4.1 INTRODUCTION

The present chapter describes polarization measurements of type III bursts observed at 25 and 35 MHz. The measurements of Faraday rotation at 35 MHz with the two-bandwidth (7.5 and 12.5 KHz) polarimeter (described in Chapter V) enabled us to correct the polarization parameters \( (m \text{ and } r) \) of type III bursts at 25 and 74 MHz which were recorded with bandwidths of 20 and 10 KHz respectively by the method suggested by Akabane and Cohen (1961). Polarization data at 74 MHz were those obtained by Bhonsle and McNarry (1964b) in Canada. Initially polarization measurements at 35 MHz were made in a bandwidth of 800 Hz only, and since it was found that the measured Faraday rotation was of the order of \( 10^3 \) radians only, we did not correct the narrow bandwidth (800 Hz) measurements of polarization parameters at 35 MHz for the Faraday rotation. To identify type III events recorded by the 25 MHz polarimeter, we made use of the film recordings of the radio spectroscope operating in the frequency range of 40 - 240 MHz at the Physical Research Laboratory, Ahmedabad. Further, some type III events, confirmed by the spectroscopes operating at the Weissenau Radio Astronomy Station, Astronomical Institute of Tübingen University, (West Germany) in the
frequency range of 30 - 1000 MHz and at the Culgoora Solar Observatory, Australia in the frequency range of 10 - 220 MHz, were recorded by our polarimeter. The actual number of type III groups of bursts recorded in the period from July, 1969 through June, 1970 was 35.

4.2 TYPICAL POLARIMETER RECORDINGS OF TYPE III BURSTS

Direct recording of the Stokes parameters $I$, $Q$, $U$ and $V$ makes it possible to recognize, at least qualitatively, the type of polarization by inspection of the polarimeter recordings. Some typical radio polarimeter recordings made at 25 and 35 MHz with a post-detection time constant of 1S are shown in Figures 4.1a and 4.1b.

Figure 4.1a shows a complex group of type III bursts at 35 MHz which lasted for about 3 minutes. The degree of polarization varied from 10 to 30 per cent. The axial ratio was variable, that is, the ellipticity was varying from one burst to another. The sense of rotation was left-handed and is indicated by the sign of $V$, which, in this case, is positive.

Figure 4.1b shows a group of type III bursts having a duration of 2 minutes. In this case both the polarization degree and the axial ratio were variable. The axial ratio changed in sign as well as in magnitude. It may be noted that the axial ratio changed sign twice.
Figure 4.1a Narrow-band polarimeter record at 35 MHz.
Figure 4.1b Polarimeter record at 25 MHz.
during the period of the burst activity, once at the beginning when the burst amplitude suddenly increased later when the burst activity subsided. We shall discuss this event later in more details.

4.3 **POLARIZATION MEASUREMENTS WITH SINGLE BANDWIDTH**

We describe single bandwidth polarization measurements of type III bursts at 25 and 35 MHz in three parts as follows:

(1) The polarization parameters of type III bursts and their statistical distribution observed at 25 and 35 MHz are presented and compared with the polarization parameters of type III bursts measured at 200 MHz by Akabane and Cohen (1961) and at 25 MHz reported by Chin et al. (1971). For statistical comparison we have also included polarization data at 74 MHz which was recorded at the National Research Council (N.R.C.) of Canada in 1963 by Bhonsle and McNarry.

(2) Polarization characteristics of a group of spectral type III bursts at 25 MHz associated with the solar event recorded on July 14, 1969 at 0813 U.T. are discussed in detail, and possible interpretation given.

(3) From January through April, 1972 a radio polarimeter was operated to measure the Stokes parameters simultaneously at two frequencies, 4 KHz apart near 35 MHz. The polarization parameters and the intensity
of type III bursts at the two closely spaced frequencies (34.993 and 34.997 MHz) are compared and discussed.

4.31 POLARIZATION PERCENTAGE m

Out of the observed 35 groups of type III bursts at 25 MHz which appeared in the period from July, 1969 through June, 1970, we have selected only 18 groups of bursts for analysis. The remaining 17 groups were quite weak in intensity. Similarly only 126 bursts were selected out of the observed 341 type III bursts at 74 MHz which occurred either singly or in groups during the observing period May to June, 1963.

Figures 4.2a and 4.3a represent the distribution of the percentage of polarization m at 25 MHz with a bandwidth of 20 KHz and at 74 MHz with a bandwidth of 10 KHz. Although the receiving bandwidth at 25 MHz was wider than the receiving bandwidth at 74 MHz, it can be seen from Figures 4.2a and 4.3a that there were only 5 bursts at 25 MHz which showed a polarization degree less than 10 per cent whereas at 74 MHz there were as many as 20 bursts, excluding completely unpolarized bursts, which showed polarization less than 10 per cent. The fact that at 25 MHz, there were very few bursts having a polarization degree less than 10 per cent, seems to be in good agreement with the observations of Chin et al. (1971) at 25 MHz with a bandwidth of 100 Hz only. The latter
Figure 4.2 Polarization percentage at 25 MHz.

