RADIO FIELD INTENSITY MEASUREMENTS AT BANGALORE DURING THE POLAR YEAR.

By P. L. Narayanan.

SUMMARY.

The paper relates to the measurement of field intensities of received radio signals of low and medium frequencies.

Abnormal polarisation and deep fading during the dark hours and characteristic intensity variations in the neighbourhood of sunset and sunrise are the chief features of transmissions from Madras on 75 kc/s. The partial solar eclipse on 21st August 1933 caused a definite decrease in the value of the field intensity followed by a gradual rise after the middle of the eclipse.

The intensity curves of the long wave stations of Rugby, 16 kc/s, and Nauen, 16·54 kc/s, show a hump between 0600 and 0700 I.S.T.

Transmissions from Bombay and Colombo broadcasting stations are characterised by violent intensity changes during the night. The nature of the interference by foreign stations with Bombay and Colombo has been indicated.

INTRODUCTION.

The measurement of the intensity of radio signals from near or distant transmitting stations has a two-fold object. It helps to determine the minimum power required in the transmitting antenna for obtaining intelligible signals at different distances under specified physical conditions of transmission. It also throws considerable light on the nature of the propagation of radio waves round the earth.

OBSERVED STATIONS AND SIGNALS.

The present measurements relate mainly to the radio telegraph transmitter (VWO) at Madras working on 75 kc/s and the broadcast transmitter (VUB) at Bombay working on 840 kc/s. Occasionally, measurements have also been made on the signal intensity of the 700 kc/s broadcast transmitter at Colombo; and, whenever practicable, the intensities of the radio telegraph transmitters at Nauen (DFY, 16·54 kc/s) and at Rugby (GBR, 16 kc/s) have also been recorded. Through the courtesy of the Director of Wireless, it was possible to arrange for special transmissions from Madras, from April to August 1933, consisting of continuous dashes of five minutes' duration, every Wednesday night from about 2200 to 0800 I. S. T. to facilitate accurate observations. Other measurements were made during the working hours of the stations concerned.

PRINCIPLE OF MEASUREMENT.

The procedure adopted in all cases was essentially the same. The signal from the required station was received on a suitable frame aerial with its plane in the direction of propagation. After tuning by a variable air condenser, the signal was passed through a suitable amplifier, the gain of which could be adjusted to the point of self-oscillation. The amplified signal was then rectified by an anode bend rectifier. In the output circuit of the latter was connected a Cambridge thread recorder giving half minute marks on a chart fixed on a drum driven by clock work. By adjusting the gear ratio, it was possible to revolve the drum at the rate of one revolution in 25 hours or in one-twelfth of that interval. Calibration of the receiver was effected by a local oscillator, tuned to the signal frequency, from which accurately known adjustable output voltages were obtainable. From the calibration curve of the receiving apparatus and the constants of the aerial circuit, the recorder chart was calibrated in terms of microvolts per metre of the incoming signal.

LOW FREQUENCY MEASURING APPARATUS.

Fig. 1 shows the diagram of connections used for the 75 kc/s signals from Madras. A similar equipment was used for observations on signals from Rugby and Nauen. These follow the method first used by Hollingworth (*Jour. I.E.E.*, 1923, **61**, 501).

Aerials.—The receiving aerials consisted of two separate square frames with sides 1·8 metres long, wound over with 7/22 stranded copper conductor. The spacing between adjacent turns was obtained by means of specially designed porcelain combs located at the four corners. The coil used for Madras had 20 turns and a measured inductance of 1500μH, while the other one had 50 turns and a measured inductance of 7650μH.

Receivers.—The receiver, housed in a screening aluminium box, consisted, in either case, of a three-stage capacity-resistance coupled amplifier with a variable condenser of 100$\mu\mu$F between the grid of the first triode and part of the anode resistance of the second for purposes of reaction control. The last triode acted as the rectifier. A pair of phones T was connected across the secondary of the transformer in the anode circuit of the rectifier for preliminary tuning. The rectified current was fed into the automatic recorder whose initial deflection in the absence of a signal gave the datum line for the record.

