POLARIZATION OF SOLAR RADIO BURSTS AT MICROWAVE FREQUENCIES I

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Summary:

The intensity and polarization of solar radio bursts have been observed at 9400, 3750, 2000 and 1000 Mc/s since July, 1957. In this paper the results of observations during 6 months are described.

In most bursts at microwave frequencies, the difference in the intensity of two circularly polarized components is observed. At 3750 Mc/s, the bursts of small degree of polarization (less than 10%) are predominant, compared with other frequencies. At 2000 and 1000 Mc/s the circularly polarized bursts were occasionally observed, but not at 9400 and 3750 Mc/s and at 3750 Mc/s the linearly polarized components were not observed. In most bursts observed at four frequencies, the sense of polarization reverses near 3750 or 2000 Mc/s and the degree of polarization is generally small at 3750 Mc/s.

At 9400 Mc/s, it seems that the sense of polarization correlates with the position of the source on the solar disk. Further observations will be continued to investigate the relation between them.

I. Introduction.

At present, there are few data of polarization measurements of solar radio bursts at microwave frequencies. In 1950, Covington[1] observed the right-handed and left-handed circularly polarized components of solar radio emission on a wavelength of 10.7 cm, using two antennas with the quarter-wave plate, and found that there are three groups of bursts, i. e. (1) the intensities of two components are equal, (2) unequal, (3) one component alone.

The observation of polarization of solar radio bursts may be very important to research the mechanism of emission of bursts and the solar atmosphere where the emission of burst takes place.

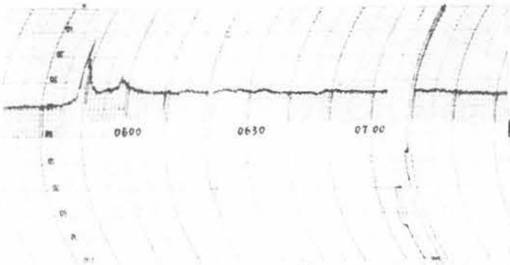
In July, 1957, we commenced the observation of intensity and polarization at 9400, 3750, 2000 and 1000 Mc/s. We have also observed E-W brightness distribution on the solar disk with 8-element interferometer with quarter-wave plate at 4000 Mc/s. With interferometric observation, we can find the position of the radio spot where a burst was emitted.

Details of the observing apparatus are reported separately in this proceedings. At 9400, 2000, and 1000 Mc/s, the sum and the difference in the intensity of the right-handed and the left-handed circularly polarized components are recorded, but at 3750 Mc/s the linearly polarized components are also measured.

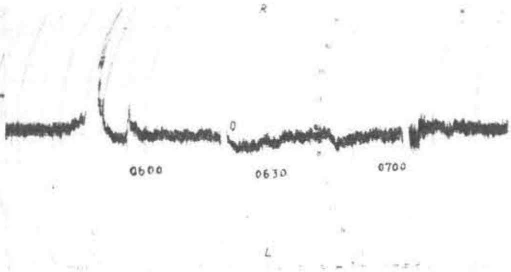
In this paper, the results of observations, obtained during 6 months since July, 1957, are described.

II. Results of observations.

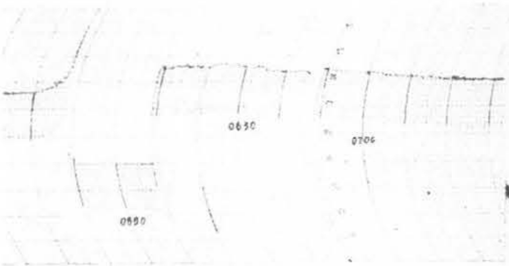
Up to the end of December, 491 bursts were observed and their data will be reported in " I. G. Y. DATA of The Research Institute of Atmospherics ". In



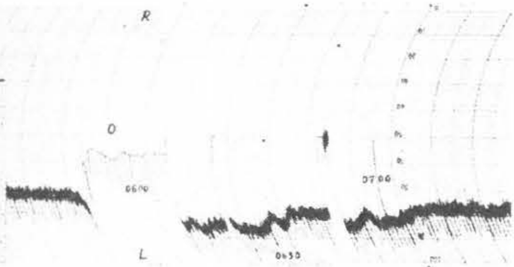
(a) Intensity at 9400 MC.



