POLARIZATION MEASUREMENTS OF THE THREE SPECTRAL TYPES OF SOLAR RADIO BURST

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Summary

A swept-frequency technique was used for measuring the polarization of solar radio bursts occurring at the beginning of the present sunspot cycle. Of special interest were the results for bursts of spectral type III. Contrary to the inference drawn from earlier work, it was found that many of these bursts are highly polarized. Furthermore, there were strong indications that the polarization is produced at the radiation source and is not imposed by propagation conditions in the overlying media.

I. Introduction

Radio spectroscopic observations of intense solar disturbances have shown that these emissions may be classified into a number of distinct spectral types (Wild and McCready 1950). Observations at discrete frequencies had first suggested the possibility of such a classification, and they had also indicated that each type of burst has its own polarization characteristics (Payne-Scott 1949; Payne-Scott and Little 1951).

During " noise storms " (spectral type I) the polarization was found to be often almost complete, while outside noise-storm periods randomly polarized bursts were found to occur. However, Payne-Scott and Little also recognized certain large " outbursts " whose polarization was random during their initial phase and later became elliptical. The identification of Payne-Scott's " unpolarized bursts " with spectral types is not clear. Many of these were certainly of spectral type III, and it was suggested by Wild and McCready that the type III burst characteristically showed no circular polarization.

In the investigation reported here, the spectrum and polarization of solar disturbances have been measured simultaneously over a wide range of frequencies. The observations were made using a modification of the spectroscope described previously (Wild, Murray, and Rowe 1954) and the technique (details of which are given in Section II) provides simultaneous records of the dynamic spectrum and polarization. Thus it has the advantage over previous methods of measuring polarization, that it provides a positive identification of the spectral type under investigation. In addition measurements can be made rapidly, permitting the study of short-lived spectral features. A broad survey is obtained of polarization as a function of time and frequency rather than accurate measures of the polarization ellipse at individual frequencies. The results largely confirm the suggested association between polarization and spectral type, but they also reveal a new

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feature. A considerable number of type III bursts have been found to be strongly polarized. A few of the polarized bursts displayed a " harmonic " structure (see Section III (c)) and, in the cases examined, the sense of rotation of the harmonic component agreed with that of the fundamental. The degree of polarization of the two components appeared to differ, however.

A preliminary report on this work was given by Wild (1955) at the I.A.U. symposium on radio astronomy at Jodrell Bank.

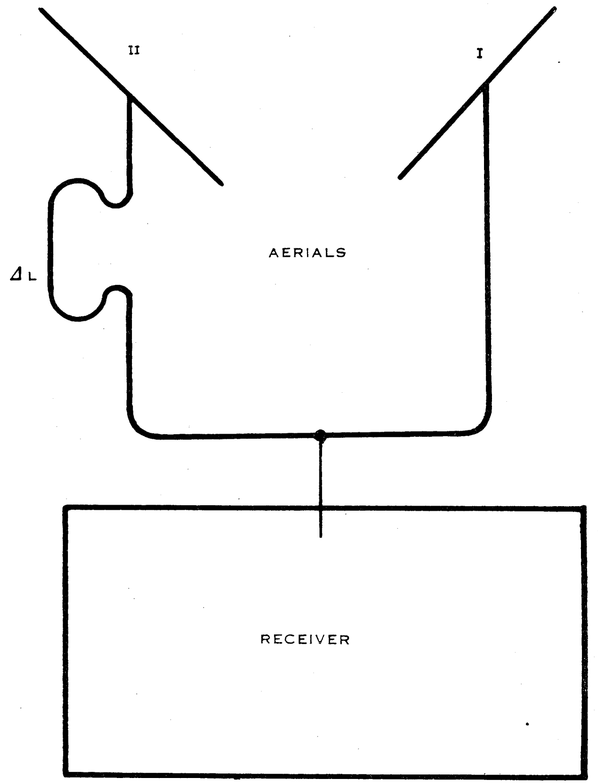

Fig. 1.—Block diagram of the equipment for measuring polarization. One unit of this type was used for each of the three frequency ranges which together covered the band 40–240 Mc/s.

II. A Swept-frequency Technique for Measuring Polarization

(a) *The Method*

The method of polarization measurement is a variant of the crossed-aerial technique, adapted to a swept-frequency instrument.

Three pairs of mutually perpendicular rhombic aerials, each pair equatorially mounted and mechanically driven to follow the Sun, are used to cover three adjacent bands of the 40–240 Mc/s frequency range. Each aerial pair has a corresponding receiver and the individual aerials of each pair are connected to the common receiver by twin-wire transmission lines of different lengths, as shown in Figure 1. If ΔL is the difference in line length, the system accepts one circularly polarized component when the receiver is tuned to a wavelength λ such that $\Delta L=(2n\pm\frac{1}{4})\lambda$, where n is an integer, the sign being determined by the sense of rotation of the electric vector. As the receiver tuning is varied the output goes through a series of maxima and minima. Examples of such patterns for type I radiation are shown in the record of Plate 1. (It should be noticed that the frequency scales are non-linear and that different values of ΔL apply to the different frequency ranges.)