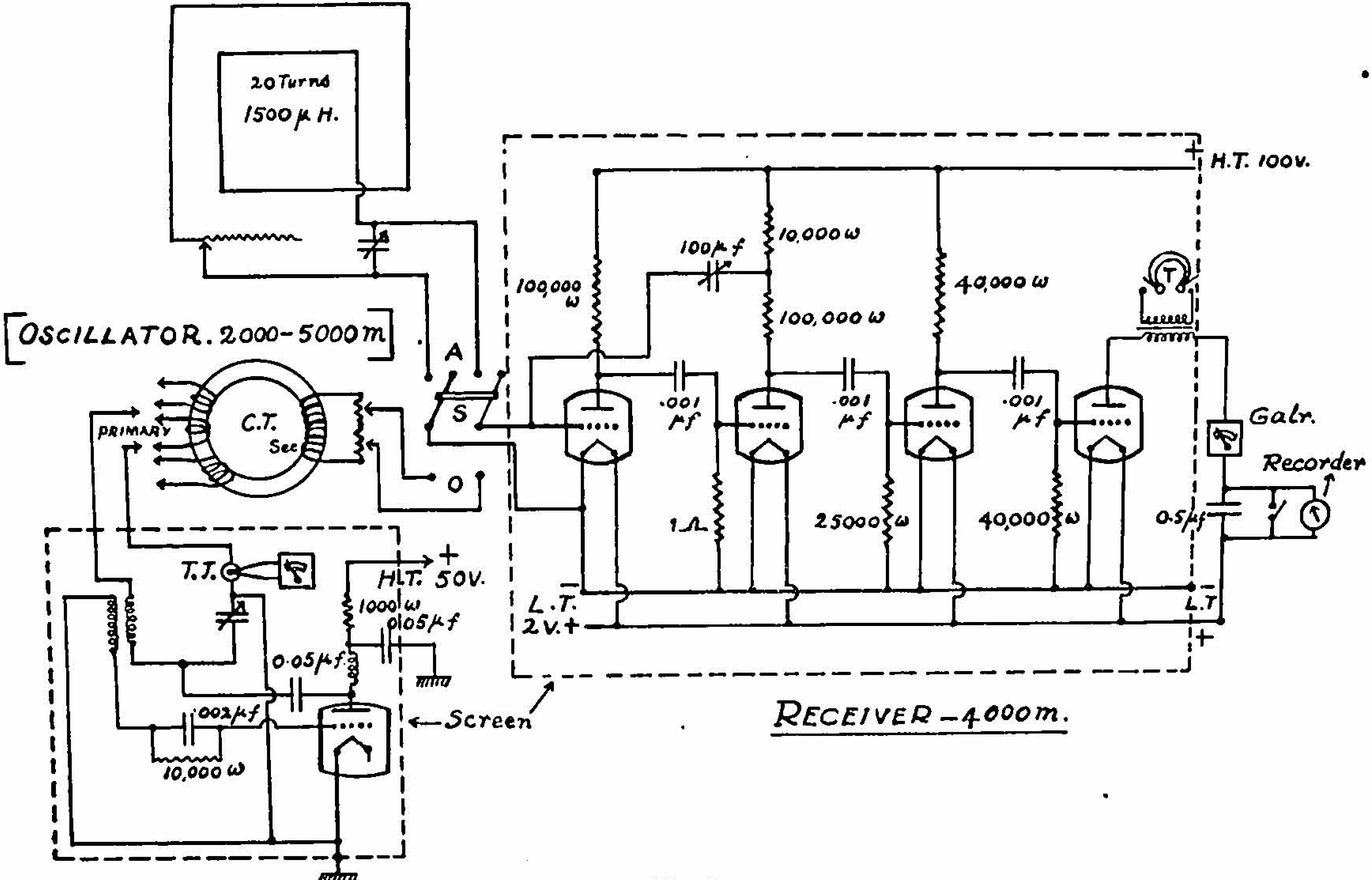

Fig. 1.
Low Frequency—Measuring Equipment.

Calibrating equipment.—The calibrating arrangement consisted, in each case, of a shielded oscillator. The oscillatory circuit included a thermo-junction T.J. and a current transformer C.T. (Dye, *Jour. I.E.E.*, 1925, **63**, 597) having a variable primary winding and a secondary winding of 100 turns. A radio frequency potential divider of 20 ohms resistance was connected across the secondary; knowing the primary current, the number of turns of primary winding and the potentiometer resistance, the output voltage could be easily calculated.

Method of operation.—The voltage developed by a field intensity F in a coil of area a, number of turns n, inductance L and effective resistance R is $\frac{2\pi a n \omega L}{\lambda R}F$, where $\frac{\omega}{2\pi}$ is the frequency, and λ the wave-length of the incoming signal. This voltage after being amplified and rectified produces a deflection in the recorder. The object of calibration is to measure the voltage which would produce the same deflection as the incoming signal. The double throw switch S is thrown over to the oscillator and deflections are obtained in the recorder corresponding to a number of input voltages, by varying the potentiometer resistance. The current in the oscillatory circuit and the ratio of the primary to the secondary turns remaining the same, the input voltages are proportional to the corresponding potentiometer resistances. From the curve connecting the input voltage and the deflection produced by it, the signal voltage corresponding to a known deflection can be obtained. The frequency of the signal and the constants of the aerial being known, the signal intensity can be calculated if R is determined.

R is the effective resistance of the entire aerial circuit and is considerably influenced by the reaction control condenser. For the determination of R, the resistance variation method was adopted on account of its simplicity. The observations were made sometimes on the incoming signal and on other occasions on a local signal tuned exactly to the frequency of the former; in the latter case, the plane of the aerial was set perpendicular to the direction of transmission to cut out the distant signal as far as possible.

Precautions.—As the receiving equipment was intended to be in continuous operation for long hours it was essential that the set should be perfectly steady in operation and free from any tendency towards instability even under the worst conditions of atmospheric disturbances. The reaction condenser was therefore set below the point of instability, but at a position to give satisfactory deflections in the recorder at all hours. After the preliminary observations had been made, the telephones were disconnected as, otherwise, the receiver was found to be unstable.