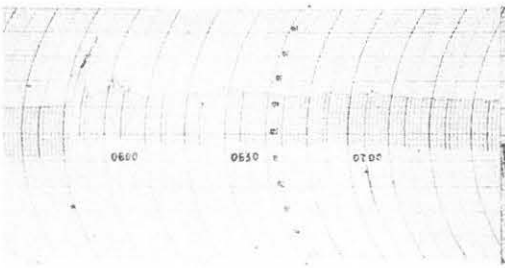
(b) Polarization at 9400 MC.



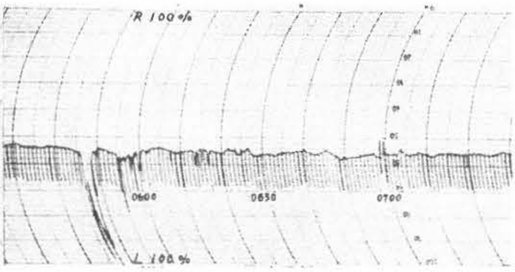
(c) Intensity at 3750 MC.



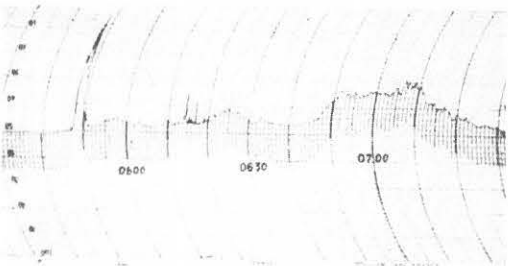
(d) Polarization at 3750 MC.



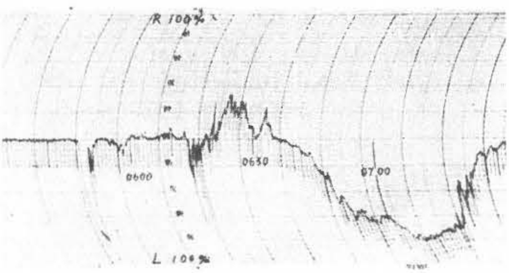
(e) Intensity at 2000 MC.



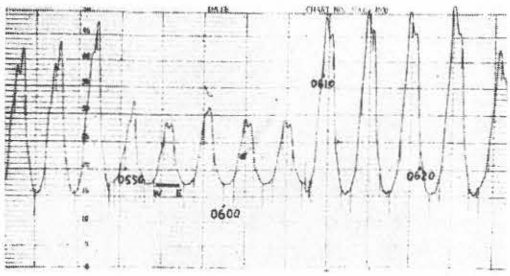
(f) Polarization at 2000 MC.



(g) Intensity at 1000 MC.



(h) Polarization at 1000 MC.



(i) Record of 4000 MC Interferometer.

Fig. 1 Record of the solar radio burst on August 31, 1957.

this report and also this paper, the bursts which have the intensity more than 20 units (1 Unit$=10^{-22}\cdot W\cdot m^{-2}\cdot(c/s)^{-1}$) at 9400 Mc/s and the bursts more than 10 units at 3750, 2000 and 1000 Mc/s are picked up. There are 87 bursts which were observed simultaneously at four frequencies ("observed" means here that the burst has an intensity greater than the level described above.) and 77 bursts at three frequencies, while there are many bursts which have a narrow bandwidth and are observed only at one frequency. It seems that the frequency spectrum of burst at microwave frequencies is complicated.

