PRELIMINARY RESULTS OF OBSERVATIONS OF THE SOURCES OF SLOWLY VARYING COMPONENT WITH TWO INTERFEROMETERS AT 9400 AND 4000 Mc/s.

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Abstract.

An 8-element interferometer for use at 9400 Mc/s has been constructed and regular observations have been made from May, 1959. In this paper comparisons of the results of observations at 9400 Mc/s and those at 4000 Mc/s for 4 selected sources of S component of solar radio emission are described. The results of observations show that the heights of the sources at 9400 Mc/s are between 3000 and 40000km and, on the average, seem to be about 10^4km lower than those at 4000 Mc/s (11000—50000 km).

The flux from the radio source at 3750 Mc/s is nearly equal to one at 9400 Mc/s or larger. Brightness temperature of the strong source is about 10^5 °K at 9400 Mc/s and about 0.7×10^6 °K at 3750 Mc/s. It seems that the brightness temperature of two sources specially near 4000 Mc/s is raised by the effect of the magnetic field of sunspots.

% polarization of S component from the radio source at 9400 Mc/s is larger than one at 4000 Mc/s. There is a radio source which has an opposite sense of polarization between 9400 and 4000 Mc/s near C.M.

Introduction

As described in vol. 6., an 8-element interferometer for use at 9400 Mc/s has been constructed and regular observations have been made from May, 1959 to investigate the source of slowly varying component of solar radio emission. This interferometer produces 4.5 min. arc. fan-shaped beams each 40 min. arc. apart near meridian. as does an old interferometer for use at 4000 Mc/s. The sun is repeatedly strip-scanned by the earth's rotation and two series of drift-curves for the sum and difference of two circularly polarized components are obtained. As shown in the results of eclipse observations, the observations of polarization of S component with an antenna having high resolving power at cm region seem to be very important, to obtain the knowledge of the density and temperature in the lower part of the source and magnetic field over the sunspot.

In this paper comparisons of the results of observations at 9400 Mc/s and those at 4000 Mc/s for 4 selected sources are described.

From a statistical investigation, it was found that there were many cases where the sense of polarization reversed between 3750 and 9400 Mc/s, and the result of the eclipse observation [1] showed that there was a source which had an opposite sense between 9400 and 3750 Mc/s. It has been also found by the interferometric observations that when a source was near the central meridian, the sense of polarization reversed between these frequencies.

Results of observations

The observation at 9400 Mc/s is carried out every day for about 15 min. around local noon (about 03h U. T.), and about 5 drift-curves for each of the sum and difference (intensity and polarization) of two circularly polarized components are obtained. They are superimposed and averaged. Subtracting the area under the quiet-sun level from the daily drift-curves, we obtain the daily drift-curves for S component which show E-W distribution of S component across the solar disk. To estimate the quiet sun level, we used the lower envelope method of W. N. Christiansen. [2] These processes are almost the same as those in the 4000 Mc/s interferometer. [3] As the quiet sun has no polarized component, the daily drift-curves for polarization directly show the contribution from the source of S component. We can find E-W position of the source on the solar disk from the position line of the peak in the drift-curve for S component and the flux from the source can be found from the area of the peak. And from the area of the peak in the drift-curve for polarization we can find the bifference of two circularly polarized