MEASUREMENTS ON MADRAS.

The observations on the Madras transmissions indicate that, in general, while the signal strength remains more or less constant during the day time, it is subject to violent fluctuations after sunset and throughout the dark hours of the day. It can be seen from the movements of the recorder needle that the signals at night are very

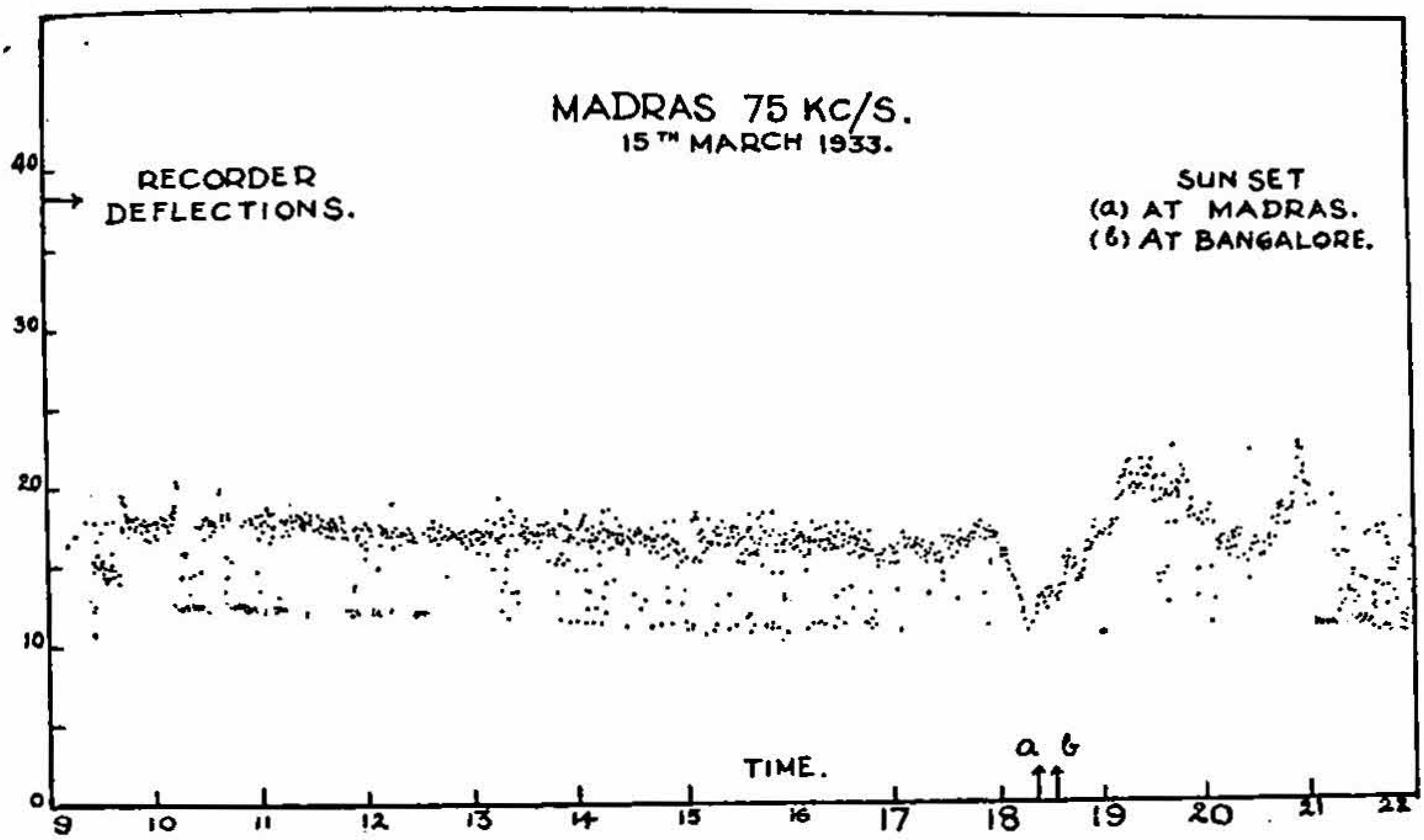

Fig. 2(a).