248 of 491 bursts were observed at 9400 Mc/s and 296, 217 and 230 bursts were observed at 3750, 2000 and 1000 Mc/s respectively.

An example of the record of the burst observed at four frequencies is shown in Fig. 1. At 9400 and 3750 Mc/s, the difference in the intensity of the right-handed and left-handed circularly polarized components is recorded, but the records of polarization of 2000 and 1000 Mc/s show directly the % polarization at the part of large intensity. From the record of 4000 Mc/s interferometer, we can find that there were two sources, i. e. one on the east side was active at the initial phase of the burst and the other on the west side at its latter phase. Although the degree of polarization is not always so large as in this example, in most cases, bursts have some degree of polarized radiation.

1. The degree of polarization.

If P_R and P_L are the flux densities of the right-handed and left-handed circularly polarized component respectively, the degree of polarization is given in % and is defined by[2]

$$\frac{P_R \sim P_L}{P_R + P_L}\cdot 100\%$$

The degree of polarization varies from time to time during a burst (see Fig. 1 and Fig. 3) and it becomes, in general, large at the peak of intensity.

Where the intensity is very small, the calculated value of % polarization largely changes according to where to take the base line of the burst and the error in reading will also increase. So we calculated the value of % polarization at the part of relatively large intensity. At 1000 and 2000 Mc/s, the receiver has a divider and we can directly read the value of % polarization.

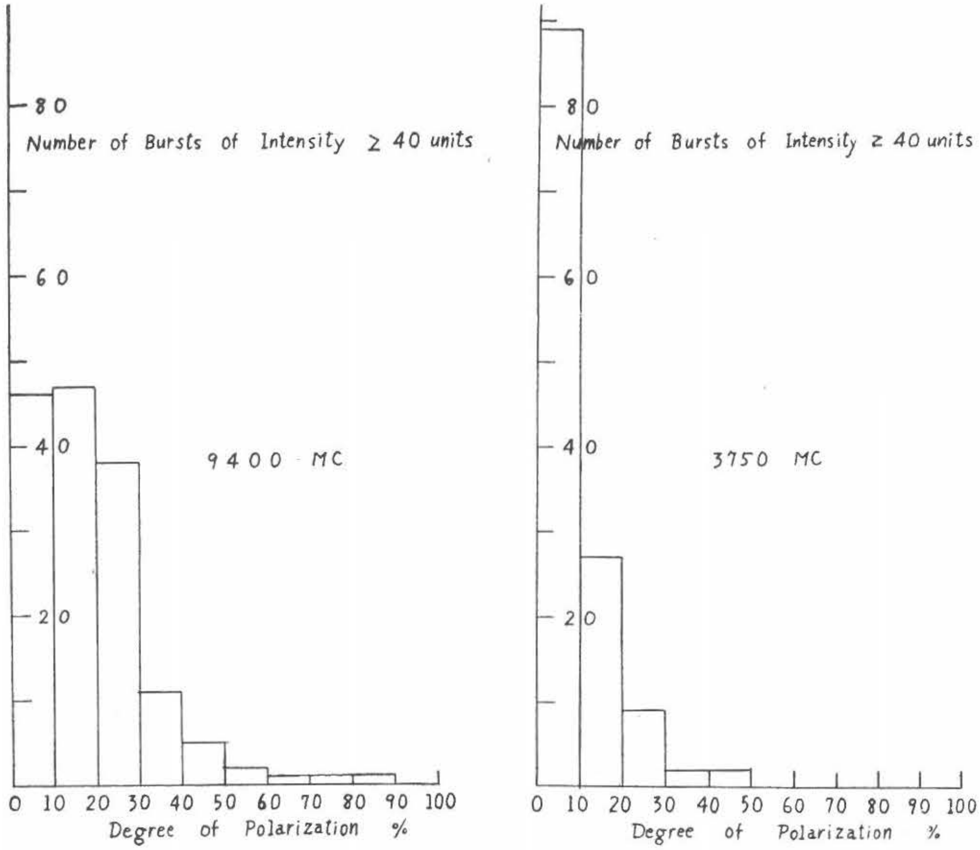
The bursts of small degree of polarization (less than 10%) are predominant at 3750 Mc/s, compared with other frequencies. Frequency distributions of maximum degree of polarization of bursts for each frequency are shown in histograms and the cumulative frequency diagrams of Fig. 2. In this case the bursts stronger than 40 units for 9400 and 3750 Mc/s and 20 units for 2000 and 1000 Mc/s are taken, as the error will increase in the case of weak intensity and small degree of polarization. In 50% of bursts observed at 9400 Mc/s, the degree of polarization was more than 16%. This value at 3750 Mc/s is 7%, 13% at 2000 Mc/s, 20% at 1000 Mc/s. These values scarecely change though the bursts of small intensity are taken.

