show any change with height. The axial ratio \( r \) and size of irregularities \( b \) are found to reduce at higher heights. The orientation of the characteristic ellipse \( \psi \) is more perfectly aligned to magnetic north-south at lower heights.

As regards \( E \)-region, simultaneous spaced aerial fading records were taken at very close frequencies. Frequency of one transmitter was kept fixed at 2.4 Mc/s while that of the other was varied by 0.1 Mc/s for each set of records. A few such records are reproduced in Fig.6.1a. The apparent drift speed and direction for these cases are shown in Table II. No systematic variation of drift
SHORT PAPER

Height variation of F-region horizontal drifts

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Abstract—The speed of horizontal drifts in the F-region of the ionosphere over Thumba decreases with height; the gradient being larger during night-time than during the daytime.

F-region horizontal drifts on 4.7 MHz over Thumba have been measured since January 1964. With the addition of another transmitter in January 1968, it became possible to measure drifts on a number of frequencies. Observations were taken on F-region reflections of 2.3, 4.7 and 6.0 MHz, whenever conditions were favourable. The present note describes the variation of the apparent drift velocity with the height of the ionosphere. The true heights of reflection of the echoes on the three frequencies were calculated from the ionograms, obtained at the same time using matrix inversion method (Budden, 1954). The receiving system consisted of the antenna $E_{1/2}$ situated 60 m ($\frac{1}{2}$l for 2.5 MHz) east of the central antenna (C) and another antenna $S_{n}$ situated 480 m (4l for 2.5 MHz) south of C. The observations were taken at three frequencies in quick succession.

Figure 1 shows an example of fading records separately on three different frequencies. It was generally noticed that the fading was faster on higher frequencies, but the characteristic of high correlation between the fadings at the three aerials was maintained on any of the frequencies. It is seen from the fading records that the time shift between the aerials 'C' and 'E_{1/2}' is significantly larger for 6.0 MHz than for 2.3 MHz.

Figure 2 shows the variation of the apparent drift speed with height for some observations during July 1968. It is clearly seen that during the night-time, drift decreased significantly with height. The gradient seems to be sharper at 260 km than at higher heights. The mean gradient was found to be 3.0 m/sec/km, during the night-time. During the daytime, the observations were confined between 150 and 250 km and the mean gradient was found to be much less, being 0.3 m/sec/km.

It is to be noticed that the F-region drifts at Thumba are invariably higher than the drifts in the F-region. Thus, there must be a region of maximum horizontal drift velocity somewhere in the lower part of the F-region.

Observations of ionospheric drift have been made by other workers on two or more frequencies. Yung (1956) found that the average drift speed at Puerto Rico was 73 m/sec on 4.57 MHz and 92 m/sec at 2.33 MHz, which indicates a decrease of speed with height. Rao and Rao (1961) observed F-region drifts on 4.2-4.8 MHz and 6.0 MHz at Waltair and found the most frequent drift speed to be 75 m/sec for F1-region and 85 m/sec for F2-region. They found the F2-region drift speeds to be generally higher than the F1-region drift speed, when measured simultaneously.
Fig. 1. Fading records on three different aerials of echoes on 2·3, 4·7 and 6·0 MHz at Thumba.

Fig. 2. Apparent drift speeds at different heights of reflection on individual observations.
Rao and Ramana (1961) discussed the drift at different heights taken during the daytime from 0800 to 1100 hr (for heights between 105 and 360 km). They found that the drift speed at first decreases with height, suddenly increases at a height of about 280 km and then fluctuates; the height gradient being about 0.7 m/sec/km. The present observations indicate that at the equatorial stations, the drift speed decreases with height during the day as well as during night-time. Observations are being continued to study the variation of drift characteristics with height.

Acknowledgements—Thanks are due to Indian National Committee of Space Research for the facilities of the experiment at Thumba Equatorial Rocket Launching Station and to the other colleagues at Thumba Equatorial Rocket Launching Station and Space Science and Technology Centre, Trivandrum, for their cooperation.

References

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<th>Publication</th>
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Right variation of drift and the anisotropy parameters for Thumba, 1963

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<th>Time</th>
<th>( V_a ) ( W/)</th>
<th>( V_r ) ( W/)</th>
<th>( V_c ) ( W/)</th>
<th>( V_c/V_r )</th>
<th>( \phi_a )</th>
<th>( \gamma )</th>
<th>( \varphi )</th>
<th>( \beta ) in North</th>
<th>( \beta ) in Frequency used in NHz</th>
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<td>3rd May</td>
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<td>86 71 10.05</td>
<td>341 83 4.7F</td>
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<tr>
<td>2300 hr.</td>
<td>85 85 24 39 1.61</td>
<td>86 71 10.05</td>
<td>341 83 4.7F</td>
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Table 1

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<td>Variable freq.</td>
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<td>1700 hr.</td>
<td>160 (2.4 kHz) 100 (2.3 kHz)</td>
</tr>
<tr>
<td>1702 hr.</td>
<td>120 (2.4 kHz) 85 (2.2 kHz)</td>
</tr>
<tr>
<td>1704 hr.</td>
<td>135 (2.4 kHz) 60 (2.1 kHz)</td>
</tr>
<tr>
<td>1706 hr.</td>
<td>140 (2.4 kHz) 100 (2.0 kHz)</td>
</tr>
<tr>
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<td>Variable freq.</td>
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<td>240°(2.4 kHz)</td>
<td>270°(2.3 kHz)</td>
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<td>270°(2.4 kHz)</td>
<td>269°(2.2 kHz)</td>
</tr>
<tr>
<td>269°(2.4 kHz)</td>
<td>290°(2.1 kHz)</td>
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<td>250°(2.4 kHz)</td>
<td>269 (2.0 kHz)</td>
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Table 2
THUMBA E-REGION
CLOSE FREQUENCY DRIFT RECORDS
6TH MAY 1968

THUMBA F-REGION
CLOSE FREQUENCY DRIFT RECORDS FOR FINDING VERTICAL DRIFTS

Figure 6.1a

Figure 6.1b
is seen with the increasing frequency separation. RAO and RAMANNA (1961) have shown for Waltair that both \( r \) and \( V_0/V_c \) decrease with height from 100 km to 180 km after which there is a sudden increase around 280 km in their values. Between 280 km to 380 km, the values of \( r \) and \( V_0/V_c \) fall off sharply.