- 120 -

25 MHz, $\Delta f = \pm 10$ KHz

CORRECTED POLARIZATION PERCENTAGE, $m_0$

NO. OF BURSTS = 159

MEASURED POLARIZATION PERCENTAGE, $m$

NO. OF BURSTS = 159
74 MHz, $\Delta f = \pm 5$ kHz

CORRECTED POLARIZATION PERCENTAGE, $m_0$

NO. OF BURSTS = 118

MEASURED POLARIZATION PERCENTAGE, $m$

NO. OF BURSTS = 118

Figure 4.3  Polarization percentage at 74 MHz.
observations made in 1966 and 1969, did not contain a single burst observed with polarization degree less than 10 and 20 per cent respectively and in 1968 there was only one burst which had polarization degree less than 30 per cent.

There were as many as 82 bursts out of 159 bursts at 25 MHz and 64 bursts out of 126 bursts at 74 MHz which had polarization degree less than 30 per cent. In Table 4.1 the summary of polarization percentage observed at 25 and 35 MHz at Ahmedabad, at 74 MHz at N.R.C. Canada and at 25 MHz at the Stanford University, U.S.A. is given. The highest degree of polarization observed at 25 MHz (Ahmedabad) did not exceed 60 per cent whereas at 74 MHz it was as high as 85 per cent. It should be noted that at 25 MHz we have not recorded any unpolarized burst whereas at 74 MHz at N.R.C., there were as many as 44 completely unpolarized bursts of intensity greater than 5 times that of the galactic background and 10 of intensity greater than 20 times that of the galactic background. The average degree of polarization both at 25 and 74 MHz was 30 per cent. At 35 MHz with a bandwidth of 800 Hz only, the average degree of polarization was 54 per cent and the highest was 90 per cent.

From the analysis of the type III bursts observed at 35 MHz (reported in the Chapter V of this thesis) the
### TABLE 4.1

**SUMMARY OF RESULTS OF POLARIZATION PERCENTAGE AND AXIAL RATIO OF TYPE III BURSTS**

<table>
<thead>
<tr>
<th>Place</th>
<th>Frequency in MHz</th>
<th>Bandwidth in KHz</th>
<th>Polarization percentage</th>
<th>Axial Ratio</th>
<th>Place</th>
<th>Frequency in MHz</th>
<th>Bandwidth in KHz</th>
<th>Polarization percentage</th>
<th>Axial Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Highest</td>
<td>Lowest</td>
<td>Average</td>
<td>Highest</td>
<td>Lowest</td>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>A.R.O.</td>
<td></td>
<td></td>
<td>85</td>
<td>0</td>
<td>30</td>
<td>.78</td>
<td>.05</td>
<td>.28</td>
<td></td>
</tr>
<tr>
<td>Ottawa (1963)</td>
<td>74</td>
<td>10</td>
<td>97*</td>
<td>0*</td>
<td>45*</td>
<td>.55*</td>
<td>0*</td>
<td>.19*</td>
<td></td>
</tr>
<tr>
<td>P.R.L.</td>
<td></td>
<td></td>
<td>57</td>
<td>5</td>
<td>29</td>
<td>.68</td>
<td>0</td>
<td>.20</td>
<td></td>
</tr>
<tr>
<td>Ahmedabad (1969-1970)</td>
<td>25</td>
<td>20</td>
<td>95*</td>
<td>5*</td>
<td>52*</td>
<td>.49*</td>
<td>0*</td>
<td>.12*</td>
<td></td>
</tr>
<tr>
<td>P.R.L.</td>
<td></td>
<td></td>
<td>90</td>
<td>16</td>
<td>54</td>
<td>.76</td>
<td>0</td>
<td>.30</td>
<td></td>
</tr>
<tr>
<td>Ahmedabad (1972)</td>
<td>35</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stanford University</td>
<td>**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1966</td>
<td></td>
<td></td>
<td>60</td>
<td>15</td>
<td>30</td>
<td>.8</td>
<td>&lt;.05</td>
<td>.3</td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>25</td>
<td>0.1</td>
<td>90</td>
<td>15</td>
<td>56</td>
<td>.2</td>
<td>&lt;.05</td>
<td>.05</td>
<td></td>
</tr>
<tr>
<td>1969</td>
<td></td>
<td></td>
<td>90</td>
<td>25</td>
<td>60</td>
<td>.7</td>
<td>&lt;.05</td>
<td>.10</td>
<td></td>
</tr>
</tbody>
</table>

* Corrected for Faraday rotation.

** Values for this station were derived from the histograms reported by Chin et al. (1971).
computed Faraday rotation is of the order of $10^3$ radians. We assumed the same value of Faraday rotation at 25 MHz to correct for its effects on the polarization parameters, namely, the polarization percentage $m$ and the axial ratio $r$ of polarization ellipse of type III bursts recorded by our radio polarimeter at 25 MHz with a bandwidth of 20 KHz. For 74 MHz polarization data we computed an upper limit on the Faraday rotation by adopting the following procedure:

The correlation factor (between the right and left circularly polarized components of the radiation) and the polarization degree $m$ (Akabane and Cohen 1961) are related by the following equation:

$$\mu = \frac{m \cos 2\beta}{(1-m^2 \sin^2 2\beta)^{1/2}} \quad \ldots (1)$$

Knowing the value of $m$ and the axial ratio $r = \tan^{-1} \beta$ for each burst we have computed the corresponding value of the correlation factor $\mu$. Figure 4.4 shows the distribution of the correlation factor at 74 MHz. The number of bursts decreases as the correlation factor increases.