Frequency distribution at 9400 Mc/s differs from those at other frequencies and has no peak at a small degree of polarization less than 10%. The number of bursts decreases as the degree of polarization exceeds 30%. The peak at small degree of polarization is very high at 3750 Mc/s, compared with other frequencies and the number of bursts decreases rapidly as the degree of polarization increases.

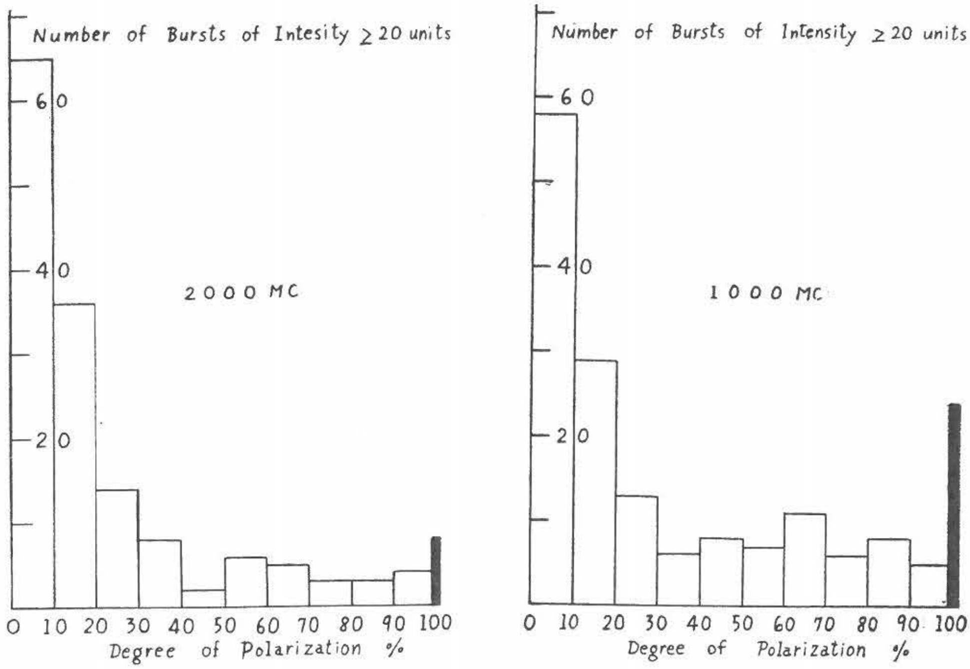
At 1000 and 2000 Mc/s, the circularly polarized bursts were occasionally observed, but not at 9400 and 3750 Mc/s.