6.2 Vertical ionospheric drift in E and F regions at Thumba

(a) Introduction

Existence of vertical movement of ionization in the F-region at the equator have been known indirectly for many years. The first direct measurement of vertical drift of ionization in F-region was reported by WOODMAN and HAGFORS (1968) for Jicamarca (2°N dip). RASTOGI (1970) reported the upward drift of the order of 17 m/sec in F-region over Thumba, using the upward moving kinks on the ionograms during daytime.

Based on the close frequency technique suggested by WRIGHT and FEDOR (1969), direct measurement of vertical drift in F-region over Thumba was made in 1968. The basic idea lies in correlating the fading records obtained at two closely spaced frequencies. So long as the vertical separation of the points of reflection of the two closely spaced frequencies is of the order of a wavelength used,
one expects to get a significant correlation between two fading records, for a certain time-lag $\Delta t$ which is a measure of the vertical drift velocity.

(b) **Experimental technique**

After the installation of a new drift equipment at Thumba in January 1968, two independent sets of horizontal drift measuring units were available each of which consisted of three channel recording units and transmitters in the range of 2 to 6 MHz. The regular drift observations at Thumba have been made using one of the systems, operated at 2.3 MHz for E-region echoes in the day and F-region echoes in the night. The receiving aerial system for Thumba is shown in Fig.1.14. The triangle $E_4S_4C$ was used for these observations. The other drift unit was operated at a closely spaced frequency of 2.2 MHz and the aerial system $N_1N_2C$ was used. Two independent central aerials 'C' were erected at the same place to be used for the two frequencies in order to avoid the cross-modulation of the two signals at closely spaced frequencies. The recording of the horizontal drifts was then possible at both 2.3 MHz and 2.2 MHz. By running both the equipments simultaneously, it was possible to record the horizontal drifts at two reflection levels at exactly the same instant of time.
CORRELOGRAMS FOR HORIZONTAL AND VERTICAL DRIFTS AT THUMBA F - REGION

2.3 MHz (HORIZONTAL) 2.2 MHz (HORIZONTAL) 2.2 MHz vs 2.3 MHz (VERTICAL)

TIME LAG IN SECONDS

FIGURE 6.28
The two recording cameras were similar and their film speeds were matched to the nearest possible by suitable gear adjustment. Common time marking circuit was linked to both the recording oscilloscopes and reference time signals were given at the beginning of the records apart from the usual 12 secs time marks. The records were finally projected and traced on the same scale side by side. A few such records are shown in Fig.6.1a and 6.1b for E and F-regions along with their specifications.

(c) Method of analysis

These records were analysed for determining the horizontal drifts at 2.2 MHz and 2.3 MHz from the shift of the maxima of the cross-correlograms. The mean apparent horizontal drift $V_H$ at the mean height of reflection for 2.2 and 2.3 MHz was then determined. These correlograms and the mean $V_H$ values along with their directions for the F-region are shown on the left hand side of Fig.6.2a. The fading records at the two central aerials were also correlated for the vertical drifts. These correlograms are shown on the right-hand side of the same figure. Ionograms corresponding to these times of observation were obtained from the vertical ionosonde operating at the same location (Thumba). These were subjected to true height reduction and the change of true height $\Delta h'$ corresponding to
a frequency difference $\Delta f = 0.1 \text{ MHz}$ was determined from the slope true N-h profile. This difference of height $\Delta h$ was divided by the time-lag $\Delta t$ corresponding to the maxima of the cross-correlograms between two frequency fading records, to obtain the vertical drift in the F-region between 250 - 300 Km. Similar experiment was also performed for the E-region at Thumba. The close frequency cross-correlograms for this are shown in Fig.6.2b. It was noticed that the maximum correlation was not significant showing that the change in the height of reflection is much more than a wavelength. This technique therefore could not be applied to E-region at Thumba.

(d) Results

Table III gives vertical drift in F-region along with the simultaneous E and F region horizontal drift. The interrelation of F-region vertical drift speed and E-region horizontal drift speed is shown in Fig.6.3. It is seen from these results that the F-region vertical drift is downward when the F-region horizontal drift is eastward and upwards when the horizontal drift is westward. It is also seen that the F-region vertical drift is proportional to the E-region horizontal drift. These results are in verification to the predictions of Martyr's theory of electromagnetic drift (see Chapt. r I).
THUMBA E-REGION

MULTI FREQUENCY CORRELOGRAM

6TH MAY 1968
1700 HR

2.4-2.3 MHz

0.4
0.2
0.1

2.4-2.2 MHz

0.3
0.2
0.1

2.4-2.1 MHz

0.3
0.2
0.1

2.4-2.0 MHz

0.3
0.2
0.1

TIME LAG IN SECS

FIGURE 6.2d

THUMBA E-REGION

F-REGION VERTICAL DRIFT M/S

E-REGION HORIZONTAL DRIFT M/S

FIGURE 6.3
<table>
<thead>
<tr>
<th>S.No.</th>
<th>Date and time</th>
<th>P-region vertical drift speed (m/s)</th>
<th>Direction</th>
<th>P-region horizontal drift speed (m/s)</th>
<th>Direction</th>
<th>E-region horizontal drift speed (m/s)</th>
<th>Direction</th>
</tr>
</thead>
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<td>7 May 1968, 1800 hr.</td>
<td>16.5</td>
<td>Up.</td>
<td>75</td>
<td>270°</td>
<td>100</td>
<td>270°</td>
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<tr>
<td>2</td>
<td>15 April 1968, 1815 hr.</td>
<td>17.3</td>
<td>Up.</td>
<td>200</td>
<td>270°</td>
<td>200</td>
<td>270°</td>
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<tr>
<td>3</td>
<td>18 April 1968, 2000 hr.</td>
<td>17.0</td>
<td>Down</td>
<td>120</td>
<td>90°</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>21 April 1968, 2000 hr.</td>
<td>19.0</td>
<td>Down</td>
<td>-</td>
<td>90°</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>13 May 1968, 2100 hr.</td>
<td>19.0</td>
<td>Down</td>
<td>200</td>
<td>90°</td>
<td>-</td>
<td>-</td>
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<tr>
<td>6</td>
<td>7 May 1968, 2200 hr.</td>
<td>16.7</td>
<td>Down</td>
<td>75</td>
<td>90°</td>
<td>142</td>
<td>90°</td>
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<tr>
<td>7</td>
<td>13 May 1968, 2200 hr.</td>
<td>17.0</td>
<td>Down</td>
<td>200</td>
<td>90°</td>
<td>150</td>
<td>90°</td>
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Table - III
6.3 **Reversal of drift direction at Thumba**