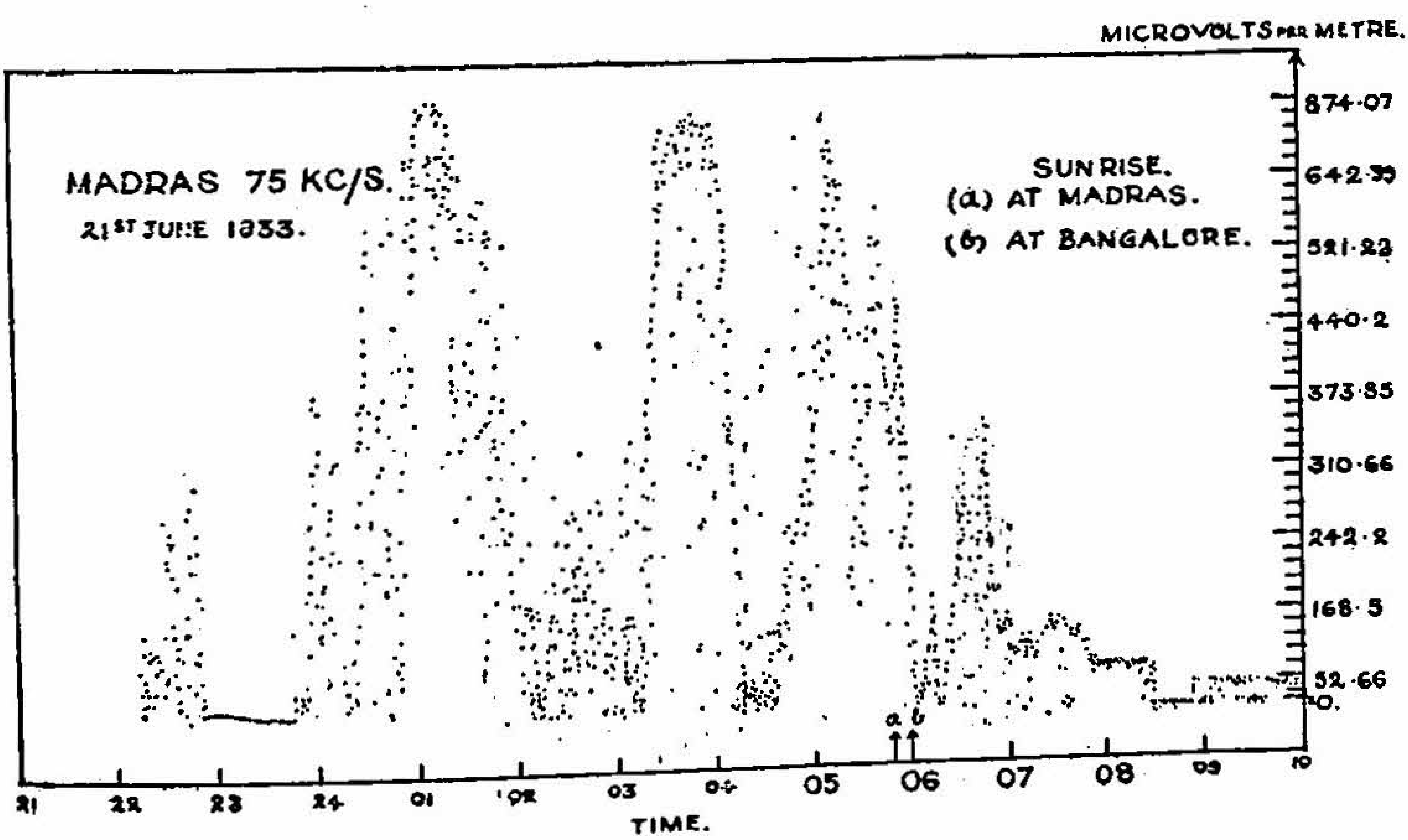

Fig. 2(b).

unstable and are subject to considerable variations within a fraction of a minute. The presence of this rapid and deep fading at the low frequency of 75 kc/s is noteworthy. At sunset there is usually a sudden well-defined dip in the intensity curve, the minimum value coinciding more or less with the time of sunset. This dip is the starting point of fluctuations during the night hours. At the hour of sunrise there is another sharp dip in the intensity curve coinciding more or less with the hour of sunrise. While similar dips occur at random at all hours of the night it is invariably present at the hour of sunrise. These dips in the intensity curves can be seen in Figs. 2a and 2b.

The average value of the intensity during the day and night hours has been calculated and shown in Fig. 3. The average day values have been worked out for the period 0800—1700 I.S.T., and the night values for 2000—0500 I.S.T. These hours do not include the time of sunrise and sunset and therefore the averages are free from the varying influences due to these. These mean values have been derived from the 24-hour charts recorded on Wednesdays from April to August 1933. The dotted lines in the graph indicate the absence of transmission or the breakdown of the recording equipment.