In the general case of partial elliptical polarization, the plane-polarized components may be unequal. The phase angle θ, by which the plane-polarized wave component parallel to aerial II lags that parallel to aerial I, may assume any value between $\pm\pi$ radians. If the type of polarization remains constant across the frequency range and the receiver is continuously tuned, a record is obtained of the radiation power spectrum modulated by a sinusoidal pattern whose maxima occur at wavelengths λ_n such that $(\theta+2\pi\Delta L/\lambda_n)=2n\pi$, where n is an integer. Hence θ may be determined from the frequencies at which these maxima occur, since

$$\theta=2\pi(n-f_n/\Delta f), \quad \text{where } \Delta f=c/\Delta L \text{ and } f_n=c/\lambda_n,$$

c being the velocity of electromagnetic radiation. Figure 2 is a schematic representation of a record for the case where $0<\theta<\pi$.

In order to specify the polarization completely at any one frequency, we need four independent measures of the radiation parameters. However, if we assume that the polarization does not change rapidly with frequency, we may derive considerable information from the modulation pattern alone.

The sense of rotation may be immediately determined from the phase angle θ, being left-handed for $0<\theta<\pi$ and right-handed for $-\pi<\theta<0$. (The convention adopted by the International Astronomical Union is followed in describing sense of rotation. The polarization is right-handed if the vector, viewed along the direction of propagation of the ray, rotates in a clockwise sense.)

The percentage polarization may be defined as

$$100(E_1^2+E_2^2)/(2R^2+E_1^2+E_2^2),$$

where E_1 and E_2 are the phase-coherent voltages received on the individual aerials and R is the random component of voltage received on each aerial.

For circular polarization the percentage polarization is equal to the percentage modulation of the power spectrum given by

$$100(P_{\text{max.}}-P_{\text{min.}})/(P_{\text{max.}}+P_{\text{min.}}) \quad \text{(see Fig. 2)}.$$

This is approximately true also for fairly broad ellipses, but, as the modulation for a given percentage polarization usually decreases as the ellipse becomes elongated, a knowledge of the degree of modulation enables us only to set a lower limit to the percentage polarization.

It is possible to estimate the shape of the polarization ellipse, which may be specified by a parameter p, defined as the ratio of the minor to the major axis of the ellipse. Sufficient information is not available to determine this parameter from individual measurements at single frequencies, but a mean value may be calculated for activity extending over a range of frequencies.

It is known that, when polarized radio waves traverse an ionized medium in the presence of a magnetic field, the polarization ellipse undergoes rotation due to the Faraday effect, the amount of the rotation being a function of both frequency and path length in the medium (Cohen 1956). Murray and Hargreaves (1954) have shown that even at 100 Mc/s there may be several complete rotations in the ionosphere, and a much larger effect may be expected in the solar corona. The magnitude of this effect is sufficiently great for polarization ellipses observed at the different frequencies within the range of our equipment to show all possible orientations. Now an ellipse whose axes lie in the aerial planes yields a phase

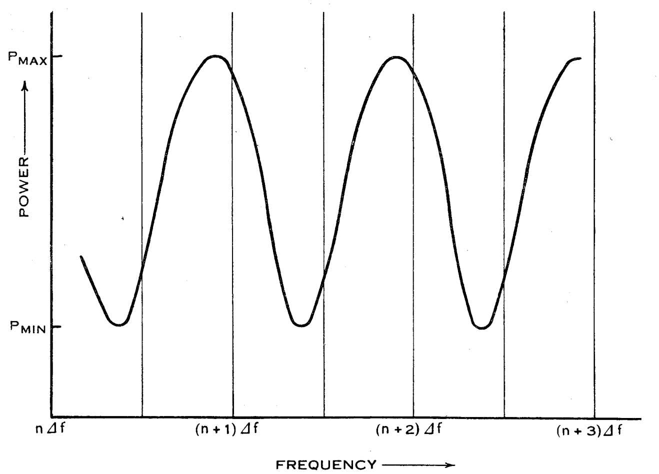

Fig. 2.—Schematic representation of a record of polarized radiation having a flat spectrum. The frequency interval Δf is defined in Section II (*c*).

measurement of $+\frac{1}{2}\pi$ or $-\frac{1}{2}\pi$, and, as the axes rotate from this position about the direction of propagation, $|\theta|$ departs from $\frac{1}{2}\pi$ at a rate which depends on the parameter p. Therefore the probability of observing a particular value of θ is determined by the shape of the ellipse. The problem is formulated in Appendix I, and probability histograms for various values of p are presented in Figure 3 (*a*). On the assumption that the ellipse shape does not vary rapidly with either frequency or time, we may compare the results of a large number of phase measurements extended across a range of frequencies with this set of computed histograms and so obtain a mean value of p.