(a) **Introduction and observations schedule**

The diurnal behaviour of eastward and northward horizontal drifts in E and F regions at Thumba has been discussed in detail in Chapter II and III. It is noticed from these results that ionospheric drifts are predominantly westward during day and eastward during night hours. The morning and evening changeover timings seem to lie between 0600 - 0730 hrs IST and 1930 - 2100 hrs IST respectively. The routine F-region drift observations at Thumba have been made at hourly intervals over the entire period of the day for every alternative day since 1967. This was however not possible for E-region owing to its rare appearance at Thumba in the night hours. This schedule of observation however was found to be insufficient to get an exact picture as to how does the drift vector change from east to west in the morning and from west to east in the evening. The hourly observations showed a complete reversal from one hour to another and it was not definite whether it is truly so or the drift vector swears around slowly with time, going through north or south before coming back to east-west line. With this in view, an extensive series of drift observations at fifteen minutes interval were conducted in 1968 around
THUMBA F-REGION
MORNING REVERSAL OF HORIZONTAL DRIFT
(CONTINUOUS RECORD)

THUMBA F-REGION
EVENING REVERSAL OF HORIZONTAL DRIFT
(CONTINUOUS RECORD)

20th SEPTEMBER. 1968

THUMBA F-REGION
MORNING REVERSAL OF HORIZONTAL DRIFTS

THUMBA F-REGION
EVENING REVERSAL OF HORIZONTAL DRIFT

13th JANUARY. 1968

THUMBA F-REGION
MORNING REVERSAL OF HORIZONTAL F-REGION DRIFTS

THUMBA F-REGION
EVENING REVERSAL OF HORIZONTAL DRIFT

11th JANUARY. 1968

19th JANUARY. 1968

15th JANUARY. 1968

Figure 6.5
the morning and evening reversal timings. These were spread over a period of one hour before to one hour after the reversal. A few records were also taken continuously for two hours or more around the reversal times, so that fade to fade variation of drift vector could be obtained for the whole period. A set of few such records for F-region are reproduced in Fig. 6.5. The top two are the continuously run records. Such a study was not possible for E-region owing to its rare appearance in the early morning and late in the evening. A few such cases were however available and are under study.

(b) Rate of fading and drift vector around reversal

The rate of fading \( N \) and the apparent drift speed and direction were computed (MITRA, 1949) for all these records at the short intervals of time. These results are listed in Table IVa and IVb. The symbol S stands for a very slow fading, during which the method of similar fades fails and drift parameters cannot be determined. The variation of \( N \) around the morning and evening reversal times is shown in Fig. 6.6, and the vector plot for the drift speed is shown in Fig. 6.7. It is seen that the fading of the echo becomes very slow around the time of the reversal of direction. The drift vector changes over from east to west or vice versa, more or less suddenly.
<table>
<thead>
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<th>0630hr</th>
<th>0645hr</th>
<th>0700hr</th>
<th>0715hr</th>
<th>0730hr</th>
<th>0745hr</th>
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<tr>
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<td>150M/s</td>
<td>180M/s</td>
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<td>S</td>
<td>86M/s</td>
<td>86M/s</td>
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<td>θ′</td>
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<td>90°</td>
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<td>S</td>
<td>130M/s</td>
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<td>90M/s</td>
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<tr>
<td>θ′</td>
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<td>90°</td>
<td>90°</td>
<td>90°</td>
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<td>269°</td>
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<td>255°</td>
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<td>90M/s</td>
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**Table - IV.a**
Rate of fading

(Morning Reversal)

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<th>0730hr</th>
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<td>9</td>
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<td>15</td>
<td>18</td>
<td>15</td>
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<td>8</td>
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(Evening Reversal)

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<th>1830hr</th>
<th>1845hr</th>
<th>1900hr</th>
<th>1915hr</th>
<th>1930hr</th>
<th>1945hr</th>
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<td>10</td>
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<td>4</td>
<td>3</td>
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<td>2</td>
</tr>
<tr>
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<td>5</td>
<td>10</td>
<td>12</td>
<td>15</td>
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</tbody>
</table>

Table - IV.b
(c) **Morning reversal and the size of irregularities**

Both S and F-region morning reversal timings are well correlated with the maxima of the semi-minor axis of the characteristic ellipse at Thumba (see Fig.3.18 and 3.19). As the axial ratio in the early morning is very small, the irregularities are very much isometric at this time. The orientation of the irregularities being magnetic north-south, the morning reversal of the drift coincides with the maximum east-west dimension of the irregularities.

(d) **Evening reversal and height of the E-layer**

It was noticed from the day to day observations that the time of evening reversal usually occurs when the F-layer is at maximum height. The relationship between $h'F$ and the E-W drift speed in F-region at Thumba is shown in Fig.6.8 for each season of the year 1967 separately. The dotted line shows the time of evening reversal. The layer height $h'F$ is maximum at this time both in winter and equinoxes. During summer season, the reversal of drift occurs earlier and the $h'F$ peak is not very pronounced.

(e) **Reversal of drift in F-region and the appearance and disappearance of sporadic E-layer**

Fig.6.9 shows the appearance and disappearance times for $E_s$ at Thumba in relation to the times of morning and evening reversals of the F-region horizontal drift.
It is seen that the $E_s$ is present only when the drift is westward. On the days of late morning reversal of the drift in $F$-region, $E_s$ also appears late while on the days when $F$-region drift is westward till late hours in the evening, the $E_s$ ionization is seen to exist. The electrojet control of drift in $F$-region is already discussed in paper No.7 of Chapter IV. On the other hand the occurrence of the equatorial sporadic-$E$ has also been shown to be controlled by the equatorial electrojet (MATSUSHITA, 1962, KNECHT and MCDUFFIE, 1962). The relationship between the direction of the $F$-region horizontal drift and the occurrence of $E_s$ is therefore linked through the electrojet.