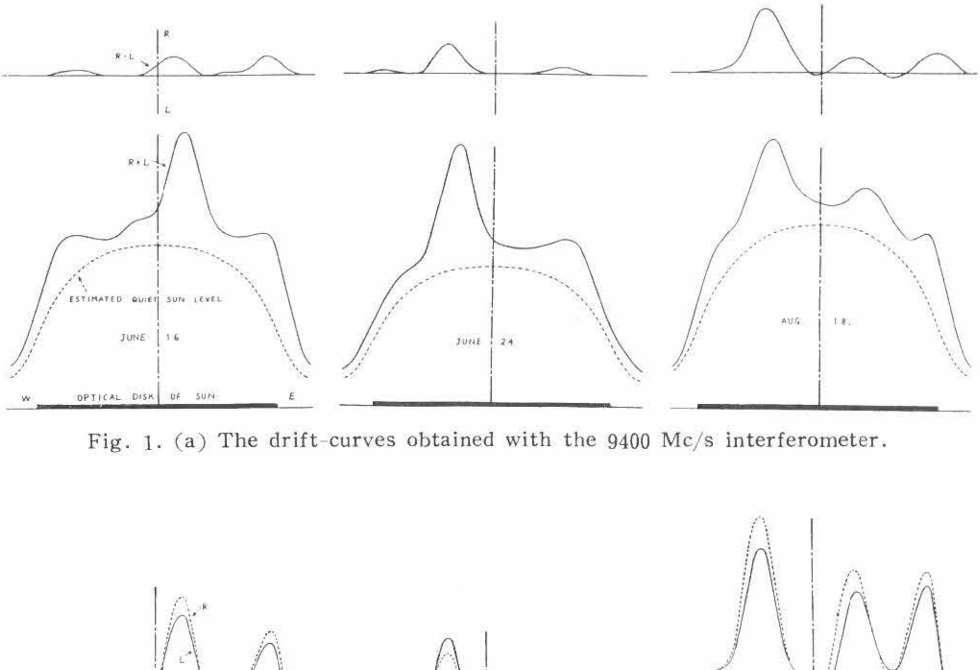
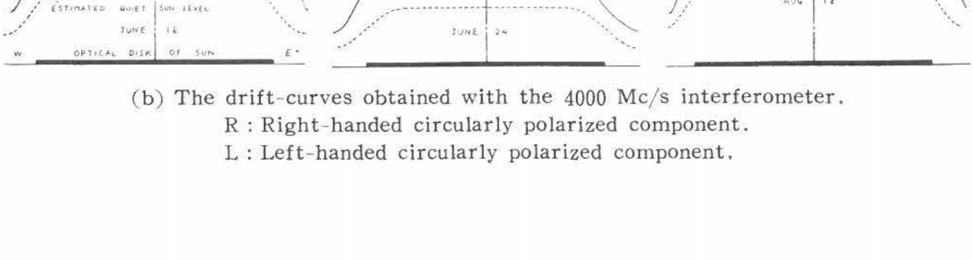


Fig. 1. (a) The drift-curves obtained with the 9400 Mc/s interferometer.



(b) The drift-curves obtained with the 4000 Mc/s interferometer.
R : Right-handed circularly polarized component.
L : Left-handed circularly polarized component.

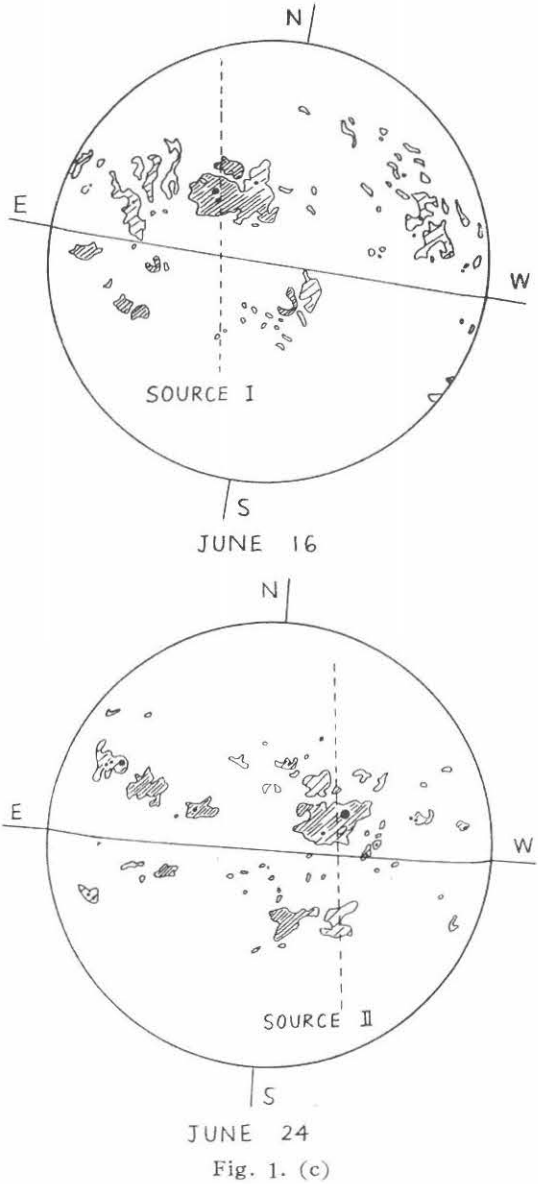


Fig. 1. (c)

radiation from the source.