(*b*) *Calibration*

The intensity scale is calibrated by injecting signals from a diode noise generator into the receiver, and the frequency scale is calibrated against the harmonics of a crystal oscillator.

The differences in length ΔL of the pairs of feeders are measured by a standing wave technique. Each line is short-circuited at the aerial and fed by a signal generator at the receiver end. The approximate length being known, the exact length is determined from the positions of standing wave minima near the receiver, the determination being carried out at a number of frequencies. As in each case it is required to determine the difference of two lengths and not their individual values, no error is introduced by imperfections in the short circuits.

(c) *Accuracy*

The two quantities which are measured from the records are the phase angle and percentage modulation. Because many of the measurements, particularly in the case of type III bursts, had to be made from intensity-modulated records the " probable errors " quoted refer to this type of display. Measurements on " A scan " records yielded somewhat better accuracy. (For a description of the two methods of display see Wild, Murray, and Rowe (1954).)

(i) *Measurement of Phase Angle.*—Reading error is the most serious limitation to the accuracy with which the phase angle θ may be determined. The error is a function of both intensity of activity and frequency and its assessment is difficult. The mean " probable error " of phase measurement across the low and medium frequency ranges is estimated to be about $\pm\frac{1}{8}\pi$ (" probable error " is taken to mean that scatter which includes 50 per cent. of observations).

(ii) *Measurements of Percentage Modulation.*—The probable error in the measurement of percentage modulation is also a function of intensity of activity and is estimated to be about 25 per cent. It is unlikely that the modulation would be detected if its absolute value were less than this.

III. The Polarization of the Three Spectral Types

Polarization measurements summarized here began in January 1955—the beginning of the new sunspot cycle. The data for type I and type III bursts cover the period between January and October 1955, and the type II burst data cover most of 1955 and 1956. The new feature revealed by the measurements is that a substantial number but by no means all of the type III bursts are strongly polarized. From earlier observations it had been inferred that their polarization was random.

Because of calibration and other difficulties with the high frequency range of the equipment, most of the results presented here were derived from the low and medium frequency records covering the band 40–140 Mc/s.

(a) *Type I Bursts* (*Storm Bursts*)

The records of 13 days' activity were examined, and the conclusion of earlier observers confirmed, that Type I bursts display a high degree of quasi-circular polarization. The radiation was polarized at all frequencies and usually showed the same sense of rotation throughout the frequency range and during any one day. For the more intense storms during this period the sense of rotation was left-handed. The sense of rotation data are presented in Table 1 (*a*). It will be seen that there was only one case in which the sense of rotation changed throughout the day—this was on January 10, 1955, when there was a sporadic storm during which both senses were observed, but on different frequency ranges and at different times. The letters L.F. and M.F. in the table refer to the low (40–70 Mc/s) and medium frequency (75–140 Mc/s) ranges of the equipment respectively.

Generally the polarization was greater than 50 per cent.

Table 1

SENSE OF ROTATION OF POLARIZATION ELLIPSE

(a) Type I Bursts			(b) Type III Bursts		
Date (1955)	U.T.	Sense of Rotation	Date (1955)	U.T.	Sense of Rotation
Jan. 6	0423–0845	L			
Jan. 10	0434–0450	L (M.F. range only)	Jan. 10	0801	L
	0514–0521	R (L.F. range only)		2052–2054	L
Jan. 11	0338–0530	L			
Jan. 12	0834–0837	L ?	Jan. 12	0705–0815	L
				2140	L
Jan. 13	2318–0634	L			
Jan. 15	0351–0841	L			
Jan. 16	2216–0511	L			
	2150–2211	L			
Feb. 2	0226–0436	R	Feb. 2	0634	R
				0712	R
				0754	R
			Mar. 3	0300	R
Mar. 4	0435–0488	R			
Aug. 12	0307–0609	R	Aug. 12	0536	R
				0538	R
Sept. 6	0003–0720	L			
Oct. 10	2242				
Oct. 11	0714	L			

Using the method outlined in Section II and Appendix I, frequency distributions of phase measurements have been prepared for some of the longer-duration noise storms, and are presented as histograms in Figure 3 (*b*), together with the set of histograms computed for a number of values of p in Figure 3 (*a*). It would appear from this figure that p generally lay between 0·5 and 1·0.

(*b*) *Type II Bursts*

Polarization observations were carried out for 13 type II bursts. Eight of these records were completely unmodulated. In the case of four of the remainder no conclusion was reached. For two of these, very weak patterns were observed which may have been spectral fluctuation. The other two occupied so narrow a band of frequencies that the observation of a modulation pattern would probably have been impossible.

Only one record was probably polarized for a short period but the modulation at its maximum was not greater than 30 per cent.

(c) *Type III Bursts*

In the course of the present investigation about 500 type III spectra were recorded, and of these, some 50 per cent. exhibited the modulation pattern characteristic of fairly strong polarization (examples of polarized and unpolarized type III records are shown in Plate 2).