(f) Reversal of drift and short-term fluctuations in $H$

As discussed in Sec. 4.6 of Chapter IV and shown in Figs. 4.11 and 4.12, the horizontal drift in both $E$ and $F$ regions is found to be reversed when the $H$ value falls down below the normal expected level. The sporadic $E$ ionization is also found to disappear during this period (RASTOGI et al. 1971).

(g) Conclusions

It can be concluded from the foregoing results that the drifts are mainly controlled by the electric fields, resulting in a sudden reversal of drift vector. Also, at the time of morning reversal, the transverse
size of irregularities is largest and at the time of evening reversal the height of the F-layer is highest. The relationship between $E_s$ and drift direction further confirms that electric fields are responsible for the drift.

6.4 Drift and anisotropy parameters at Thumba during spread-F conditions

(a) Introduction

SPREAD-F at Thumba (0.6°S) is predominantly a night-time phenomenon and increases with increasing solar activity (HARISH, 1971). The year 1968-69 was therefore specially suited for the study of the characteristics of the fading of the signal reflected from the F-region of the disturbed ionosphere i.e. the spread-F. The drift and anisotropy parameters of the ground diffraction pattern can also be studied at the same-time by using closely spaced fading records on the ground. A special series of observations was therefore planned during 1968-69 so that a sufficient number of records at the onset and during the existence of spread-F could be collected. Spread-F at Thumba usually started at 1900 hr and the rise of the F-layer on these days was unusually large. This was one indication of the likely occurrence of spread-F on a particular night and the drift observations on such nights were conducted till the spread-F lasted. Mostly it died out by 22 to 23 hr but there were a few days on which it continued for the
<table>
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<th>2201 HR</th>
<th>2202 HR</th>
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</table>

25TH NOVEMBER, 1967, 4-7 MHz

Figure 6.10
whole night till 06 hr. All recordings were performed on the leading edge of the spread-$F$ echo by reducing the width of the gating pulse to as small as possible. The slant echoes are thus avoided as far as possible.

(b) Fading characteristics during spread-$F$

A few continuous drift records were taken from the onset to disappearance of spread-$F$. One such record is reproduced in Fig.6.10. A number of isolated drift records during Spread-$F$ conditions are shown in Fig.6.11. The very prominent and important feature of these fading records was the presence of a super-imposed fast fading over the normal slow fading of the signal, appropriate to the evening time on no-spread days. A few such records were analysed for the cross-power spectrum and the drift spectrum using JONES and MAUDÈ (1968) relations. The results for one such case are shown in Fig.6.12. Presence of two distinct fading frequencies centred at about 0.5 c/s (i.e. 38 fades/minute) and 1.4 c/s (i.e. 84 fades/minute) is prominent. The first peak corresponds to normal fading rate at 1900 hr at this time of the day while the second peak corresponds to ripples of fast fading, the special feature of spread-$F$ echoes.

The variation of the apparent drift speed with fading frequency is shown by the thick line. The dotted
portion corresponds to the low power region of the record and the results are not significant. The drift speed is seen to be clearly higher (almost double) for the higher fading frequency region than the normal fading frequency region, which would be the actual drift of the ionization on a no spread-F day. The drift direction however shows no significant variation with frequency and is not shown here. A higher value of drift speed at higher fading frequency can also arise due to a positive dispersion of drift in the ionosphere. The various causes of the origin of such a dispersion are discussed at length in Chapter 7.

(c) Results for $V', \phi, V, \phi, V_o, V, \theta, r$ and $\phi'$

All these records were also analysed for $V'$ and $\phi'$ by the similar fades method and the results are shown in Fig. 6.13 in comparison to the normal no spread-F days. The variation of the rate of fading $N$ is also shown. The increase in $N$ as well as $V'$ is maximum in the early part of the night, when the spread-F is usually very strong. The direction $\phi'$ does not show any significant change over the normal eastward drift in the night.

Steady and random drift parameters, $V, V_o$ and $V_o/V$ were also computed using the full-correlation method of analysis and are shown in Fig. 6.14 along with the normal
day variation. The increase in steady drift $V$ is comparatively less than that in the apparent drift. The increase in the random drift $V_c$ however accounts for this discrepancy as the apparent drift includes the effect of both. The ratio $V_c/V$ shows a fairly large increase in the early part of the night, during which $N$ and $V'$ also increase to a larger extent. Thus the high fading rate during spread-$F$ adds to a higher random component of drift.

The anisotropy parameters of the ground diffractive pattern during spread-$F$ are shown in Fig.6.15 in comparison to the normal day variation. Both axial ratio and the semi-minor axis increase and this increase is much larger in the early part of the night, same as that for $N$, $V'$ and $V_c/V$. The orientation $\gamma$ of the characteristic ellipse however does not change significantly excepting in the earlier part of night, when the ellipse tilts more towards the west of north. The increase in $r$ and $b$ along with that of $N$, $V$ and $V_c$ is consistent. The Fig.6.16 finally gives variations of the spread-$F$ index, the height of F-layer and the eastwest component of the apparent drift speed at Thumba during 1967. There is a close correspondence between the time of the onset of the spread-$F$, the peak of $h'F$ and the evening reversal of the east-west drift.
Discussion

The super-imposed fast fading during the spread-F condition can be interpreted in terms of the presence of smaller scale irregularities within the bigger lumps of ionization. The spread-F at an equatorial station is more pronounced during the quiet days (CHANDRA and RASTOGI, 1971) (see Fig.6,17) and hence the present results namely the increase in V', V, V_c and r and b are consistent with those of Chapter IV where drift and anisotropy parameters are shown to have reduced during the magnetically disturbed days. SIVRAM (1960) has however shown a reduction in V but an increase in r during the magnetic disturbances for Waltair. FOKKES (1961) has discussed the result of drift parameters for Cambridge during the magnetically disturbed conditions and the spread-F. The appearance of the large values of V_c is explained in terms of the different drifting velocities at different parts of the spread-F echo, due to the finite height range of the gating pulse in the drift recording equipment. He has also shown that the irregularities during the magnetic disturbance are more nearly aligned to the magnetic north-south and are smaller in size. Hence the larger size of irregularities tilted slightly away from the magnetic N-S during the spread-F conditions at Thumba are the representative of a relatively quiet conditions. CLIMSHA (1964) has
FIGURE 6.16