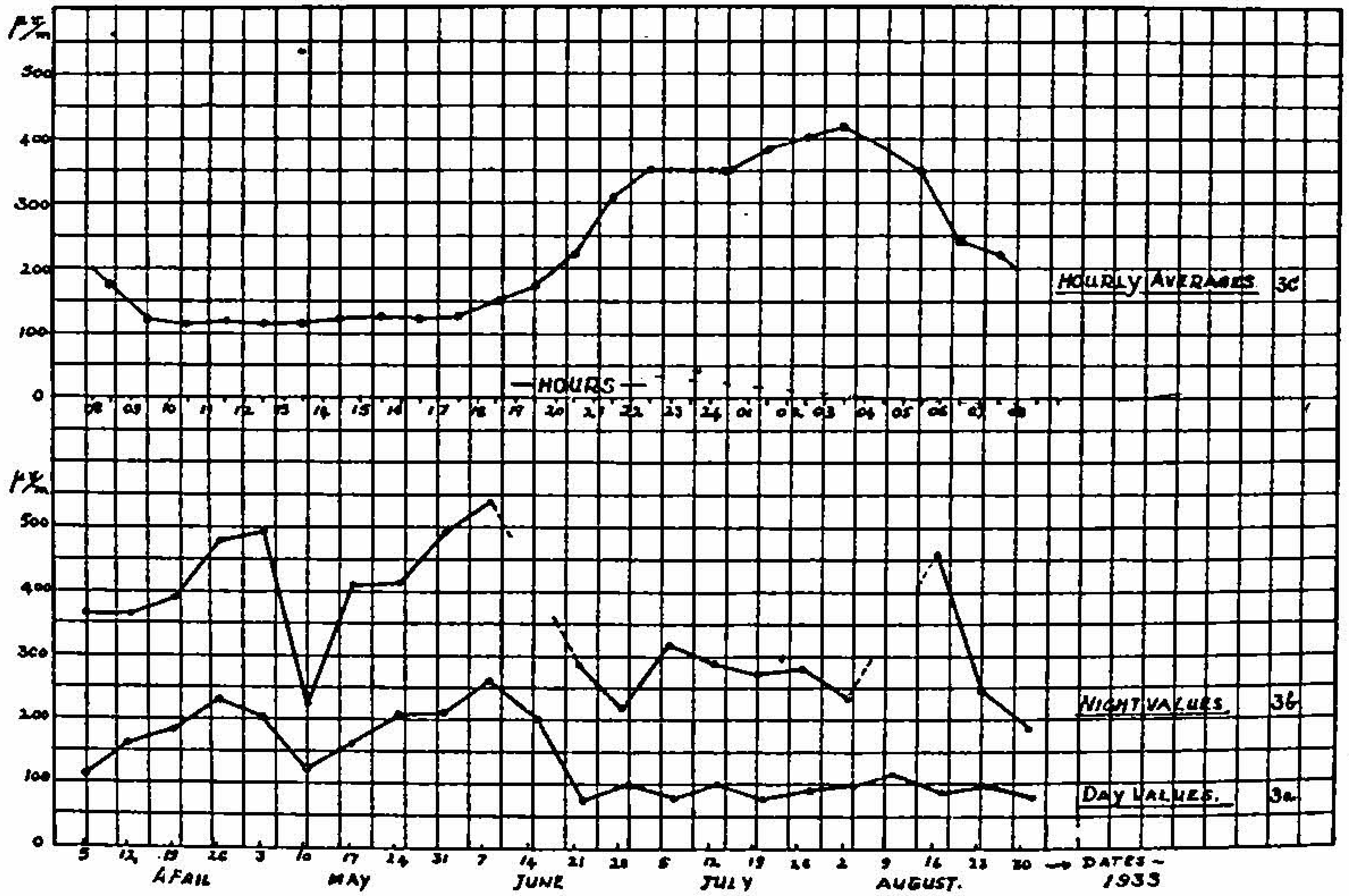

Fig. 3.

Average Intensity Curves.

Fig. 3a, for the average day value, indicates a considerable variation in intensity during April and May and a very much smaller variation in June, July and August. The variations during the night as indicated by 3b are much greater than the day values. The mean of the night values (325 μv/metre) is nearly three times the mean of the day values (121 μv/metre). The observations on the special transmissions alone gave the mean average night value of 387 μv/metre for the field intensity of Madras at Bangalore. These may be compared with the signal intensities calculated from the Austin-Cohen's and Fuller's formulæ. Taking the usual current of 50 amperes in the transmitting aerial and assuming the effective height of the aerial to be half the geometrical height (80·47 metres), the intensities calculated from these formulæ are respectively 527 and 543 μv/m.

Fig. 3c shows the hourly average values of signal strength over the entire period and indicates more clearly the difference in the signal strengths between the day and night hours. It also shows the comparative constancy of intensity during the day hours and the large fluctuations at night.