There were as many as 72 bursts out of 126 bursts which had a correlation factor less than 0.3. It should be noted that there were only 13 bursts which had a correlation factor less than 0.1. The correlation factor did not exceed 0.8.
Figure 4.4 Computed correlation factor at 74 MHz

74 MHz, $\triangle f = \pm 5$ KHz

NO. OF BURSTS = 126
We assume that the solar corona is a magnetized plasma and that the radio wave propagates in the quasi-longitudinal mode of the magneto-ionic theory. The dispersion in polarization angles $\theta$, produced as a result of the spread in the orientation angle $\chi$, which in turn is due to the Faraday rotation $\gamma$ suffered by radiation coming from the solar corona, is given as

$$\theta = 2\gamma \frac{\nu}{B} \text{ radians} \quad \ldots (2)$$

where $\nu$ = frequency in Hz; $B$ = bandwidth in Hz.

The dispersion in position angles depolarizes the wave and the simplest way to express this is in terms of the cross-correlation function between the two circular modes:

$$\langle \mu \rangle = \mu_0 \exp \left(-\frac{\theta^2}{4}\right) \quad \ldots (3)$$

where $\mu_0$ is the correlation factor between the two circular modes at the source.

Under the assumptions mentioned above and the one that at the source $\mu_0$ is unity, that is, the radiation emitted by the source region is hundred per cent polarized, we computed the upper limit on Faraday rotation at 74 MHz by using the equations (2) and (3).

It was found that 72 bursts at 74 MHz had the cross-correlation factor $\langle \mu \rangle$ less than 0.3 and that the highest value was $\approx 0.8$. Using relation (3), we thus get

$\theta \leq 2.2$ radians for $\mu_0 = 0.3$ and $\theta \leq 1.2$ radians for $\mu_0 = 0.7$. 
Making use of relation (2) and the computed value of $\theta$, we get an upper limit on Faraday rotation $\theta$ at 74 MHz as $7.4 \times 10^3$ radians for $\mu = 0.3$ and $10^3$ radians for $\mu = 0.7$. This shows that the value of Faraday rotation may vary between $10^3$ and $7.4 \times 10^3$ radians. Thus, we find an excellent agreement between the upper limit on the total Faraday rotation at 74 MHz and the experimentally measured value of Faraday rotation at 35 MHz, which is of the order of $10^3$ radians. Thus we have used a value of $5 \times 10^3$ radians to correct the polarization parameters at 74 MHz. The upper limit on the Faraday rotation at 74 MHz is calculated only to justify the value ($5 \times 10^3$ radians) of the Faraday rotation used for correcting the polarization parameters at 74 MHz.

Figures 4.2b and 4.3b represent the distribution of polarization percentage at 25 and 74 MHz respectively corrected for the effect of Faraday rotation. Assuming that the depolarization is caused due to the Faraday rotation suffered by the radiation while passing through the intervening magneto-ionic medium, that is, the solar corona and the earth's ionosphere, it is shown in Table 4.1 that the highest degree of polarization increases from 57 to 95 per cent at 25 MHz and 85 to 97 per cent at 74 MHz. This corrected average degree of polarization increases from 30 to 52 per cent at 25 MHz and at 74 MHz it increases from 30 to 45 per cent.
4.32 AXIAL RATIO $r$

The histograms shown in Figures 4.5a and 4.6a relate to the distributions of axial ratio $r$ at 25 and 74 MHz respectively. At 25 MHz the number of bursts decreases as the axial ratio increases. This does not seem to be the case with type III bursts observed at 74 MHz. At both the frequencies the range of axial ratio is quite large but in the case of 74 MHz the distribution seems to be more or less uniform between $r = 0$ and $r = 0.45$. The spread in the distribution of axial ratio observed by Chin et al. (1971) at 25 MHz is explained by Fokker (1971) as a result of possible systematic difference in the amount of Faraday rotation from year to year within the receiver bandwidth. Considering the fact that the two histograms relate to two different periods, namely, 1963 (74 MHz) and 1969 - 1970 (25 MHz) and that Fokker's explanation needs Faraday rotation of the order of $10^5$ radians, which may not be the case, we feel that the spread in axial ratio should be explained on different lines. If an assumption is made that the observed polarization properties of type III bursts are not associated with the mechanism of generation of the bursts but are imposed entirely due to the effects of propagation through the solar corona, then the axial ratio is dependent upon the angle that the magnetic field makes with the direction of
25 MHz, $\Delta f = \pm 10$ kHz

Figure 4.5 Axial ratio at 25 MHz.
Figure 4.6 Axial ratio at 74 MHz.
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propagation (Cohen 1959). The large variation in the axial ratio of different bursts within a group could be explained as a result of different directions of propagation for different bursts within a group.