THUMBA 1965-67

MEAN SPREAD-F INDEX (a, b)

MINIMUM VIRTUAL HEIGHT AT IN KM

TIME IN HOUR 75° E.M.T.
also studied the drift of spread-F type of the irregularities and found it to be of the order of 100 m/s towards east. He also showed using Doppler shift measurements, that the irregularities sometimes exhibit large vertical velocities. The irregularities are shown to be anisotropic in the E-W vertical plane.

6.5 Occurrence of opposite drifts in E and F-regions at Thumba

It has been shown earlier (Chapter II and III) that the E and F region drifts at Thumba are predominantly westward during day and eastward during night hours. A detailed study of individual records of drift for the year 1968-69 showed that out of nearly two thousand sets of successive E and F region records, nearly one hundred showed opposite drifts. This included the periods around the normal morning and evening reversals of the drift.

A few simultaneous E and F-region drift records at the same frequency were also taken by using the two drift recording units and a common transmitter. Two such sets of records are reproduced in Fig.6.18. A number of successive E and F region records in the day and night time, when the drifts are found to be in opposite directions are reproduced in Fig.6.19.
THUMBA 1968

SIMULTANEOUS E- AND F-REGION DRIFTS

2nd APRIL, 1968, 1700 HR
2-3 MHz, E-REGION
4-7 MHz, F-REGION

Figure 6.18

THUMBA 1968-69

OCCURRENCE OF OPPOSITE DRIFTS IN E- AND F-REGIONS

DAY TIME
E, C
S, C

27th MAY, 1968 1000 HR

NIGHT TIME
F-REGION
E-REGION

10th NOV., 1968 2100 HR

Figure 6.19
Opposite drift in E and F regions show that the E and F region reflections refer to two well separated height ranges and the fading is introduced near the level of reflection. There is however some integration of drift velocities over a finite height range.

6.6 Dependence of the drift and anisotropy parameters of the ground diffraction pattern at the equator on the E-W and N-S extent of antenna separation

(a) Introduction

The D_i-method of drift measurements is based on the tacit assumption that the aerial separation in any direction is such that all the three antennae see the same irregularity at any time. This separation is normally taken as one wavelength, so that the similarity of the variation patterns at the three spaced receivers is not lost and it is thus possible to estimate the drift of the diffraction pattern on the ground in a particular direction from the time lag between the similar features on the variation patterns at two points in that direction. It is also assumed here that the ground pattern is more or less isometric so that the use of equal north-south and east-west separation of receiving aerials yields equal sensitivity in both the directions.
For equatorial stations however, where the diffraction pattern on the ground is highly elongated in the magnetic north-south direction, some irregularity traverses vast the two north-south aerials C and N for a long-time, leading to extremely high correlation between the two records of fading at central and north aerials, whereas the predominant eastwest drift and lesser extent of the irregularity in this direction causes a relatively much sharper fall of the correlation.

(b) Special observations

The routine measurements at Thumba for the ionospheric drifts were conducted from Jan 1964 through Aug 1966 using a right angled isoceles triangle of receiving aerials, namely $W_1CS_1$ ($W_1C = CS_1 = 120$ meters). There was almost a complete absence of the time-lag in N-S direction so that the N-S drift could not be determined. The E-W true drift speed $V$ was found to be on the average 100 m/s and the axial ratio and orientations of the characteristic ellipse of the ground diffraction pattern was found to be on the average 5.0 and $\pm 2^\circ$ of the magnetic north respectively. The north-south separation of receiving aerials was however increased to twice the wave-length in Sept '66, in order to get an appreciable time-lag in this direction. Though it made no appreciable change in the sensitivity as per
the time-lag is concerned, the axial ratio of the characteristic ellipse was noticed to have on the average increased slightly for the year 1967 for both E and F regions.

In the year 1968, along with the installation of a new drift recording unit at Thumba, a much extended north-south aerial system was erected, which is shown in the Fig. 1.14. A total separation of four wavelengths corresponding to 2.5 MHz (i.e. 480 meters) was used in the north-south direction for the routine observations. The east-west separation on the other hand was reduced from one to half wavelength. The values of axial ratio 'r' were once again found to have gone up slightly for both E and F regions over the 1967 values though the true velocities were found to be slightly less. The effect of solar activity on the drift and anisotropy parameters at Thumba is discussed in Sec.2.7 of Chapter II and 3.5 of Chapter III. The apparent drift speed does not show any significant variation from 1964 to 1969 whereas the true drift speed decreases. The axial ratio is found to increase and b is found to decrease from 1964 to 1969. The orientation angle $\psi$ is not affected much. The decrease in the values of V from 1967 to 1968 was however much pronounced and appears to be caused by a reduced E-V separation of the aerials. The increase in 'r' was much
THUMBA F-REGION
FIVE "ANTENNA SIMULTANEOUS FADING RECORDS"
13th MAY 1968, 2200 HR

Figure 6.22
sharper with the change over of antenna system and this lead to a series of special observations by the author in 1968 which were aimed at determining the dependence of drift and anisotropy parameters of the ground diffraction pattern on the east-west and north-south extent of aerial separation at the equator.

Simultaneous drift records were taken at the same frequency for E and F regions using two different drift recording units operating for two different adjacent triangles of receiving aerials. One aerial system was kept to be $T_1 N_2 C$ and the other one was having much more N-S separation and lesser E-W separation, namely $E_2 S_3 C$. The common central aerial C was used, by installing two central aerials at the same place. This was necessitated by the need of a reference aerial, so as to get a common auto-correlation function for both the sets of drift records, while subjecting it to full correlation analysis of PHILLIPS and SPENCER (1955). A set of four such simultaneous drift records are reproduced in Fig.6.22. The arrow indicates the same instant of time on the two records.