The drift-curves obtained with the 9400 Mc/s interferometer are shown in Fig. 1, with the records at 4000 Mc/s.

In order to find the position of a source or the flux from it, the source must be sufficiently isolated to be resolved by the strip-scanning observation. We have selected 4 radio sources of S component in June and Aug. 1959, which seem to be approximately isolated, using the optical data, and compared the results of observations of these sources at 9400 Mc/s with those at 4000 Mc/s. The latitude and C. M. P. of the selected regions are shown in Table I and the associated optical

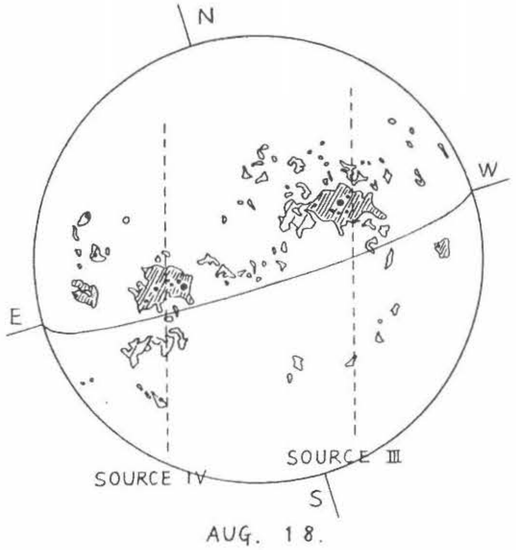


Fig. 1 (c) Sunspots andplages asscciated with the selected radio sources. (the map of the sun published by the Tokyo Astronomical Observatory.) The broken line is the position line of the peak in the radio record.

active regions are shown in Fig. 1 (c) (The map of the sun published by the Tokyo Astronomical Observatory), There seems to be a slight uncertainty of the position of the center in the record. but the effects to the results in this paper are considered to be negligible.

I. Height.

Variations of position with the solar rotation for the 4 sources at two

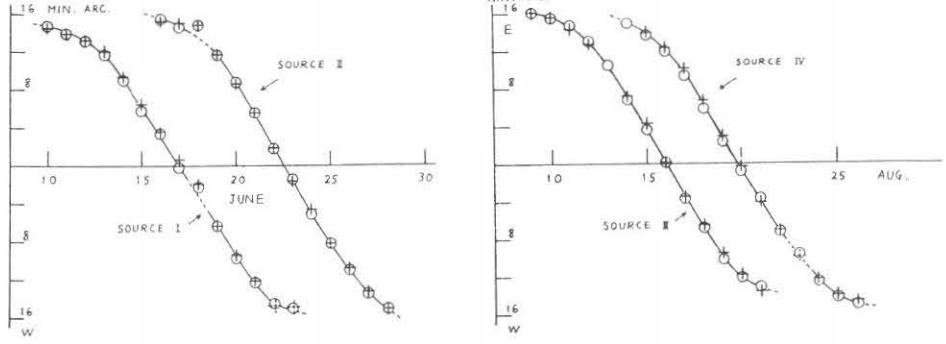


Fig. 2. Variations of position of the sources. + : 9400 Mc/s. ○ : 4000 Mc/s. At 4000 Mc/s mean positions of two circularly polarized components are plotted.