2. The sense of polarization.

Refering to the sense of circular polarization, the radio-electric definition is adopted. The sense of polarization is the sense of the stronger one when two circularly polarized components of burst are received and is denoted by the symbols

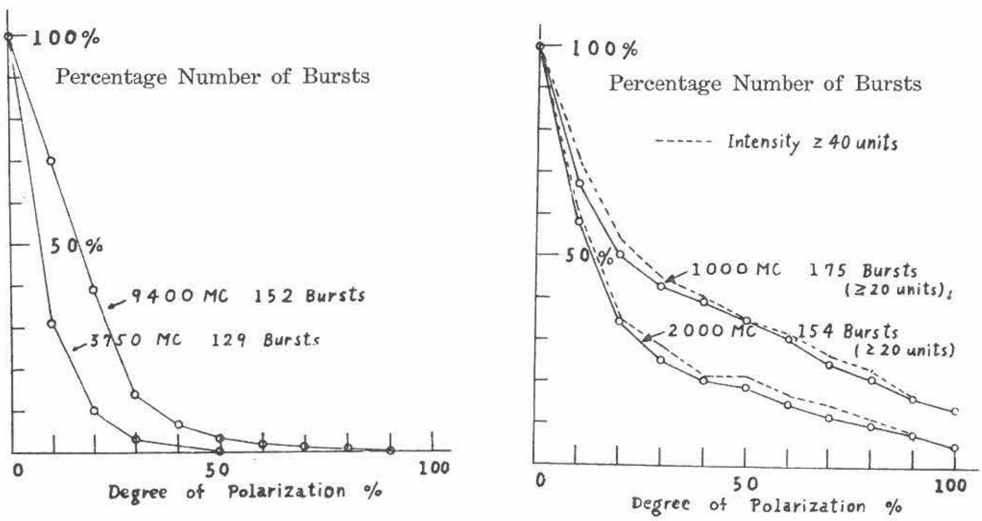


(a)-1



(a)-2

(a) Histograms



(b)

(b) Cumulative frequency diagrams.

Fig. 2 Histograms and cumulative frequency diagrams showing the frequency distribution of the degree of polarization of bursts. Cumulative frequency diagrams of bursts of intensity ≥40 units at 1000 and 2000 Mc/s are also shown (- - - -).

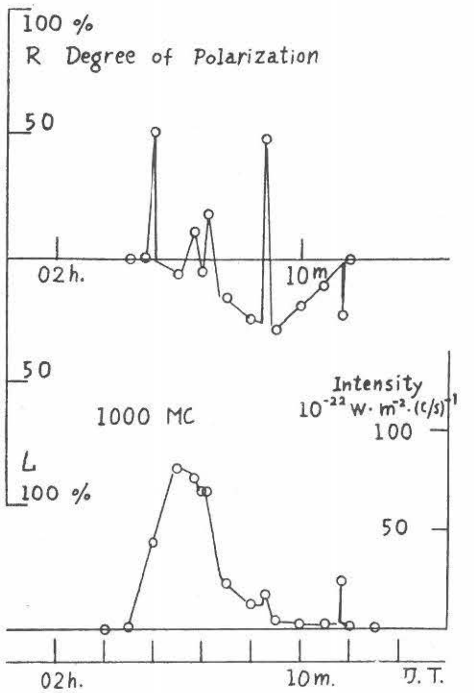


Fig. 3 Intensity and polarization of the burst observed on Sep. 1, 1957.

the excess of left-handed circularly polarized component and the other emitted impulsively the excess of r. h. circularly polarized component. In about 4% of bursts observed at 9400 and 3750 Mc/s, the sense of polarization changed during burst and 10% for 2000 and 1000 Mc/s.

The sense of polarization varies with frequency. An example is shown in Fig. 4. In this case, the degree of polarization at 3750 Mc/s is very small and the sense of polarization reverses between 2000 and 3750 Mc/s, i. e. the sense of polarization is right-handed at 9400 and 3750 Mc/s and left-handed at other frequencies.