(c) Results
Auto and cross-correlation functions were computed for the two sets of records and the $V_c'$ ellipses
THUMBA F-REGION DRIFT
CORRELOGRAMS FOR THE SIMULTANEOUS DRIFT RECORDS ON TWO DIFFERENT ANTENNA SYSTEMS

17th May 1968
2300 HR 2.3 MHz

7th May 1968
2100 HR 2.3 MHz

7th May 1968
2200 HR 2.3 MHz

17th May 1968
2200 HR 6.0 MHz

TIME IN SECONDS

FIGURE 6.23a

THUMBA F-REGION DRIFT
DEPENDENCE OF ANISOTROPY PARAMETERS ON AERIAL SEPARATION (SIMULTANEOUS CHARACTERISTIC ELLIPSES)

FIGURE 6.23b
were drawn following PHILLIPS and SPEICHER (1955). These are shown in Fig. 6.23a and Fig. 6.23c respectively. The various drift and anisotropy parameters, namely apparent and true drift speed and direction, the random drift speed, the axial ratio, orientation and the semi-minor axis of the \( V_c \) ellipse were computed and these are given in Table V.

Following points are noteworthy from these results:

1. The apparent drift speed and direction \( (V_a \text{ and } \phi_a) \) do not show much dependence on the E-W and N-S aerial separation.
2. The true drift speed \( V \) increases with increasing E-W separation while \( \phi \) shows no significant change.
3. Random drift \( V_c \) is slightly higher for the smaller E-W separation.
4. The axial ratio 'r' of the characteristic ellipse increases significantly with the increase in N-S separation.
5. Semi-minor axis 'b' also shows a very slight increase with increasing E-W separation.
6. The orientation angle \( \psi \) tends to be more N-S with increasing N-S separation.

A few more records for the year 1967 were looked for this effect. The results for two of such successive
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<th>$\phi_a$</th>
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<th>$\phi$</th>
<th>$V_c$</th>
<th>$r$</th>
<th>$b$</th>
<th>$\gamma$</th>
<th>Triangle used for calculation</th>
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<td></td>
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<td>92°</td>
<td>128</td>
<td>95°</td>
<td>67</td>
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<td>115</td>
<td>359°</td>
<td>E3S4C</td>
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<td>180</td>
<td>86°</td>
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<td>42</td>
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**Table - V**

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<th>$b$</th>
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<td>7°</td>
<td>b' = 480M</td>
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**Table - VI**
records, taken within few minutes of each other, are shown in the Fig.6.24a and 6.24b. The values of various parameters are listed in Table VI. Assuming that the drift and the size of the irregularities remained constant during the period of these successive recordings, once again the dependence of \( V, \gamma_c, r \) and \( \gamma \) on the aerial separation is clear. The semi-minor axis 'b' is also slightly lower with a lower E-W separation.

(d) Interpretation of results

BENYMON and WRIGHT (1969a) have also discussed the effects of the aerial separation on the drift parameters for higher latitudes namely Aberystwyth and Halley Bay. The variation in the values of \( V \) and \( \theta \) are accounted for the curvature of line of maximum. The case of an equatorial station is however studied for the first time here in regard to the effect of the size of aerial system. The fact that there is no change in the apparent drift speed with the increasing E-W aerial separation at Thumba while the true drift \( V \) increases, indicates towards the non-uniform variation of the shape of the correlograms with the aerial separation. This can arise due to various reasons, particularly the curvature of the line of maximum amplitude. As the drifts at Thumba are predominantly E-W, the effect of N-S aerial separation on \( V_c \) and \( V \) will
THUMBA F-REGION DRIFT

CORRELGRAMS FOR SUCCESSIVE DRIFT RECORDS WITH DIFFERENT ANTENNA SEPARATIONS

TIME LAG IN SECONDS

THUMBA F-REGION

DEPENDENCE OF THE ANISOTROPY PARAMETERS ON AERIAL SEPARATION (CHARACTERISTIC ELLIPSES FOR SUCCESSIVE DRIFT RECORDS)

- $\alpha = 60$ METERS
- $\beta = 120$ METERS

- $\alpha = 120$ METERS
- $\beta = 480$ METERS

$6^{th}$ OCT 1967
0500 HR
47 MHz

$23^{rd}$ OCT 1967
1500 HR
47 MHz
be negligible. The presence of waves in the ionosphere can also cause the increase or decrease of the drift velocity with the increase of aerial separation (see 7,9). The increase in random drift $V_c$ with a smaller $E-W$ separation shows the existence of larger number of smaller scale irregularities which are undergoing changes in their shape than the bigger ones. The increase in $r$ with increasing $N-S$ separation indicates towards a highly elongated $N-S$ irregularities in the ionosphere over Thumba, the size of which could be even bigger than $r$ determined by the maximum available 480 meters separation in $N-S$ direction. No further increase in the value of $r$ with the increase in the $N-S$ aerial separation should be observed once this separation is of the order of the size of irregularity in $N-S$ direction.

The semi-minor axis $b$ increases only slightly with $E-W$ separation, indicating that the separation of the order of a wavelength in this direction is optimum as the irregularities are nearly of the same size in their $E-W$ extent. Orientation angle $\Psi$ tends to be more and more $N-S$ with increasing $N-S$ separation which shows that the irregularities are highly elongated and almost oriented in magnetic $N-S$ directions. BENYON and WRIGHT (1969b) have shown for Halley Bay and a few other stations that
there is a distinct tendency of the correlation ellipse to be oriented with its major axis along the longest side of the antenna system. They have shown that this dependence can be explained in terms of the distortion of the ground pattern from an exact ellipse which is the basic assumption of the BRIGGS, PHILLIPS and SHINN (1950). All these results point towards the necessity of optimization of the size and geometry of the receiving aerial system for all the drift stations over the world. It is suggested that for a station like Thumba, the N-S aerial separation be further increased keeping the east-west separation between $\lambda$ and $\frac{1}{2}\lambda$.