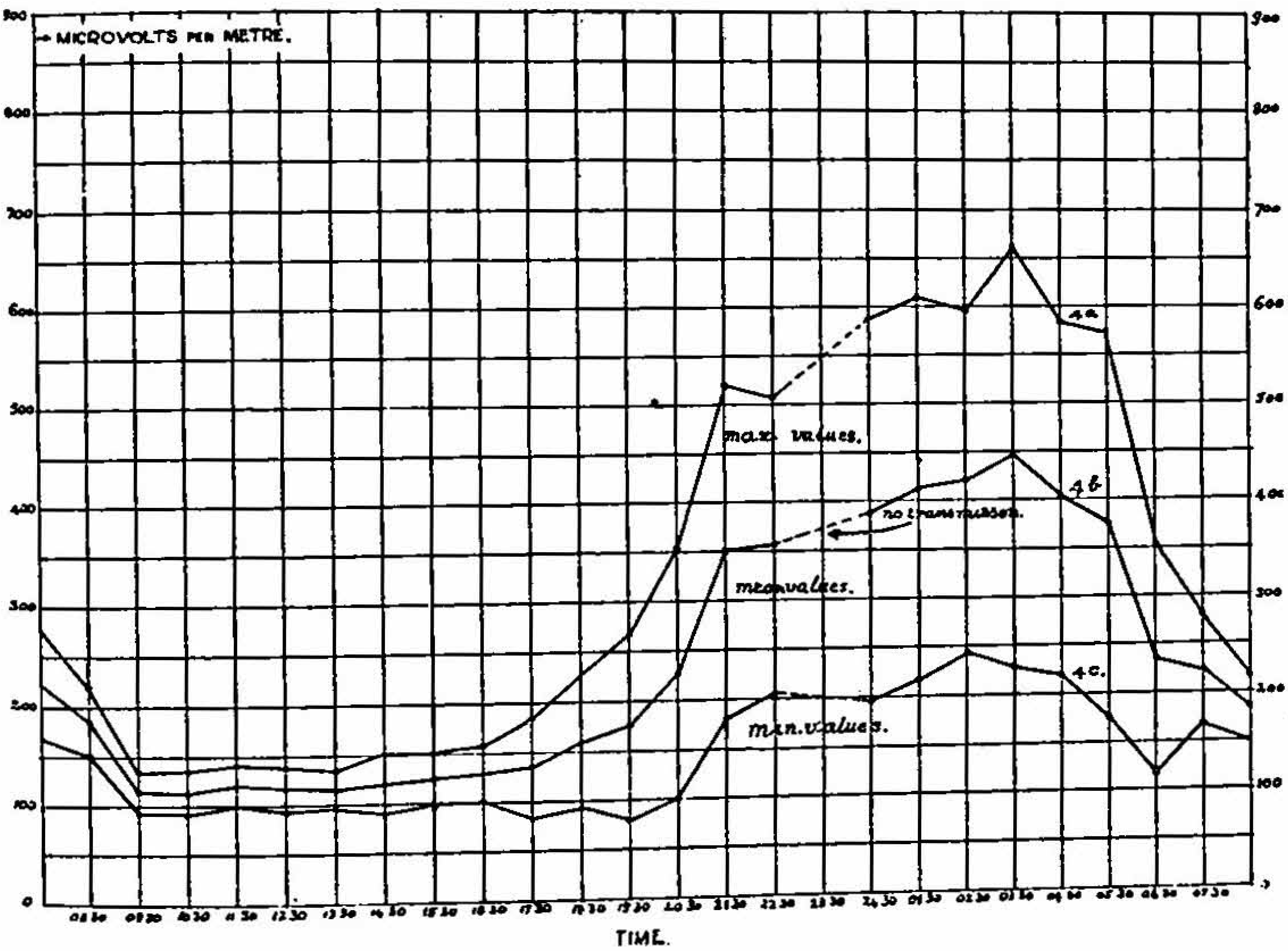

Fig. 4.

Hourly Intensity Curves.

Curves a and c in Fig. 4 show the average of the maximum and minimum values of intensities occurring during each hour taken over the whole period. Fig. 4b represents the mean of these curves. The width of the ordinate between 4a and 4c at any point indicates the extent of the variation of the signal at that hour. The ratio of the mean variation to mean intensity is about three times as great during night as during day.

Abnormal polarisation.— Fig. 5a is the record of the signal with the axis of the receiving frame aerial parallel to the direction of transmission. From the commencement of transmission at about 1000