It is possible that terrestrial effects were responsible for some of the modulation. This was first suggested by the observation that, in the period January–May 1955, the ratio of modulated to unmodulated bursts rose sharply for the higher

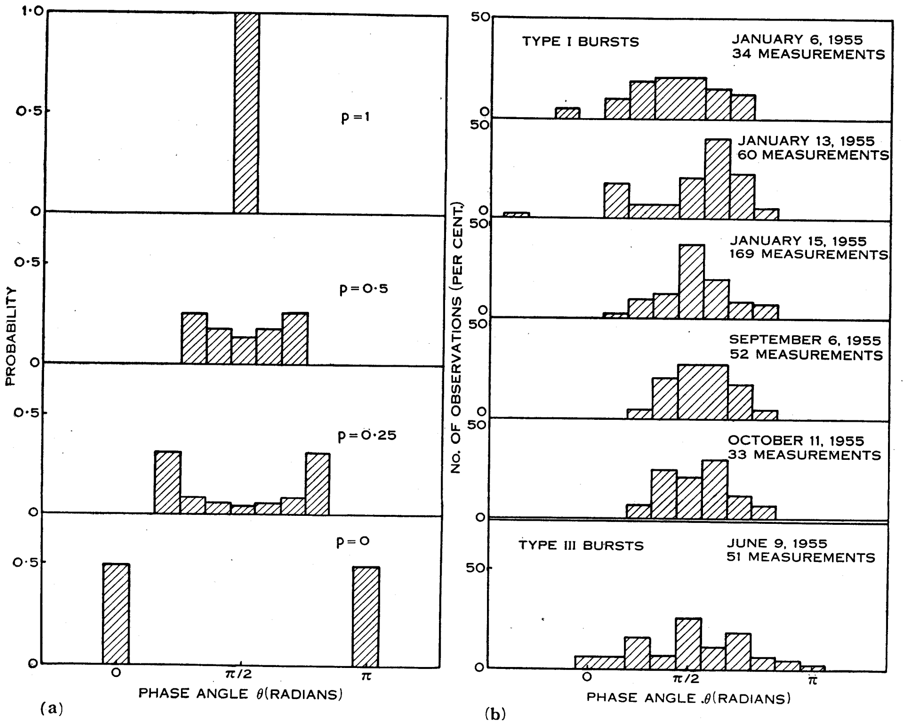

Fig. 3 (*a*).—Probability distributions of phase angle θ, for various values of the parameter *p*, calculated according to the method described in Appendix I.

Fig. 3 (*b*).—Observed frequency distributions of phase angle for type I and type III radiation occurring on the days indicated.

solar zenith angles. Two terrestrial mechanisms capable of producing spurious polarization effects are differential absorption of oppositely polarized modes in the ionosphere and ground reflection.

It can be shown that polarization produced by differential absorption in the ionosphere is not likely to exceed 5 per cent. Moreover, Slee (unpublished observations), observing at 85 Mc/s, found that the polarization of the source in Taurus (at about 56° from zenith) was less than 2 per cent. These figures are below the threshold of detectability of our equipment.

The effect of ground reflection is more difficult to assess. The broad lobes of the rhombic aerials are capable of receiving both direct and ground-reflected radiation components over a large range of solar zenith angles, and these components may give rise to interference patterns. Determination of the amplitudes of these patterns involves extremely lengthy calculation and has been carried out for only a few special cases. However, the fact that only three of a total of thirteen type II records show evidence of (extremely faint) modulation, suggests that over considerable periods the effect is not large.

Although terrestrial effects cannot be completely ruled out, there is considerable evidence of a solar origin for much of the type III polarization. This may be summarized as follows:

(1) Observations for the period May–October 1955 do not show the trend with zenith angle shown by the earlier results.

(2) Measurements of phase angle have been made for about 40 bursts and are presented in the histogram of Figure 4. Clustering of phase values about $+\frac{1}{2}\pi$ and $-\frac{1}{2}\pi$ indicates components of genuine quasi-circular polarization.

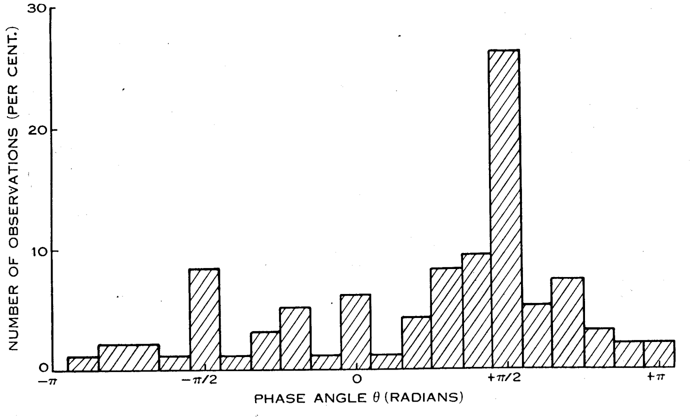

Fig. 4.—Frequency distributions of phase angle of 40 type III bursts occurring throughout the year.