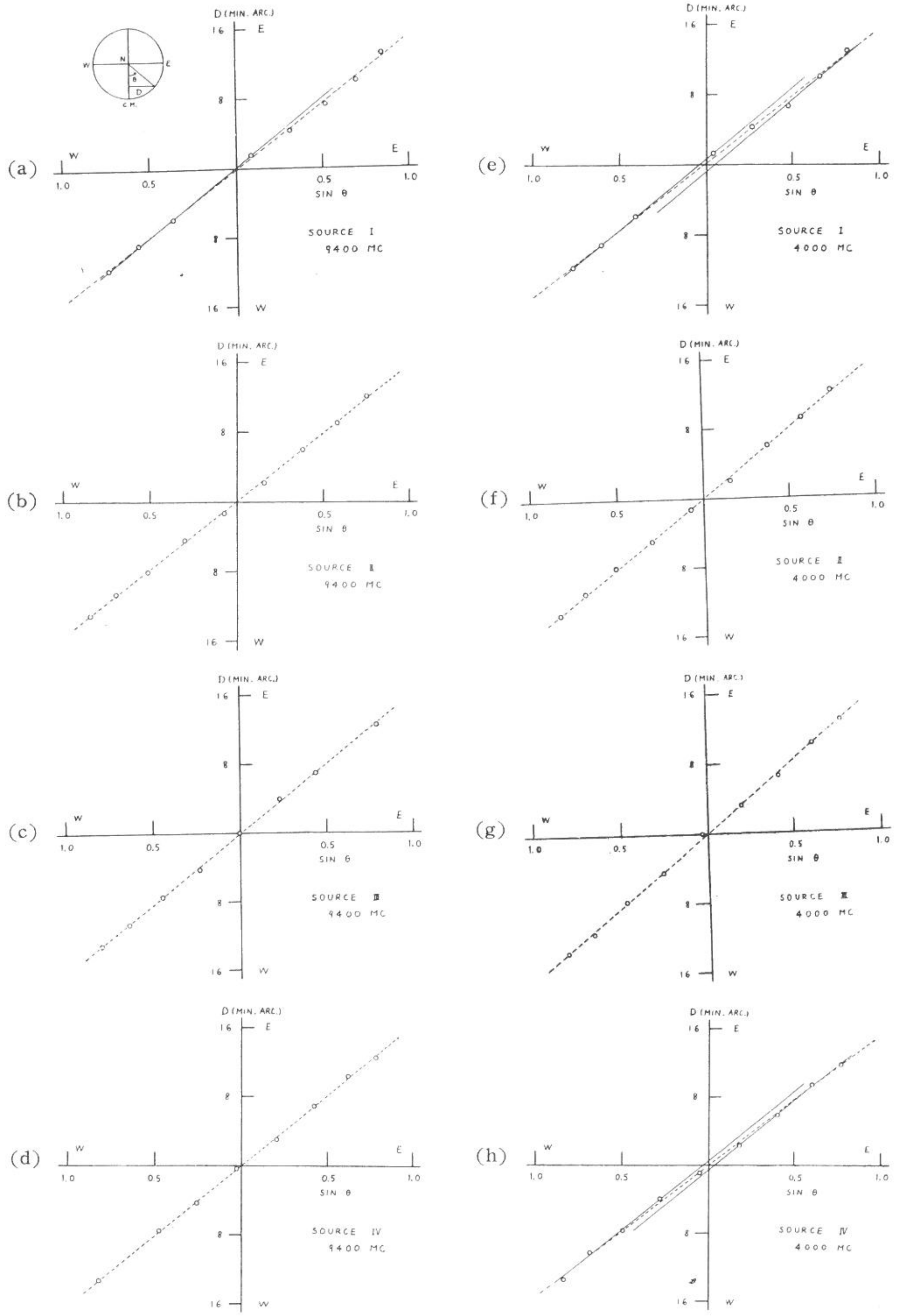


Fig. 3. The displacement from the central solar meridian of the sources.

frequencies are shown in Fig. 2. We have calculated by D. S. Mathewson's method[4] the height of these sources from displacement from NS line in Fig. 2, assuming that the sources have the same latitude and the angular velocity as the associated sunspot group. The displacements of the sources from central meridian (C. M.) are plotted in Fig. 3 against sin θ. From the slope of these curves the heights can be calculated. The heights for $\pm$ 4 days from C. M. P. (calculated from the slope of the broken line in Fig. 3) are shown in Table I.

Table I

	C. M. P (mean)	Latitude	Height above photosphere (km)	
			9400Mc	4000Mc
Source I	17.4 June	17° N	13000±10000	5000±14000
Source II	22.8 June	10° N	3000±6000	11000±6000
Source III	16.0 Aug.	12.5° N	33000±8000	49000±8000
Source IV	19.9 Aug.	7.5° N	24000±6000	−4000±10000