At 25 MHz there are 33 groups of bursts which showed right handed sense of rotation for all the bursts within a group and 2 groups with left handed sense of rotation. Similarly, at 74 MHz 28 groups of bursts showed left handed and 8 right handed sense of rotation. There were two groups of bursts at 25 MHz and 8 at 74 MHz which changed the sense of rotation during the period of burst activity. Assuming that the sense of rotation to be dependent upon the polarity of the magnetic field associated with the source of radiation, the bursts having right handed sense of rotation should be associated with the south polarity of the magnetic field and vice versa. The change in the sense of rotation within a group of bursts could then be explained to be due either to more than one source emitting the radiation within a group, but situated in regions with opposite magnetic fields or, according to Suzuki (1961), the source is of sufficiently large size so as to occupy regions of opposite polarities above a centre of activity. Yip (1970) has pointed out that it could be due to the situation that in such cases the second harmonic components pass through the polarization limiting region where the magnetic field is
in the direction opposite to that in the source region.

At 25 MHz we have not observed any completely circularly polarized isolated burst or a burst within a group. However, at 74 MHz, there were 6 bursts, which had intensity greater than 20 times the galactic background intensity, with axial ratio unity and right handed sense of rotation. The polarization degree did not exceed 16 per cent for any of the completely circularly polarized bursts.

Table 4.1 summarizes the results of the axial ratio of polarization ellipse of type III bursts observed at 25 and 74 MHz. The largest value of the axial ratio did not exceed 0.7 at 25 MHz and 0.8 at 74 MHz. The lowest value of the axial ratio remained quite close to zero, that is, highly elliptically polarized bursts were observed both at 25 and 74 MHz. The mean value of the axial ratio at 25 MHz was 0.2 which is less than the mean value of 0.28 at 74 MHz. It should be noted that the receiving bandwidth of the 25 MHz radio polarimeter was twice that of the 74 MHz radio polarimeter at N.R.C. The lower value of the mean axial ratio observed at 25 MHz seems to be consistent with the fact that the Faraday rotation decreases as the frequency of radiation decreases (Akabane and Cohen 1961, Bhonsle and Mattoo 1973). 15 per cent of the type III bursts at 25 MHz and 12 per cent at 74 MHz had axial ratios less than 0.05,
Figures 4.5b and 4.6b represent the distribution of the axial ratio corrected for the effect of Faraday rotation at 25 and 74 MHz respectively. After the correction it is found that the range of the axial ratio decreases considerably. This decrease in the range of the axial ratio may not be true at the source region; and could be verified either with very narrow band radio polarimeters (small thickness of the source region and a negligible spread in the Faraday rotation angles) or by correcting the polarization parameters of each burst with the corresponding experimentally measured value of the Faraday rotation. In Table 4.1 we have indicated the values of the highest, lowest and mean axial ratio corrected for the Faraday rotation both at 25 and 74 MHz. It is seen that the corrected mean value of the axial ratio at 25 MHz comes on the order of the mean value obtained for the observations at 25 MHz reported by Chin et al. (1971).

In Table 4.2 we have compared the fraction of type III bursts having axial ratio less than 0.2 (highly elliptical) with and without correction for the Faraday rotation effects. It is seen that the uncorrected fraction of type III bursts increases from 0.3 at 200 (Akabane and Cohen 1961) and 74 MHz to 0.54 at 25 MHz (PRL, Ahmedabad). The corrected fraction of type III bursts increases from
### TABLE 4.2

**SUMMARY OF AXIAL RATIO DATA OF HIGHLY ELLIPTICALLY POLARIZED TYPE III BURSTS**

<table>
<thead>
<tr>
<th>Place</th>
<th>Frequency in MHz</th>
<th>Bandwidth in KHz</th>
<th>Year and period</th>
<th>No. of bursts used for analysis</th>
<th>No. of bursts having axial ratio less than .2</th>
<th>Y((H))</th>
<th>Expected probability of occurrence under random magnetic field conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornell University, Ithaca</td>
<td>200</td>
<td>10</td>
<td>March-Sept. (1959)</td>
<td>64</td>
<td>21</td>
<td>.3</td>
<td>.014 (1 Gauss)</td>
</tr>
<tr>
<td>N.R.C., Ottawa</td>
<td>74</td>
<td>10</td>
<td>May-June (1963)</td>
<td>120</td>
<td>38 60</td>
<td>.3 .5</td>
<td>.018 .0038 (1.5 Gauss)</td>
</tr>
<tr>
<td>Stanford University</td>
<td>25</td>
<td>.1</td>
<td>1966</td>
<td>45</td>
<td>17</td>
<td>.4</td>
<td>.011 .0022 (1 Gauss)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1968</td>
<td>41</td>
<td>40</td>
<td>.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1969</td>
<td>130</td>
<td>100</td>
<td>.77</td>
<td>.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>216*</td>
<td>157*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P.R.L. Ahmedabad</td>
<td>25</td>
<td>20</td>
<td>(July 69 to June 70)</td>
<td>159</td>
<td>86 127</td>
<td>.54 .8</td>
<td>.011 .0022 (1 Gauss)</td>
</tr>
<tr>
<td>P.R.L. Ahmedabad</td>
<td>35</td>
<td>.8</td>
<td>Jan-March (1972)</td>
<td>26</td>
<td>11</td>
<td>.4</td>
<td></td>
</tr>
</tbody>
</table>