(3) Polarization of type III bursts occurring on the same day showed the same sense of rotation; furthermore, this was the same as that of any type I radiation occurring within a period of one or two days (see Table 1).

(4) The occurrence of bursts showing a harmonic structure (see below) in which the fundamental component is more deeply modulated than the harmonic, cannot be explained in terms of any local mechanism.

To establish more definitely the solar origin of the polarization of type III bursts and to determine the features of this polarization, a sample record was chosen for detailed analysis, the record being one for which instrumental effects appeared to be negligible. The record selected was that of June 9, 1955. Table 2 is a summary of this day's activity.

Both highly polarized and unpolarized bursts were observed between 0008 and 0248 U.T. during which period the solar zenith angle changed by only about 6·5°. Furthermore, polarized bursts were observed at 0129 and 0153 U.T. on the previous day, June 8, whereas bursts occurring at 0118 on June 9 were unpolarized. The depth of modulation to be expected from ground reflection was calculated for these bursts and no significant difference was found between the depth of modulation due to ground effect at the times when the records were modulated and those when they were not. In any case the effect was near the threshold of detectability of the equipment.

As there were no " A scan " records available, a microphotometer was used to evaluate the depth of modulation of the cluster of bursts occurring between 0246 and 0250 U.T. This was found to vary between about 30 and 70 per cent. Phase measurements made on this same cluster are presented in the histogram of Figure 3. Although there is considerable " scatter ", it can be seen that the values cluster around $\frac{1}{2}\pi$, indicating that the polarization was elliptical, with the left-handed sense of rotation.

TABLE 2

SUMMARY OF ACTIVITY JUNE 9, 1955

Time (U.T.)	Bursts	Observed Modulation
0001–0002	Type III	None
0008–0019	Main part of type II burst	None
0032	Tail of type II burst	No evidence of modulation
0033½	Cluster of type III bursts	High
0118–0120	Cluster of type III bursts	None
0246½–0250	Cluster of type III bursts some showing harmonic structure	High—up to 70 per cent.

Several " harmonic " bursts were observed during the present investigation, and of these some were polarized, though not all. The spectrum of these bursts consists of two components, one duplicating the features of the other at about twice the frequency. Their occurrence was first reported by Wild, Murray, and Rowe (1954), who attributed the spectral structure to the emission of a fundamental frequency and its second harmonic from the same coronal level.

Of the cluster of (polarized) bursts observed between 0246 and 0250 U.T. on June 9, two show a well-defined harmonic structure. This record is reproduced in Plate 2. In each case it appears that the fundamental is more deeply modulated than the harmonic. This visual impression is confirmed by microphotometer measurements, and Figure 5 is a plot of degree of modulation versus frequency for each component of these two bursts.

IV. DISCUSSION OF RESULTS

(a) *Comparison with Other Observations*

As noted earlier, the present work confirms the conclusion of earlier observers (notably Payne-Scott and Little 1951) who have reported that the bursts now known as type I (" storm bursts ") are strongly polarized. For bursts of spectral types II and III, a perfectly definite comparison of the present results with those of earlier observers is not possible because of the uncertainties involved in attempting to identify features observed at single frequencies with those observed with the spectrometer.

Our observations of type II bursts have indicated that polarization, if it is present at all, is very slight. Payne-Scott and Little (1951), on the other hand, reported surges of activity whose intensities and durations would suggest type II bursts, but they found that, although these were initially unpolarized, they often went through a period of elliptical polarization. The apparent conflict may be resolved if we assume that the period of elliptical polarization represented the beginning of a type I storm. The single-frequency records do not, however, provide sufficient information to settle this point.

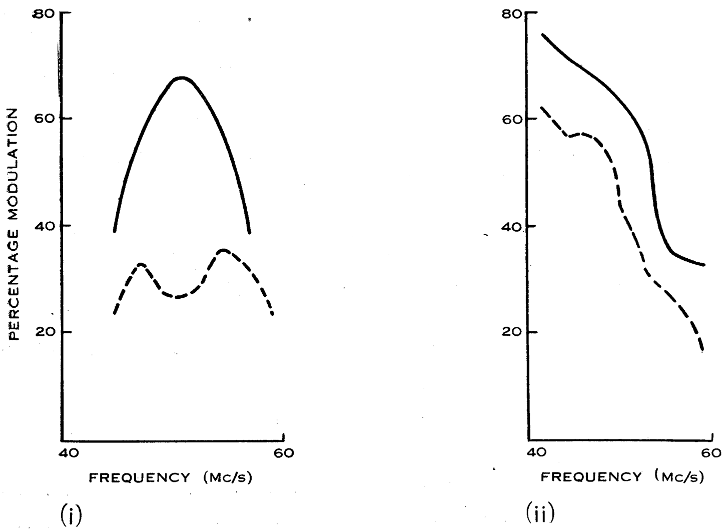

Fig. 5.—Degree of modulation as a function of frequency for the two polarized harmonic type III records of June 9, 1955 shown in Plate 2. The full line refers to the fundamental and the broken line to the harmonic component in each case.