The heights of source I and IV at 4000 Mc/s are calculated to be lower than those at 9400 Mc/s. But it seems that the points on E side in Fig. 3 (a), (e) and (h) lie on the different line from that determined by the points on W side, as shown by solid line, i. e. it seems that the centroid of the brightness of the source moved from the preceding part of the source to the following part near C. M. P.. It seems to be remarkable at 4000 Mc/s. So the average heights for ±4 days from C. M. P. may be calculated to be lower than the actual values. The sense of polarization (see Fig. 6) of the radiation from source I and IV reversed near C. M. P.. The eclipse observations[1] show that, when the associated sunspot group is bipolar, the source of polarized component (extraordinary wave) over the preceding sunspot is stronger than that of opposite sense over the following spot on east side of C. M. and vice versa on west side. It may be considered that, if the brightness temperature of the region over the sunspot rise with the increase of the intensity of the polarized component (extraordinary wave) by the effect of magnetic field, the centroid of brightness move from the preceding part to the following part. Its probability is suggested by H. Tanaka.[8] Such movement of the centroid of brightness in source II and source III seems to be small, which is presumable from the optical observation (small distance between two spots[7]) and the observation of polarization (see Fig. 6). If we use the slope of the solid line in Fig. 3, the heights of source I at9400 and 4000 Mc/s are calculated to be about 40000 and 50000 km respectively and the height of source IV at 4000 Mc/s about 40000 km. On the average the height of the radio sources at 9400 Mc/s seems to be about 10^4 km lower than that at 4000 Mc/s.

2. Flux from the source and brightness temperature.

Variations of radio flux from the selected sources at 9400 and 3750 Mc/s are shown in Fig. 4. The flux at 4000 Mc/s are all converted to the scale at 3750 Mc/s.

As the beam width is 4.5′ and the observation is of strip-scanning type, the value of flux in Fig. 4 may include a little contribution from other sources near the selected one. The flux from source I is nearly equal at both frequencies and the flux from source II at 3750 Mc/s is a little larger than that at 9400 Mc/s in many cases. The size of the source may be roughly estimated from the half-power width of the peak. As shown in Fig. 5, E-W width of the source is nearly equal at both frequencies and is estimated to be about 4~5 min. arc near C.M. The

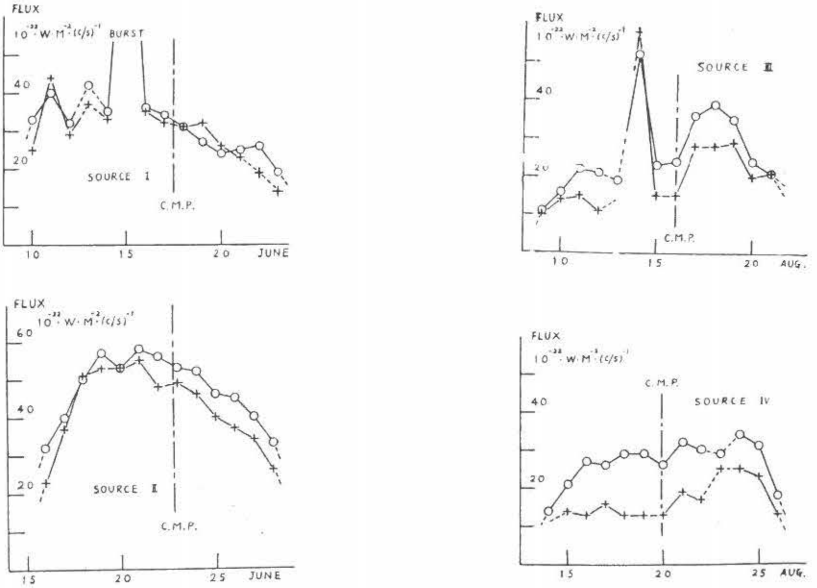


Fig. 4. Variations of radio flux (R+L) from the selected sources.
+ : 9400 Mc/s. ○ : 4000 Mc/s.