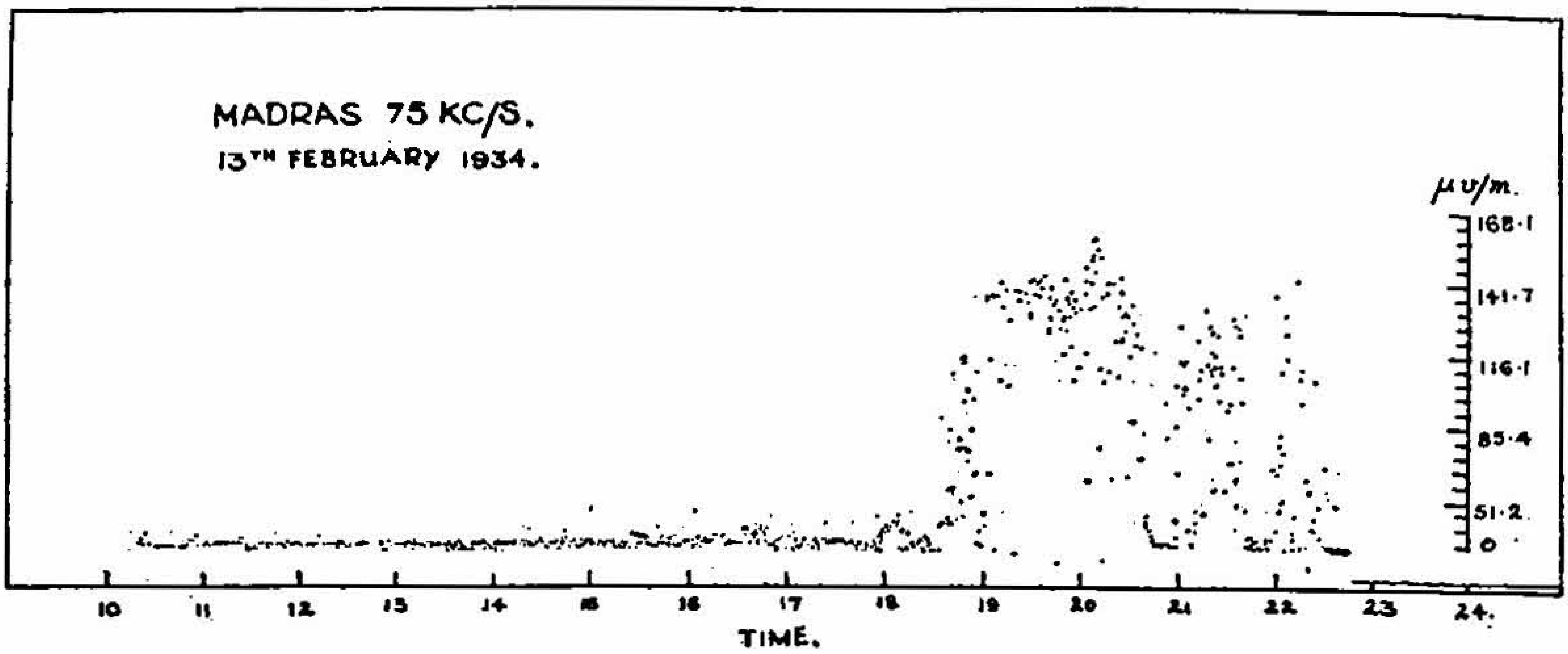

Fig. 5(a).

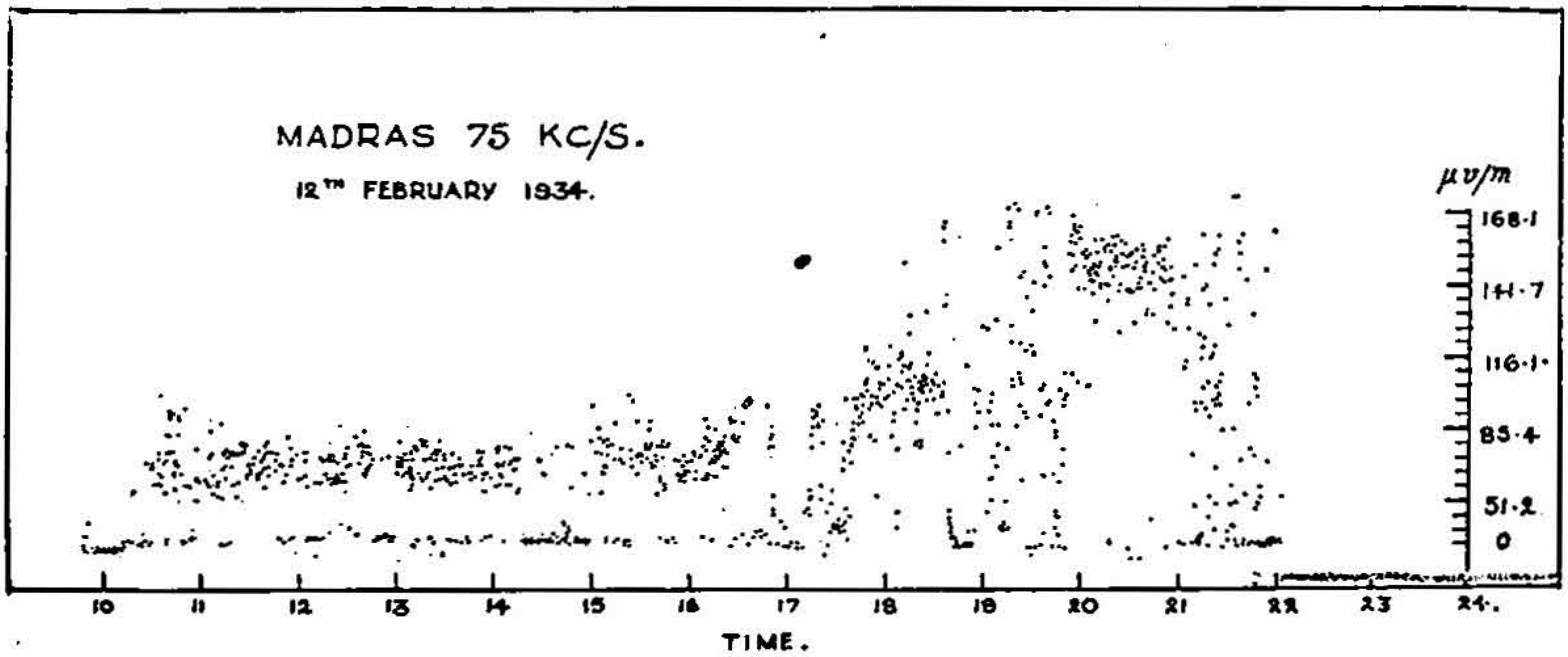

Fig. 5(b).

till 1745, there is no deflection in the recorder. This indicates that during these hours the electric vector of the down-coming wave has no component perpendicular to the plane of propagation. As the time of sunset approaches the recorder needle begins to move and the deflection rapidly increases to a maximum at about 1910. The sky wave undergoes a rotation of its plane of polarisation, giving rise to a component of the electric vector perpendicular to the plane of propagation. That this abnormal component is not constant in intensity and that it fades almost as severely as the component in the plane of propagation are shown on the two figures between the hours 1900 and 2300.