* Total number of bursts analysed in the years 1966, 1968 and 1969 at Stanford University.
0.5 at 74 MHz to 0.8 at 25 MHz. The latter value compares well with the observations at the same frequency with a very narrow bandwidth (100 Hz) radio polarimeter (Chin et al. 1971). In the same table we have indicated values of \( Y \), which is equal to the ratio of the gyro-frequency \( \omega_H \) to the radiation frequency \( \omega \), at the coronal emission levels of different frequencies assuming the magnetic field values of 1, 0.5 and 0.1 Gauss at the coronal levels of emission of 200, 74 and 25 MHz respectively. The value of \( Y \) is required to calculate the expected probability of observing linear polarization under the assumption of randomly oriented magnetic fields. The expected probability can be found out as follows:

In the case of a magneto-ionic medium which has magneto-ionic parameters \( X, Y \) \( (X = \omega_p^2/\omega_o^2, \omega_o) \) being the plasma frequency, Ratcliffe 1959) both much less than 1 and also negligible collisions, the axial ratio \( r \) of the magneto-ionic modes is given as (Cohen 1959)

\[
r = \alpha/Y
\]

where \( \alpha \) is the angle that the magnetic field makes with the perpendicular to the propagation direction. For a fixed direction of propagation and randomly oriented magnetic fields, the probability \( P(r_o) \) that the axial ratio is less than the specified value \( r_o \) is given by finding the probability \( P(\alpha_o) \) of \( \alpha_o \) obtained from the
relation (4) under the assumption of randomly oriented magnetic fields. The following relation can be used to find out the probability \( P(r_o) \) at different frequencies:

\[
|P(r_o)|^r_o = |P(a)|^{a_o}
\]

\[
= \int_{90-a_o}^{2\pi} \int_{90+a_o} \sin \theta \ d\theta \ d\Phi / 4\pi
\]

\[
= \sin a_o
\]

\[
\sin a_o \approx a_o \quad \text{for small values of } a_o, \text{ where } \theta \text{ and } \Phi \text{ have usual meanings as referred to the coordinate system used. Table 4.2 shows the probability of observing the axial ratio } r \text{ of less than 0.2 at various frequencies. It should be noted that the indicated values of the probability } P(r_o) \text{ at various frequencies are the same as that of a ray, starting from the source-region meets the transverse field configuration on its outward passage through the solar corona. It follows from Table 4.2 that:}

(1) the probability of finding the axial ratio of less than 0.2 under the assumptions of randomly oriented magnetic fields is on the same order at all the frequencies.

(2) the observed fraction of bursts having the axial ratio of less than 0.2 at all the frequencies is much greater than the expected probability under the assumption of randomly oriented magnetic field conditions. This shows that the magnetic field is ordered at all these coronal
levels so as to cause the high occurrence of highly elliptical polarization.

(3) the experimentally observed probability of finding linear polarization seems to increase as the frequency decreases. As mentioned in section 2.33, Fokker (1971) pointed out that it is difficult to explain the existence of linearly polarized bursts if the Faraday rotation suffered by type III bursts is as large as $10^5$ radians. Grognard and McLean (1973) attempted to detect the linear polarization at 80 MHz by making use of a technique which completely eliminates the effect of ground reflections. They claimed non-existence of linearly polarized type III bursts. However, their method of detection of linearly polarized bursts has a limitation if the Faraday rotation is of the order of $10^3$ radians (Bhonsle and Mattoo 1973). Thus, the possibility of the existence of linear polarization for type III bursts cannot be entirely ruled out.

(4) the observed fraction of bursts having uncorrected axial ratio of less than 0.2 at 25 MHz is greater than the same at 74 MHz despite the fact that the receiving bandwidth at 25 MHz is twice as large as that at 74 MHz. This seems to be consistent with the trend that measured Faraday rotation decreases as the frequency decreases (Akabane and Cohen 1961, Bhonsle and Mattoo 1973).
The last two conclusions are not completely unambiguous because the observations refer to two different periods. Again, the observations of Chin et al. (1971) at 25 MHz show that the fraction of type III bursts having axial ratio less than 0.2 at 25 MHz varies from 0.4 in 1966 (though number of bursts analyzed is small) to 0.97 in 1968. It would be interesting to observe polarization properties of type III bursts simultaneously at different frequencies.