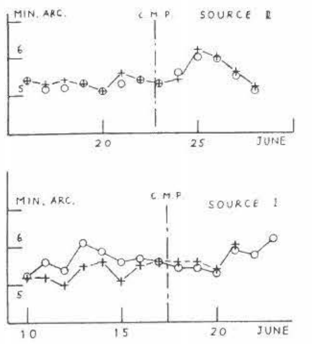


Fig. 5. Half-power width of the peak in the drift-curve. + : 9400 Mc/s. ○ : 4000 Mc/s. At 4000 Mc/s the mean values of two circularly polarized components are plotted.

brightness temperature near C. M. of source I is calculated to be about 0.5×10^6 K at 3750 Mc/s and about 0.7×10^5 °K at 9400 Mc/s and that of source II is 0.7×10^6 °K and 1.1×10^5 °K respectively, assuming the source size is 20 sq. min. arc. The difference in flux from source IIIor IV between two frequencies is large and the flux from source IV at 3750Mc/s on Aug. 18 and 19 is more than twice larger than the one at 9400 Mc/s. The size of the source is also considered to be nearly equal at both frequencies. The strong sources observed on Apr. 19 1958 (eclipse) and Nov. 30 (see page77) also have a similar spectrum of intensity and the flux at 3750 Mc/s is larger than the one at 9400 Mc/s. The spectrum of

S component derived statistically[5] has also similar shape. If S component is the thermal emission from the ionized gas with no magnetic field, the flux cannot decrease with increasing frequency, [6] as, at these frequencies, the source may be considered to be rarefied, i. e. $x<1$. ($x=f_0^2/f^2$, f_0; plasma frequency.)

If the electron temperature of the source gradually decrease with decreasing height near the chromosphere, the flux will increase with increasing frequency. So it may be considered that the brightness temperature of the source III and IV specially at 3750 Mc/s is raised by the effect of the magnetic field of sunspot, (in source IV, it is presumablie from the movement of the centroid of brightness near C. M. P. at 4000 Mc/s.) and the optical depth of the source at 3750 Mc/s in case where no effect of magnetic field is taken into account, should be small. If so, the degree of polarization at 3750 Mc/s should be much larger than actually observed values. [1] Further discussions are necessary to solve this contradiction.

The increase of flux from source III on Aug. 14 is due to a post-burst increase and the inerease of flux from source I on June 15 is due to the small bursts which have a long duration. In these cases, the flux at 9400 Mc/s is larger than that at 4000 Mc/s. It may be considered to be due to the increase of electron density in the source.

3. **Polarization.**

Variations of the degree of polarization are shown in Fig. 6.

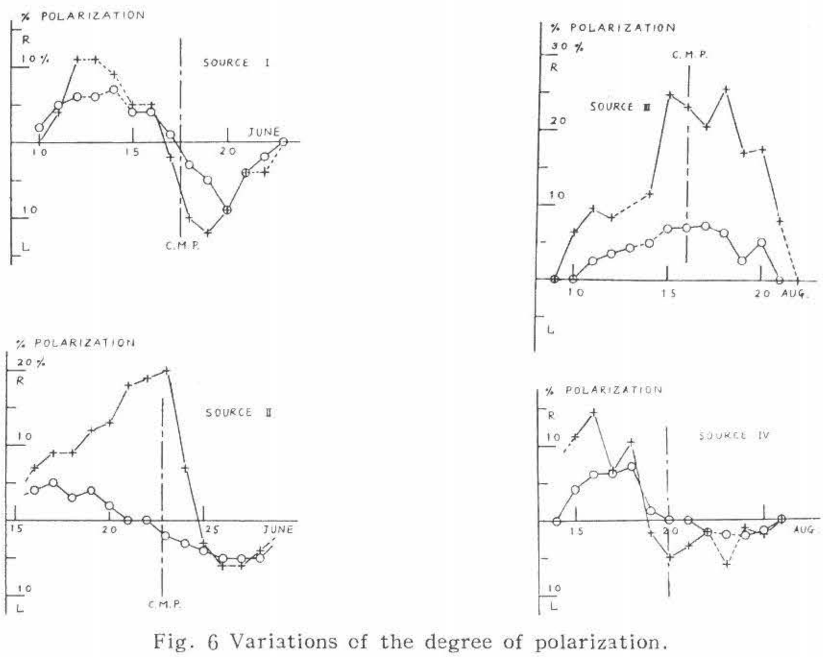


Fig. 6 Variations of the degree of polarization.
+ : 9400 Mc/s. ○ : 4000 Mc/s.

According to the eclipse observations, [1] the source of polarized component is confined in a small area over the sunspot, and in the bipolar spot two sources of polarized components of different senses exist over each pole. The observed drift-curves of polarization also support this bipolar structure of sources. The position of peaks in these curves generally deviates from the peaks in drift-curves of intensity towards the stronger sources of polarization, and in some cases near C. M. two positive (R) and negative (L) peaks are clearly identified. However, as resolving power is insufficient to separate the individual sources, we cannot help considering only the difference between two circularly polarized components of opposite senses emitted from the region over each pole.