(e) Discussion

KELLEHER (1966) found that the magnitude of true drift velocity increases with triangle size, but did not indicate any upper limit. GOLLEY and ROSSITER (1969) have made an extensive study of this effect using an array of 89 dipoles (at Buckland Park, Adelaide) and found that though $V_a$, $R_a$ and $\phi$ are independent of triangle size, $V, r, b$ and $\psi$ show a strong dependence till the optimum size is reached (about 300 m for E-region). Equatorial triangle avoids the dependence of $\psi$ on the diagonal of the triangle.
GOLLEY and ROSSITER (1970) have studied the effect of the triangle size on the drift parameter for the partial reflections for D-region at Adelaide. Little dependence was found as the pattern size was comparable with the smaller triangle size of 140 metre (a side of an equilateral triangle) for Adelaide. SASTRI and RAO (1971) have recently reported for Waltair the results similar to Thumba.

Advantage of the equilateral triangle has been pointed out by BIEL, HARNISCHMACHER and RAVER (1955) and BARBER (1957). SPRENGER and SCHMINDER (1969) considered the effects on drift parameters of filtering the fading records. They subtracted the running mean from each record which had the effect of removing low frequency component and by varying the width of the running mean, the filter cut off frequency was varied. Full correlation analysis was applied to the original and filtered records. They found that the true and apparent drift directions and the apparent drift velocities were unaffected by the filtering but the true velocity increased as the cut off frequency is increased. By filtering the low frequency components, the scale size of the pattern is effectively reduced. Thus SPRENGER and SCHMINDER (1969) effectively varied the pattern size relative to a fixed triangle size. The result is therefore consistent
with those quoted here as well as by KELLEHER (1966) and GOLLEY and ROSSITER (1969), that the true velocity increases with the ratio of the triangle size to pattern scale size.

6.7 Effect of solar flares on the drifts at Thumba

E and F region drifts at Thumba during solar flares of period 1968-69 were studied and their variation around the time of maximum of the flare is depicted in the accompanying Fig. 6.26. Flare data of Kodaikanal observatory was used for this study. It was observed consistently that both E and F regions apparent drifts were reduced considerably over their normal values. During some of the very severe flares, there was a complete black-out of the signal and no drift record could be taken.

RAO and RAO (1961) have however shown an increase in the E region drifts on two solar flare days, at Waltair. An interesting feature of their result was a large phase difference of about three hours between the drift vector on solar flare days and the quiet days, the former being ahead. This indicates that the drift systems for these two cases are situated at different levels. In view of the fact that the drift measurements made at E-region reflections might be considerably affected by the enhanced ionization in the lower levels during the solar flares,
IONOSPHERIC DRIFTS AT THUMBA DURING SOLAR FLARES
(1968-69)

**E-REGION**

- 8/9/69
- 9/4/65
- 7/27/68
- 7/10/68
- 5/2/65

**F-REGION**

- 8/9/69
- 9/4/65
- 7/27/68
- 7/10/68
- 5/2/65

**FIGURE 6.26**
it may be possible that the drift velocities during flares refer to lower levels in E-region or higher levels in D-region. VOLLARD and TAUBENHEIM (1958) have shown that the disturbed current system may also extend down to the D-region.

6.8 Drift and anisotropy parameters from first and second order reflections recorded at spaced aerials

(a) Introduction

The closely spaced aerial technique of measuring ionospheric drift (MITRA, 1949) assumes that the diffraction pattern on the ground moves with twice the velocity of the ionospheric irregularities. WRIGHT (1968) suggested that the point source effect is valid for the waves reflected totally from the ionosphere at normal incidence. He found discrepancy between the neutral atmospheric winds and the ionospheric drifts determined simultaneously. It has been suggested that the computed ionospheric drift depends on the antenna spacing used to observe it (KELLEHER, 1966) and for small spacing is less than true velocity by a factor of the order of two. PELGATE (1970) using multiple antenna showed that a classical interpretation is true for waves both totally and partially reflected. BOOKER et al. (1950) have shown that the auto-correlation function $\rho_2(t)$ of the amplitude of a doubly reflected
echo is equal to the square of the auto-correlation function \( \rho_1(t) \) of the amplitude of a singly reflected echo i.e.,
\[
\rho_2(t) = (\rho_1(t))^2 \tag{1}
\]
SEn (1964) generalized this result for the \( n \)th order reflection from the ionosphere:
\[
\rho_n(t) = (\rho_1(t))^n \tag{2}
\]
The experimental observations by SEN (1964) indicated that the above relation holds only approximately. ESSEX and HIBBERD (1967) have shown that the equation number(2) is valid experimentally when the signal amplitude has a Rayleigh type of distribution. HARANG and PEDERSON (1956) have measured the fading records on eastwest base on the first and second order echoes simultaneously and have found that the relative displacement of fading maxima was same in the first and the second order reflections.

This paper describes the results of closely spaced drift records from the first and second order echoes from the ionosphere at an equatorial station Thumba.

(b) Specular and diffusive reflection mechanisms

The reflection of the radio waves from the ionosphere can be treated as the reflection from the plane
mirror or from a completely diffused layer. The geometry of the two nodes of reflections are shown in Fig. 6.29. In the specular reflection case, a series of plane mirrors moving with a velocity \( V \) at the height of the reflection are reflecting the wave and we obtain the first order reflection pattern on the ground moving with a velocity \( 2V \). When the radio wave from this moving pattern is again reflected from a suitable mirror which now will have only half of the velocity relative to the beam from the pattern, the ground diffraction pattern for the second order reflection will be stationary. The second model of diffusive reflection could be somewhat similar to the model of the diffractive reflection outlined by RATCLIFFE (1947). According to this model the fadings are produced by the doppler effect of the moving diffraction centres which are distributed at random and the diffractive reflection process, the prehistory of the primary waves falling on the radiating centres will be of minor importance and the drift effects will be the same in the first and second order reflection ground patterns. It is assumed so far that the ground is not rough and acts as a plane mirror so as to produce a specular reflection of radio-waves. This condition more or less holds when the soil conductivity is high. Thumba is one such station. In the case of rough ground however, the reflection of radio
THUMBA 1968-69

SPECULAR REFLECTION FROM IONOSPHERE

DIFFUSIVE REFLECTION FROM IONOSPHERE

FIGURE 6.29

SIMULTANEOUS GATING OF TWO MULTIPLES

GATE INTENSIFYING PULSE

FIGURE 6.30

THUMBA 1968-69

APPARENT DRIFT SPEED

APPARENT DRIFT DIRECTION

V' BY SECOND MULTIPLE IN M/S

V' BY FIRST MULTIPLE IN M/S

ϕ BY SECOND MULTIPLE IN DEGREES EAST OF NORTH

ϕ BY FIRST MULTIPLE IN DEGREES EAST OF NORTH

FIGURE 6.31
waves from the ground is diffusive. It can be seen geometrically that if the ionospheric reflection is specular and the ground reflection is diffusive, the drift velocity of the ground pattern as derived from various higher multiples will be same and it will be double of the actual drift velocity of the ionization. In the other case, when both ionospheric and ground reflections are diffusive in nature the drift velocities derived from different order echoes will be same and equal to the actual drift velocity of the ionization.