Type III bursts, largely as a result of Payne-Scott's earlier work (1949), have been thought to be unpolarized, whereas it is clear from the present investigation that many, though not all, are strongly polarized. In this case the conflict would appear to be terminological rather than real. Payne-Scott used "unpolarized burst" as a definitive term, and showed that short-lived bursts of this kind occurred almost simultaneously at widely separated frequencies, that is, that they corresponded to what were later designated spectral type III. She did not discuss the converse problem—whether all bursts having this spectral feature were unpolarized. Single-frequency records available in this laboratory have been examined in the light of the present results, and a number of examples have been found in which bursts occurring nearly simultaneously at 85 and 60 Mc/s were quite highly polarized. In the case of type III bursts there is, therefore, no conflict between the earlier and the present results.

(*b*) *The Origin of Polarized Radiation*

The present results enable us to draw some general conclusions about the origins of type I and type III polarization. We may explain the occurrence of polarized radiation either in terms of the generation mechanism or in terms of propagation conditions in the medium between the source and the observer. Polarization imposed by the medium may arise in two ways, as discussed below.

(i) *Polarization by Total Internal Reflection in a Birefringent Medium.*—The radiation may pass through a region in which the refractive index for one propagation mode is zero. In this case only the mode for which the refractive index remains finite will be transmitted, and the radiation will be completely polarized. Now, it is well known that, for radiation to escape from the corona (see for example Smerd 1950), it must originate above the level for which the refractive index for the ordinary propagation mode is zero. The height of this level is determined by the electron density distribution. In the presence of a magnetic field, there is another level, above the first, at which the refractive index for the extraordinary mode is zero. The separation of these two levels increases with the intensity of the magnetic field. Radiation generated in the region between them is polarized because only the ordinary mode escapes. For quite a wide range of angles between the direction of propagation and the magnetic field, the polarization is very nearly circular. If radiation extending over a broad frequency range is to be polarized in this way, each frequency component must originate between the corresponding levels of zero refractive index. Figure 6 is a plot of the heights of the levels of zero refractive index in an extreme case—above a very large unipolar spot group whose magnetic field at the chromospheric surface is 3600 oersteds. For more common spots the separation between the two levels is less than that shown.

It is possible to explain the polarization of type I radiation in terms of total internal reflection, but such an explanation implies that the radiation source is vastly extended in space. It can be seen from Figure 6 that, for radiation occupying the frequency band 40–140 Mc/s to be polarized by this means, its source must extend over a radial distance of at least 10^5 km.

On the other hand, we cannot explain the polarization of harmonic type III bursts in terms of total internal reflection. The fundamental and harmonic frequency components originate from the same source (Wild, Murray, and Rowe 1954), and, referring again to Figure 6, we see that in no case do the regions between the two reflection levels overlap for frequencies whose ratio is 2 : 1 when the lower frequency lies in the range 20–40 Mc/s.

(ii) *Polarization by Differential Absorption.*—A second way in which the medium may impose polarization is by differential absorption of modes, an effect which depends on the electron collision frequency. Although differential absorption possibly contributes to the polarization of the fundamental, it is quite inadequate to explain the high polarization of the harmonic components of type III bursts. Because the absorption is most marked in the vicinity of the region at which the refractive index is zero, the polarization impressed on the second harmonic radiation (which is propagated outwards from a region in which the frequency of zero refractive index is only about one-half of the wave frequency) is negligible.

It is difficult to escape the conclusion that at least the type III bursts showing harmonic structure originate in a source which emits polarized radiation.