4.33 ORIENTATION ANGLE $\chi$

Figure 4.7a and 4.7b show the distribution of the orientation angle $\chi$ of type III bursts observed at 25 and 74 MHz, respectively. It is seen that the orientation angles of the major axis of the polarization ellipses of the type III bursts, both at 25 and 74 MHz, are not evenly distributed with respect to the given antenna reference system as would be expected, because the orientation data cannot be extended to the source in the presence of large amount of Faraday rotation suffered by the radiation while passing through the solar corona and the earth's ionosphere. At 25 MHz, the $\chi$ values are grouped in the range $-10^\circ$ to $20^\circ$. Similarly at 74 MHz the $\chi$ values are grouped between $-50^\circ$ and $-30^\circ$. This is quite interesting particularly because the observations at 25 and 74 MHz refer to two different periods and also that the observations sites
Figure 4.7 Orientation angle at 25 and 74 MHz.
are different. In a group of bursts the orientation angles of different bursts were within \( \pm 10^\circ \) about the mean value. Similar tendency for clustering of orientation angles was reported by Cohen (1959) at 200 MHz and recently by Dodge (1972) at 34 MHz.

In view of the clustering of orientation angles presented in Figure 4.7, the following conclusions can be drawn:

1. The magnitude of the total electron content and magnetic field in the path of radiation must remain essentially constant for the duration of the group of bursts. This also implies that the scattering effects, so far as their effect on orientation is concerned, are not that excessive so as to randomize the orientation angles.

2. For linear polarizations to be intrinsic to the source, the occurrence of constant position angle requires an extreme stability of the source position, if the Faraday rotation is large near the source (Cohen 1959).

4.4 POLARIZATION CHARACTERISTICS OF THE SOLAR EVENT ON JULY 14, 1969

Figure 4.1b shows the four-channel polarimeter recording of a group of solar radio bursts of spectral type III observed between 0813 and 0815 U.T. One can distinguish 10 different peaks on the I-channel. It may be noted that the intensity of radiation does not drop to
zero between the two successive peaks. This could either be due to a possibility that the bursts occurred in quick succession or that there might be a simultaneous emission of a background component with a longer duration. The average duration of individual type III bursts at 25 MHz has been estimated to be about 10 seconds and since the polarimeter output time constant is about 1 second the time-profile of the intensity of type III bursts will not be affected. We favour the latter possibility, that is, the simultaneous emission of background and burst components, in view of the fact that the dynamic spectrum of the same group of bursts shown in Figure 4.8 shows the presence of individual bursts superimposed upon a diffuse background radiation. Further, it may be noted that all the individual bursts in this group do not have the same drift speed.

4.41 INTENSITY

Figures 4.9a - d show the variation in intensity, degree of polarization, axial ratio, and the orientation angle of the major axis of the polarization ellipse as a function of time. The values of I, Q, U and V have been scaled manually from the polarimeter recording at the peaks and troughs of the intensity of radiation. For comparison the total radiation I and the computed polarized component of radiation I_e are plotted on the same scale. It can be seen that I_e is less than I throughout the
Figure 4.8 A group of type III bursts along with a continuum recorded on July 14, 1969. Recorded by Ahmedabad radio spectroscope at 0813 U.T.
Figure 4.9 Various polarization parameter of the solar event recorded on July 14, 1969.
duration of the event except at one or two points where \( I_e \) is comparable to \( I \). Thus it can be concluded that the radiation was partially polarized.

4.42 DEGREE OF POLARIZATION

The variation of the degree of polarization \( m \) during this event may be seen from the plot in Figure 4.9b. It can be noticed that \( m \) varied between about 30 per cent to 85 per cent during the event. Making point to point comparison, the general trend in the time variation of \( m \) is to increase when the total intensity \( I \) decreases and vice versa. This means that the radiation is relatively weakly polarized in the presence of bursts. This can be explained if the burst component of radiation is either unpolarized or weakly polarized as compared to the polarization of the background component of radiation or, if polarized, it must be incoherent with the background component. Since the polarization percentage drops down during the life time of the burst, it is logical to conclude that the burst component of radiation is to a large extent unpolarized (or weakly polarized). In other words, it can be concluded that this solar event consisted of two components of emission occurring simultaneously, the burst component that is unpolarized or weakly polarized and the background component that is strongly polarized. The dissimilarity in the degree of polarization of the
burst and that of the background component of the radiation suggests (a) that they must originate in the coronal regions pervaded by weak and strong magnetic fields, respectively and (b) that their mechanisms of generation may also be different. One can visualize this as a situation in which bunches of energetic electrons are ejected in different directions from the source. The burst component may be resulting from the plasma oscillations excited by those electrons, which escape more or less along the neutral plane in the magnetic field configuration of a coronal streamer, whereas the background component may be caused by those electrons which are injected in the strong field regions. Further evidence that the type III bursts are generated in weak field regions comes from the absence or low degree of circular polarization of bursts. The interpretation suggested above is consistent with the model of burst source given by Wild and Smerd (1972) for type III, V and U from their radioheliograph observations at 80 MHz. This model has already been described in detail in section 1.31 (see also Figure 1.4).