(c) Experimental arrangements

Regular drift observations at Thumba were started in 1964. With the installation of another drift equipment in 1968, two independent closely spaced drift recording units were available for observations other than the routine drift measurements. It was also possible to obtain higher order multiple echoes with the high power transmitter installed in 1968. The drift measurements on the first and the second order echoes were made both for E and F regions by the three different techniques. Firstly the fading records could be obtained by a single unit on first order echo for a few minutes and immediately later on the second order echo, so that the aerial system remains the same. This method assumes that the ionosphere
has not changed within this interval of few minutes. Two sets of such records are reproduced in Fig.6.28 for \( E \) and \( F \) regions respectively. In the other method, single transmitter and two independent receiving and recording system were used. Thus drift records could be obtained simultaneously on the first and second order echoes but using two different aerial systems. Third method was based on the use of the very broad gating pulse of the width sufficient to gate both the first and second echoes but the envelope being trapezeum rather than square (see Fig.6.30). It was thus possible to record on the same film, fading of the first and second multiples. The intensity modulation of the two multiples is unequal and hence the second multiple fading appears as a less intense trace on the film than the first one and the two can be followed independently. A few such records are reproduced in Fig.6.27. The advantage of this system is the use of the same receiver and the aerial system used to record the fadings of two multiples and at exactly the same time. The records were analysed by similar fades (MITRA, 1949) method as well as full-correlation technique (BRIGGS et al. 1950; PHILLIPS and SPENCER, 1955) and the results are discussed below.
THUMBA F-REGION
FIRST AND SECOND MULTIPLES TOGETHER

26<sup>th</sup> April 1968, 1900HR.

2-3 MHz

26<sup>th</sup> April 1968, 2300HR.

2<sup>nd</sup> December 1968, 2100HR.

Figure 6.27

THUMBA DRIFT RECORDS

2 December 1968, 2100HR, E-REGION

Figure 6.28
(d) **Apparent Drifts**

The results, both for the first and second multiple echoes are given in Fig. 3. It is seen from the diagram that the drift direction is invariably the same for the first and the second order echoes. In no case, the direction were found to be opposite. Regarding drift speed, the second multiple drifts are always lower than those derived from the first multiple. The dotted line in the Fig. shows when the two would be equal.

According to the specular reflection mechanism, the drift speed of the second multiple should be zero irrespective of the first multiple speed while according to diffusive mechanism they should be equal. In general, the \( V' \) by second multiple is roughly two third of the \( V' \) derived from the first.

(e) **Steady and random drift**

In Fig. 6.32 are shown the following parameters derived from both the first and the second multiple: (1) apparent drift speed \( V_a \) derived from the shift of the optimum cross-correlation coefficient (2) the true drift speed \( V \) (3) the characteristic drift speed \( V_c \) and (4) the ratio of random to true drift, \( V_c/V \). The apparent speeds are only slightly less for the second multiple as compared to the first while the true drifts are only slightly more for the second than for the first multiple. Seeing to the scatter of
points it is rather more proper to assign the true drift to be of the same order. The slight difference between the relation of $V_e$ and $V$ between the first and the second multiple is due to the $V_e/V$ being slightly higher in the second multiples. On the average one may suggest that the true drift speed derived from the second and the first multiple suggest that the mechanism which is operative at least at the magnetic equator is predominantly diffusive where the factor of two is not valid.

(f) **Anisotropy parameters of the diffraction pattern**

In Fig.6.33 are shown the parameters of the characteristic ellipse fitted to the diffraction pattern on the ground, namely the axial ratio ($\gamma$) the semi-minor axis (B) and the orientation ($\phi$) of the major axis of the ellipse with respect to the magnetic north-south. The axial ratio ($\gamma$) seems to reduce for the second multiple. This would be understandable by the increasing scattering component of the radio wave in the second multiple than in the first. The semi-minor axis (b) and the orientation ($\phi$) of the characteristic ellipse are nearly the same for the two multiples.

(g) **Autocorrelation functions**

The mean autocorrelation functions for both first and second multiples were calculated and Fig.6.34 shows the variations of the auto-correlation function of the
first and second multiple ($\gamma_1$ and $\gamma_2$) for corresponding time lags. As the logarithm of the correlation function are plotted, the slope of the straight line will give the coefficient 'n' of the equation (2). It is seen from the diagram that although the 'n' lies between 1.5 - 2.7, but still the validity of the equation (2) is more or less verified.

**Discussion**

The comparison of drift speeds derived from the first and second multiple echoes from E and F region reflections at Thumba indicate that the process of reflection of the radio waves in the ionosphere are neither completely specular nor completely diffusive but the tendency is more towards diffusive than towards a specular process. The drift speed derived from the second multiple is never zero nor insignificantly low but nearly of the same order as the drift speed of the first, suggesting that the division by two of the drift speed of the ground pattern to obtain the drift speed at the ionospheric level is not valid in most of the cases. The change in the autocorrelation coefficients with the order of multiple is found to be approximately as expected on the theory of diffraction grating suggested by BOOKER et al. (1950)
It is suggested that the routine drift observations should be taken by the Ionospheric stations whenever possible both by first and second multiple echoes, in order to ascertain the mechanism of reflection operative for the individual cases. The dividing factor of two should accordingly be modified.