So the value of % polarization in Fig. 6 is the average value over the whole of a source and the sense of polarization is the sense of the stronger one of the two circularly polarized components.

The observed % polarization at 9400 Mc/s is generally larger than that at 4000 Mc/s.

The sense of polarization reversed near C. M. P., following the ordinary rule, excepting that of source III. The sense of polarization of the radiation from source II at 9400 Mc/s reversed about 3 days later than that at 4000 Mc/s, so this source had an opposite sense between 9400 and 4000 Mc/s for 2 days near C. M. P. At 9400 Mc/s, the max. value of % polarization, when the sense was right-handed, was very large compared with that of the case when the sense was left-handed. While at 4000 Mc/s the max. values of % polarization in two cases are nearly equal. It will suggest that the maximum values of polarized components for each bipolar source are largely different at 9400 Mc/s while they are almost equal at 4000 Mc/s. This assumption will support the later reversal of polarization at 9400 Mc/s. According to the "Bulletin of Solar Data, U. S. S. R. (7)", the associated sunspot group is of bipolar type and the magnetic field of the preceding spot (N pole) is stronger than that of the following spot and the area of the preceding spot is also larger. The results of observation at 9400 Mc/s will be explained by this optical data, but not the result at 4000 Mc/s. At 4000 Mc/s it appears that the intensity of circularly polarized component does not depend only on the magnetic field strength and the area of sunspot. It may be considered that the electron density is high in the region over the N pole and therefore the region is more opaque than it is over the S pole.

The sunspot group associated with source I is also bipolar and the area and the magnetic field strength of the following spot is larger than those of the preceding one, but its difference is not so large as in the sunspot group associated with source II,

The sunspot group associated with source III is supposed, from the results of former observations with 4000 Mc/s interferometer, (3) to be of complex (multipolar) type.

The general change of balance of polarization over the bipolar sunspots is likely to be explained by assuming a certain directivity for each source of polarization, but we can not yet find a clear model. It will be necessary to observe, with a highly directional aerial of beam width less than 1', the variation of the intensity of polarized component emitted from the region over a magnetic pole with solar rotation.

Conclusion

The results of observations show that the heights of the sources of slowly varying component at 9400 Mc/s are between 3000 and 40000 km and, on the average, seem to be about 10^4 km lower than those at 4000 Mc/s. (11000—50000 km) The **average** height near C. M. P. of the source associated with bipolar sunspot group, calculated by D. S. Mathewson's method, seems to be lower than the actual heights.

The flux from the radio source at 3750 Mc/s is nearly equal to one at 9400 Mc/s or larger. It seems that the brightness temperature of two sources specially near 4000 Mc/s is raised by the effect of the magnetic field of sunspot. Brightness temperature of the strong source is about 10^5 °K at 9400 Mc/s and 0.7×10^6 °K at 3750 Mc/s. % polarization of S component from the radio source at 9400 Mc/s is larger than one at 4000 Mc/s. There is a radio source which has an opposite sense of polarization between 9400 and 4000 Mc/s near C. M..

The interferometer for use at 9400 Mc/s is expected to be increased to 16 elements in spring, 1960. The half-power beamwidth will be about 2 min. arc. and it is expected that more radio informations will be obtained.

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References

1) H. Tanaka and T. Kakinuma : Report of Ionosph. Res. Japan. vol.XII, 3, 273 (1958)
2) W. N. Christiansen and J. A. Warburton : Aust. J. Phys. vol. 6, 262 (1953)
3) T. Kakinuma : Proc. Res. Inst. Atmos. vol. 4, 78 (1956)
4) W. N. Christiansen, D. S. Mathewson, et. al. : Ann. d'Astrophys. 23, 75, 1960.
5) H. Tanaka and T. Kakinuma : Proc. Res. Inst. Atmos. vol. 5, 87 (1958)
6) J. L. Pawsey and R. N. Bracewell : Radio Astronomy. 101 (1955)
7) Bulletin of Solar Data, U. S. S. R. no. 6 (1959)
8) H. Tanaka : International Summer School at Varenna. Italy, July (1959).