4.43 AXIAL RATIO AND ORIENTATION ANGLE

Figure 4.9c shows the variation of the axial ratio with time. It can be noticed that the axial ratio varied
between -0.18 to 0.13. The sequence of variation of the axial ratio was as follows: Initially the axial ratio remained positive, when the burst activity became intense the axial ratio changed its sign from positive to negative and when the burst activity subsided the axial ratio again returned to its positive value. Thus we conclude that the change of sign is due to the appearance of burst component. This argument seems to give us evidence for that there were two generating mechanisms simultaneously operative, one giving rise to fast drifting type III bursts and the other background and/or that the two components originated in two disimilar magnetic field regions. The suggestion that these two components came from different regions can be appreciated by referring to Figure 4.9d in which the orientation angle of the major axis of the polarization ellipse with respect to the antenna system is plotted as a function of time. Although the orientation data cannot be directly related to the source owing to the large amount of Faraday rotation suffered by the radiation in the intervening magneto-ionic medium, it seems that the observed relative changes in the instantaneous values of the orientation angles can be attributed to the source in this case. It is seen that when the axial ratio changed from left-handed to right-handed the value of \( \chi \) changed by 17° and remained more or less steady around this value until the burst activity subsided after which the orientation angle returned
to the initial value. It should be pointed out here that after the burst activity subsided the original sense of rotation was restored simultaneously with the return of the orientation angle to its original value.

The variation in the magnitude of the axial ratio can be appreciated from the plot shown in Figure 4.10 in which the unpolarized radiation, \( I_u = I - I_e \), is plotted against the axial ratio \( r \). It is seen that for a large unpolarized radiation the axial ratio has remained negative and it is during this time that the burst component contributed largely to the total radiation. When the burst activity seemed to be subsided, the background and the burst component either contributed equally to the total radiation or else it is the background component which contributed largely to the total radiation. The axial ratio changed sign when the burst activity subsided and remained positive till the end of the event. This point of view can be appreciated from the point 'A' in the plot in Figure 4.10. At this point there was a burst which thus raised the level of the unpolarized radiation and \( r \) tends to be negative.

The changes in the sense of rotation of the polarization ellipse is expected to occur if the radiation encounters a quasi-transverse magnetic field configuration on its passage out from the source region to the observation point. The QT conditions could exist either in the
Figure 4.10 shows the relation between the unpolarized intensity and the axial ratio for type III burst recorded on July 14, 1969. Arrows indicate the direction of increasing time.
corona or in the earth's ionosphere when the angle between the direction of the ray propagation and the magnetic field is close to 90 degrees. As will be discussed later (Chapter V) for the solar event observed around local noon the mode of radio propagation in the earth's ionosphere should be quasi-longitudinal. Under these circumstances we expect that the effect of the earth's magnetic field and electrons in the ionosphere is to cause the Faraday rotation of the plane of polarization unaccompanied by any changes in the axial ratio. The observed changes in the axial ratio must, therefore, be attributed to the region close to the source of radiation in the solar corona.

Since the sense of rotation for the background radiation and for the polarized part of the burst component of the radiation were opposite, the two components cannot originate in the same source region with the similar polarity of the magnetic field. Assuming that the state of polarization was entirely due to the effects of propagation of the radiation through the corona, the mixed polarizations R and L may result either from the burst component and the background component coming from two different centers of activity, or from one and the same center of activity (Fokker 1965). In both the cases, however, it is necessary that the rays coming either from the sources of burst component or from the background
Figure 4.11 Distribution of
(a) intensity ratios,
(b) ratio of polarization degree,
(c) ratio of axial ratio, and
(d) difference between the orientation angles of type III bursts at 34.997 and 34.993 MHz.
Figure 4.12 Polarization percentages at two closely-spaced frequencies (34.993 and 34.997 MHz).
in general greater than that at 34.993 MHz. This is clearly borne out by Figure 4.11b which represents the distribution of the ratios of polarization degree $m'$ at 34.993 MHz to the polarization degree $m$ at 34.997 MHz for each burst. It is seen that there are as many as 18 bursts which had $m'/m$ ratio less than unity. It should be noted that the lowest value of $m'/m$ is 0.25 and the highest 1.4.

4.53 **AXIAL RATIO**

Figures 4.13a - b represent distribution of axial ratios $r$ and $r'$, respectively. The occurrence of right handed polarity is more frequent than left handed one at both the frequencies during the period January - March, 1972. Not a single burst was observed which had opposite sense of rotation at two frequencies. The range of the axial ratio is quite large at both the frequencies. In Figure 4.11c we have plotted the distribution of the ratio of axial ratios $r'$ to $r$ for each burst. As many as 12 bursts had $r'/r$ less than 1 and 16 bursts had $r'/r$ greater than 1.