The great portion of 87 bursts, observed at four frequencies, are such bursts and are grouped as Table 1. The sense of polarization reverses near 3750 Mc/s or 2000 Mc/s and the degree of polarization is small at these frequen-

R and *L*. The sense of polarization is, in most cases, constant during a burst, but sometimes it changes from left-handed to right-handed or vice versa. An example of such bursts, observed at 1000 Mc/s, is shown in Fig. 3. In this case, the sense varied in a complex manner and it appears that there were two sources, i. e. one source emitted

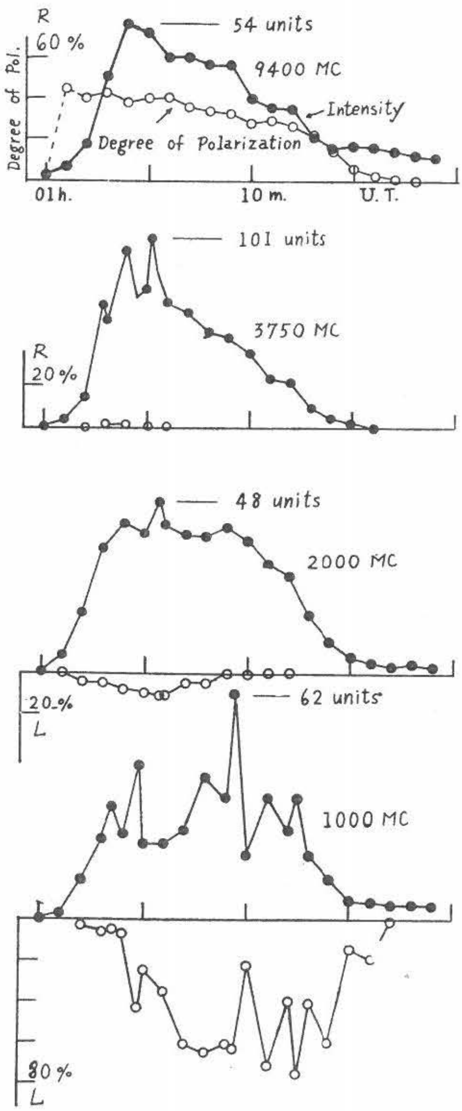


Fig. 4 Intensity and polarization of the burst observed on July 15, 1957.

cies, in most cases at 3750 Mc/s. Mean values of max. degree of polarization of such bursts (57) are 20%, 10%, 27% and 36% at 9400, 3750, 2000 and 1000 Mc/s respectively.

Table 1

The sense reverses				The sence does not reverse	The degree of polarization is nearly 0 at all frequencies.	others
between 9400 and 3750 Mc	between 3750 and 2000 Mc	between 2000 and 1000 Mc	twice between 9400 and 1000 Mc			
12	28	9	9	11	7	11
Tatal	58			11	7	11

When the sense of polarization varies with time, the sense of each frequency was compared at the corresponding phase of burst. For example, in Fig. 1, the sense of polarization reverses between 9400 and 3750 Mc/s at the initial phase of burst.

30 of 77 bursts observed at three frequencies are also such cases and the sense reverses near 3750 or 2000 Mc/s.

It seems that this character of bursts is not affected by the position of the source on the solar disk.

As the sense of polarization reverses near 3750 Mc/s and in most cases the degree of polarization is small, it is expected that the linearly polarized radiation may be observed at this frequency. So we improved 3750 Mc/s receiver and have observed the linearly polarized component since October, but, in 100 bursts, it was not observed. Accordingly, it may be concluded that most bursts at 3750 Mc/s are nearly randomly polarized wave. However, the linearly polarized radiation, though it exists, may not be observed by the Faraday effect of solar atmosphere[3], because the bandwidth of the present receiver is 10 Mc/s.