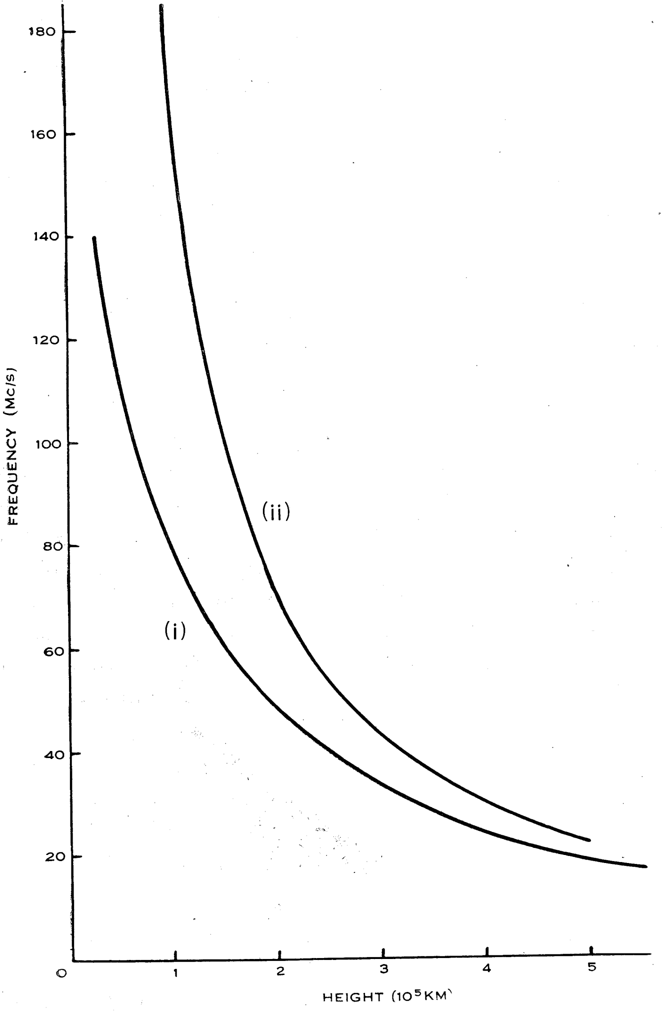

Fig. 6.—Heights of the levels of zero refractive index in the corona above an extremely large unipolar sunspot group having a surface magnetic field intensity of 3600 oersteds. The field and coronal models used are those described by Smerd (1950). The numbers (i) and (ii) refer to the ordinary and extraordinary mode respectively.

V. Acknowledgments

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Appendix I

Estimate of Ellipse Shape based on Many Phase Measurements

Consider elliptically polarized radiation incident on a pair of crossed rhombic aerials, the direction of propagation being along the common aerial axis.

Then the voltages induced in the aerials are proportional to the coordinates, with respect to a pair of Cartesian axes lying in the aerial planes, of a point describing an ellipse having the same shape and orientation. Therefore, if the ellipse axes lie in the aerial planes, the voltages are proportional to x_1 and x_2 where

$$x_1=\cos \omega t,$$
$$x_2=p \sin \omega t,$$

and p is the ratio of the minor to the major axis. If the ellipse rotates through an angle φ about the direction of propagation, then x_1x_2 must be replaced by $x_1'x_2'$, where

$$x_1'=x_1 \cos \varphi - x_2 \sin \varphi,$$
$$x_2'=x_2 \cos \varphi + x_1 \sin \varphi.$$

Therefore,

$$x_1'=(\cos^2 \varphi + p^2 \sin^2 \varphi)^{\frac{1}{2}}.\ (\cos \omega t + a),$$
$$x_2'=(p^2 \cos^2 \varphi + \sin^2 \varphi)^{\frac{1}{2}}.\ (\cos \omega t + b),$$

where

$$a=\text{artan}\ (p \tan \varphi),$$
$$b=-\text{artan}\ (p \cot \varphi).$$

Therefore the angle θ by which x_2' lags x_1' is

$$\theta=a-b,$$

and

$$\tan \theta=\frac{p}{1-p^2}\, 2 \operatorname{cosec} 2\varphi. \quad \ldots\ldots\ldots\ldots\ldots\ (1)$$

Now, if an ellipse of given shape (denoted by p) may assume all orientations in the plane perpendicular to the direction of propagation and all orientations are equally probable, then the probability of observing a particular value of θ, lying in the range $\theta_1-\theta_2$, is proportional to the corresponding range, $\varphi_1-\varphi_2$, given by equation (1).

Hence, using equation (1), we may construct a set of histograms, each for a constant value of p, indicating the way in which the probability of observing values of θ lying in a range centred on θ_0, varies with θ_0. This has been done in Figure 3 (*a*).

Explanation of Plates 1 and 2

Plate 1

Sample records of strongly polarized type I radiation. The bright streaks parallel with the time axis are maxima of the modulation patterns. Unmodulated sections of record obtained with single aerials are included for comparison in each case. The faint sloping lines crossing the records are due to radiation from power lines having a 50 c/s modulation.

(*a*) January 13, 1955 at about 0040 U.T.

(*b*) January 15, 1955 at about 0800 U.T. This record shows the effect of reversing the aerial connection, causing the pattern to shift by one half-fringe width.