4.54 **ORIENTATION ANGLE**

Figures 4.14a - b correspond to the distributions of the orientation angle of the polarization ellipse of type III bursts observed at 34.997 and 34.993 MHz, respectively. At both the frequencies there seems to be
Figure 4.13 Axial ratio at two closely spaced frequencies (34.993 and 34.997 MHz).
Figure 4.14 Orientation angle at closely spaced frequencies (34.993 and 34.997 MHz).
some preference for orientation angles within $\pm 20^\circ$, that is, clustering of orientation angles. Similar clustering tendency of orientation angles has been reported earlier by many workers (Cohen and Pokker 1959, Cohen 1959a, Bhonsle and McNarry 1964b, Bhonsle et al. 1967, Dodge 1972). Figure 4.11d represents the distribution of the difference of orientation angles $(\chi - \chi')$ at the two frequencies. For 15 bursts the position angles of polarization ellipses do not differ by more than $\pm 20^\circ$. For the other 18 bursts the difference in the position angles is in the range $80^\circ$ to $160^\circ$. The observed small difference in the orientation angles at the two frequencies can be explained from the following simple calculation of the Faraday rotation at 35 MHz:

The amount of Faraday rotation $\phi$ may be expressed as

$$
\phi = 2.36 \times 10^4 \frac{N H_{||}}{\nu^2} \int N \cdot H_{||} \, dz \quad \ldots (5)
$$

where $N$ is the electron density,
$H_{||}$ in Gauss is the component of the magnetic field parallel to the propagation direction and $\nu$ = frequency in Hz.

If $\phi_1$ and $\phi_2$ refer to the Faraday rotations at two closely spaced frequencies $\nu_1$ and $\nu_2$, respectively, then from relation (5) we have
\[
\frac{\phi_1 - \phi_2}{\phi} = \frac{\nu_1^2 - \nu_2^2}{\nu^2} \quad \ldots (6)
\]

if \( \nu_1 - \nu_2 \approx \nu \), then, to a first approximation

\[
\frac{\phi_1 - \phi_2}{\phi} = 2(\nu_2 - \nu_1) \quad \ldots (7)
\]

For our observations \( \nu_2 - \nu_1 \approx 4 \times 10^3 \) Hz

and \( \nu = 35 \times 10^6 \) Hz

Substituting the values for \( (\nu_2 - \nu_1) \) and \( \nu \) gives

\[
\frac{\phi_1 - \phi_2}{\phi} \approx 2 \times 10^{-4} \quad \ldots (8)
\]

If the Faraday rotation suffered by the radiation while passing through the solar corona and the earth's ionosphere were as high as \( 10^5 \) radians, then

\( \phi_1 - \phi_2 \approx 20 \) radians. This should have been sufficient to randomize the distribution of \( (\chi - \chi') \), particularly when scattering effects cannot be ignored. Although the Faraday rotation at 35 MHz may be as low as \( 10^3 \) radians, still it is not possible to extend the orientation data to the source but it seems reasonable that the scattering effects should be rather less severe in randomizing the \( (\chi - \chi') \) distribution. These results are in good agreement with those of Dodge (1972) who measured the spread in orientation angles at 34 MHz within an overall bandwidth of 3 KHz. He derived an upper limit on the Faraday rotation to be of the order of \( 1.75 \times 10^3 \) radians.
in order to explain the lack of measurable effect of Faraday rotation on the orientation angles at different frequencies within the 3 KHz bandwidth.

4.55 POLARIZATION OF TYPE IIIb BURSTS RECORDED ON ONE CHANNEL ONLY

In course of this analysis, we came across 3 interesting bursts, mentioned earlier in the Section 4.5, which were recorded only on the 34.993 MHz polarimeter channel. Two of these events did not have their counterpart on the 34.997 MHz channel, while the third one had a few very small spikes during the event. This lack of correspondence between the two channels could be attributed to a fine-structure in frequency, as is obtained in the case of type IIIb bursts.

Two bursts were strongly (95 per cent) linearly polarized and remained constant at all the peaks of the bursts in the group. The third burst showed polarization degree varying from 30 to 50 per cent and the axial ratio varied from 0.05 to 0.62 and had left-handed sense of rotation throughout the duration of the burst. In all the three cases the orientation angle of the major axis of the polarization ellipse remained constant throughout the period of the burst activity.
5.6 CONCLUSIONS

The main conclusions of this chapter are summarized below:

1) Average degree of polarization of type III bursts at 25 and 74 MHz was of the order of 30 per cent with bandwidths of 20 and 10 KHz respectively and 54 per cent at 35 MHz with a bandwidth of 800 Hz.

2) More than 30 per cent of the total number of type III bursts were highly elliptically polarized (axial ratios 0.2) at all the frequencies. Axial ratios < 0.05 (almost linear polarization) have been observed in about 15 per cent of the total number of bursts.

3) Clustering of orientation angles within ± 20° have been observed in certain groups of type III bursts at all the frequencies.

4) Changes in the polarization behaviour of the solar event of July 14, 1969, suggested the existence of more than one radio source with different polarization characteristics; a highly polarized background radiation and relatively weakly polarized burst component.

5) Polarization characteristics on two closely spaced (4 KHz apart) frequencies near 35 MHz show appreciable differences between them.
6) Difference in orientation angles at 34.993 and 34.997 MHz was about 20° for the same bursts. This implies that the total Faraday rotation may not have been more than about $10^3$ radians.

7) The existence of a fine-frequency structure similar to that observed in the case of type IIIb bursts was indicated by the absence of three bursts on one of the two closely spaced frequencies.