The relation between the sense of polarization and the position of the source on the solar disk at 9400 Mc/s is shown in Fig. 5. The bursts, in which the posi-

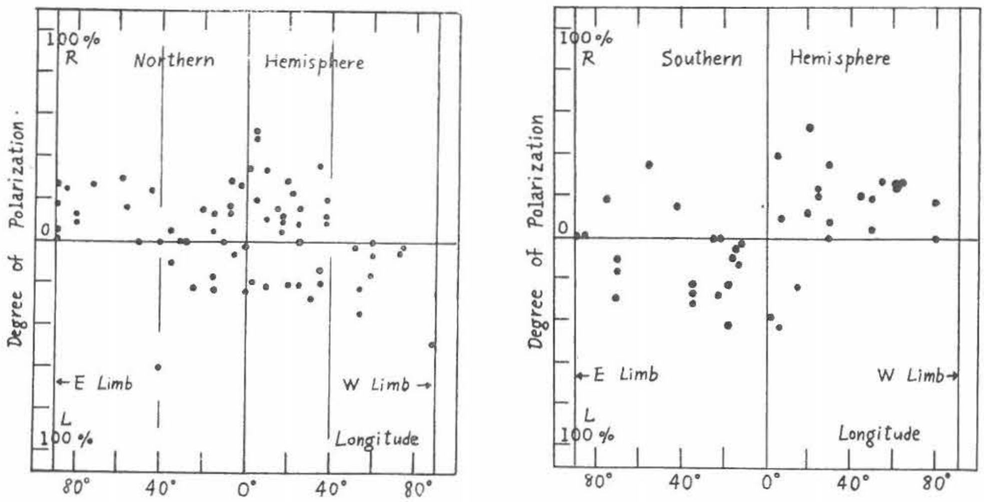


Fig. 5 Relation between the sense of polarization of bursts and the position of the source at 9400 Mc/s.

tion of the source was found, are divided into two groups; one has its source in the northern hemisphere and the other in the southern hemisphere. And for each group, the longitude of the source, the sense and degree of polarization of burst are shown. The position of the source is that of the associated flare given in I. G. Y. solar maps of the Tokyo Astronomical Observatory or that of the sunspot group, where the burst was emitted, found from the results of observation with 4000 Mc/s interferometer and optical data of sunspots. The longitude of the source of the burst observed with interferometer on a rainy day is the approximate value.

As shown in Fig. 5, when the source was in the northern hemisphere and near the central meridian, the sense of polarization looks irregular, but when the longitude of the source was more than 40°, the sense of polarization was right-handed for the source in east, and left-handed for the source in west.

When the source was in the southern hemisphere and on the east side of longitude 20°W, the sense was, in most cases, left-handed, and right-handed for the source on the west side.

In the case of the slowly varying component[4)5)] at around 4000 Mc/s, when the radio spot is in the northern hemisphere, the sense of polarization changes, in general, from right-handed to left-handed whithin 3 days before or after C. M. P. of the spot, and opposite for the spot in the southern hemisphere. Above results show that the sense of polarization of burst at 9400 Mc/s tend to change with the position of the source in the same manner as S component.

In order to find the relation between the sense of polarization and the position of the source, it is to be desired that the spot groups which emit many bursts at various positions during its movement across the solar disk are frequently observed. There was one example in October. The sources of the bursts in Table 2 were in

Table 2 Sunspot group; C. M. P. Oct. 17, Latitude 23°S.
(found from the maps of the Sun of the Tokyo Astronomical Observatory.)
Bursts at 9400 Mc/s. (0: Degree of polarization is 0.)

Date	Starting Time. U. T.	Sense of Polarization
Oct. 12	0416	L
15	0235	R
15	0328.5	0
16	0051	0 ?
16	0151.8	L
16	0332	0
16	0420	R—L—R
16	0653	L
18	2242	L
19	0120	R
19	0400	R
19	0634	0
20	0145	R
20	0238	R
22	0405	R
22	0500	R
23	0228	R
23	0334.5	R
23	0622.4	R

the same spot group. Only right-handed sense was observed after Oct. 19, but both senses were observed on the east side.