Plate 2

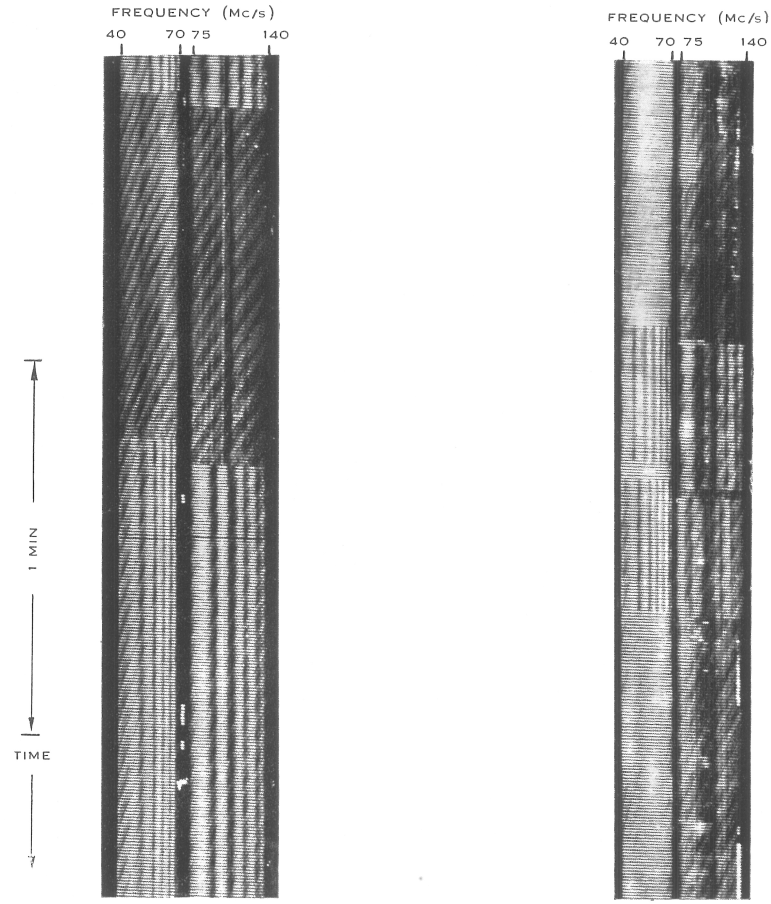
Sample records of type III bursts.

(*a*) Record of a typical group of unpolarized type III bursts observed on August 15, 1955 at 0155 U.T. The dark spaces on this record and on records (*b*) and (*c*) at 70 and 140 Mc/s are produced by switching of the three receivers which together cover the frequency range. The absence of a modulation pattern of vertical dark lines in this record (cf. records (*b*) and (*c*)) shows that the radiation was unpolarized.

(*b*) Polarized type III bursts observed on January 12, 1955 at 0749 U.T. These bursts were part of a polarized type III " storm " lasting several hours.

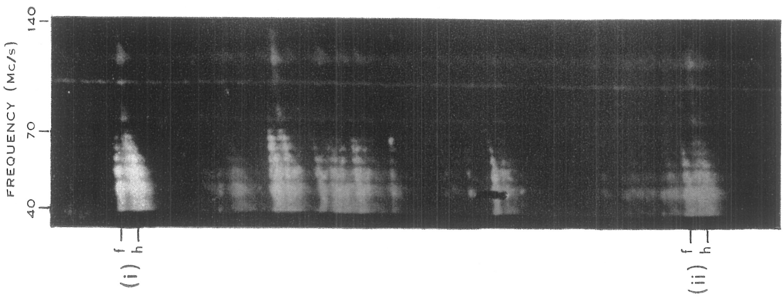
(*c*) Cluster of polarized type III bursts observed on June 9, 1955 between 0246 and 0250 U.T. The numerals (i) and (ii) indicate bursts showing a definite harmonic structure. The fundamental and harmonic components are denoted by the letters f and h respectively. At any time, the frequency of maximum intensity of component h is very nearly twice that of component f. In each of the examples marked, the two components start at frequencies of about 130 and 65 Mc/s respectively.

POLARIZATION MEASUREMENTS OF SOLAR RADIO BURSTS

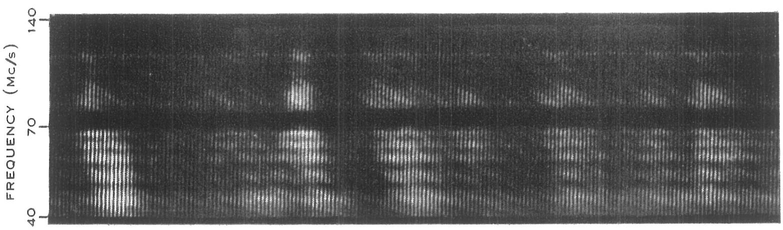


(a) (b)

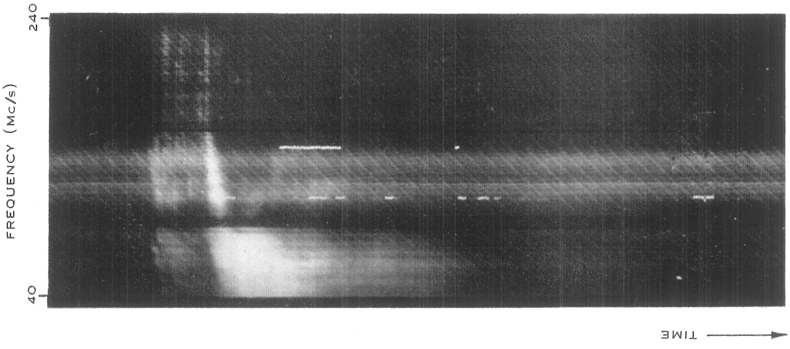
POLARIZATION MEASUREMENTS OF SOLAR RADIO BURSTS



(c)



(b)



(a)