The sense of polarization of burst at 9400 Mc/s is not always coincident with that of S component at 4000 Mc/s emitted from the same spot, though such cases were mostly observed in the exceptional radio spots refering to the sense of polarization of S component.

As, at present, there are a few data to conclude that the sense of polarization of burst at 9400 Mc/s depends on the position of the source in the same manner as S component, it will be necessary to continue the observations.

At other frequencies, it seems that the sense of polarization is not affected by the position of the source.

The reverse of the sense of polarization of burst near 3750 or 2000 Mc/s will be concerned with the mechanism of emission and the propagation of burst in the solar atmosphere pervaded by the magnetic field over a sunspot.

If the sense of polarization at 9400 Mc/s depends on the position of the source in the same manner as S component, it may be considered that the source of burst emits the excess of the extraordinary wave at this frequency[4].

If so, the reverse of the sense may be interpreted as follows. The reflection levels of the ordinary wave ($x=1$ level) will be in the chromosphere in the frequency range from 1000 Mc/s to 9400 Mc/s. The reflection level of the extraordinary wave ($x=1-y$ level) is higher than that of the ordinary wave and its height depends on the sunspot magnetic field[4][6]. "x" and "y" are the parameters of the magneto ionic theory.

If we assume that the reflection levels of the extraordinary wave[4] for each frequency and the position of the source are as shown in Fig. 6, the extraordinary wave emitted from the source at 1000 Mc/s cannot escape and only the ordinary wave will be observed. At 2000 Mc/s, the emission from the greater part of the source below $x=1-y$ level is the ordinary wave, though both waves are emitted from the part above this level. So at this frequency the excess of the ordinary wave will be observed and the burst has its characteristic polarization.

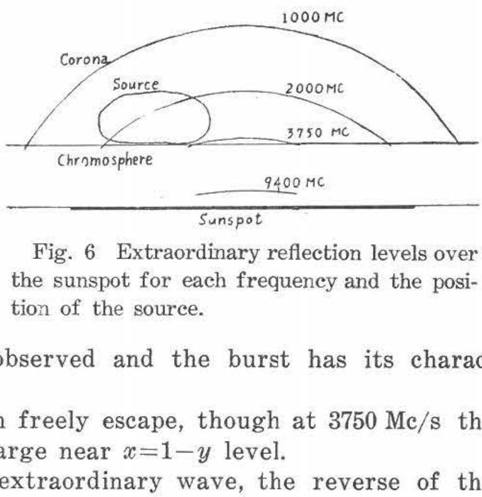


Fig. 6 Extraordinary reflection levels over the sunspot for each frequency and the position of the source.

At 3750 and 9400 Mc/s, both waves can freely escape, though at 3750 Mc/s the absorption of the extraordinary wave is large near $x=1-y$ level.

If the source emits an excess of the extraordinary wave, the reverse of the sense of polarization between 3750 and 2000 Mc/s will be observed. It seems that the reverse of the sense shows the height of the source over the photosphere.

As the burst at 1000 Mc/s is not, in general, circularly polarized, there must be a source also above $x=1-y$ level at 1000 Mc/s. If the source moves upward, a change of the sense and degree of polarization will be also observed.

III. Conclusion.

The results of observations show that a difference in the intensity of two circularly polarized components exists in most bursts at microwave frequencies. At 3750 Mc/s, the bursts of small degree of polarization (less than 10%) are predominant, compared with other frequencies.

At 2000 and 1000 Mc/s the circularly polarized bursts were occasionally observed, but not at 9400 and 3750 Mc/s, and at 3750 Mc/s the linearly polarized components were not observed. In most bursts observed at four frequencies, the sense of polarization reverses near 3750 or 2000 Mc/s and the degree of polarization is generally small at 3750 Mc/s.

At 9400 Mc/s, it seems that the sense of polarization correlates with the position of the source on the solar disk, in the same manner as that of S component, but it will be necessary to continue the observations to confirm this relation.

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