While the absence of any deflection between 1000 and 1700, with the coil in the broadside-on position shows that the electric vector of the down-coming wave is entirely in the plane of propagation, the constant deflection between the same hours with the coil in the end-on position, as shown in 5b, is evidence of the constancy of its intensity during this period. It is only towards sunset that its intensity and plane of polarisation begin to change. During the period of darkness both the normally and abnormally polarised components are strong and undergo violent and rapid changes in intensity.

In Fig. 6 are shown two curves representing the signal strengths between 1750 and 1950, obtained simultaneously on two different

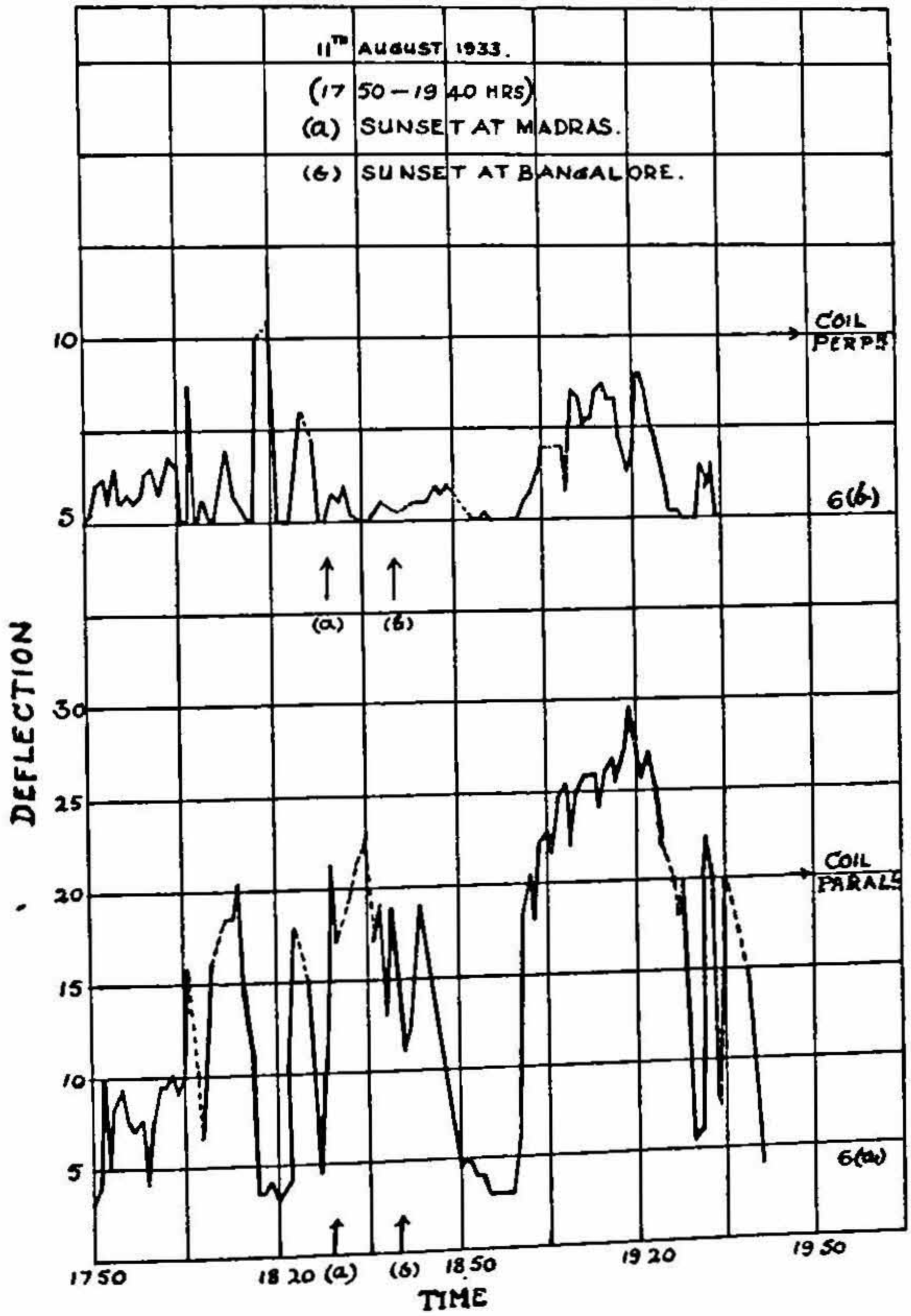

Fig. 6.

receivers with their coil aerials parallel and perpendicular, respectively, to the plane of transmission. The ordinates are not to the same scale. Between 1817 and 1827 there seems to be a change in the plane of polarisation, while from 1850 to 1930 the plane of polarisation appears to have changed but little, while the intensity has varied considerably.

Effect of the Solar Eclipse.— Fig. 7a shows the intensity

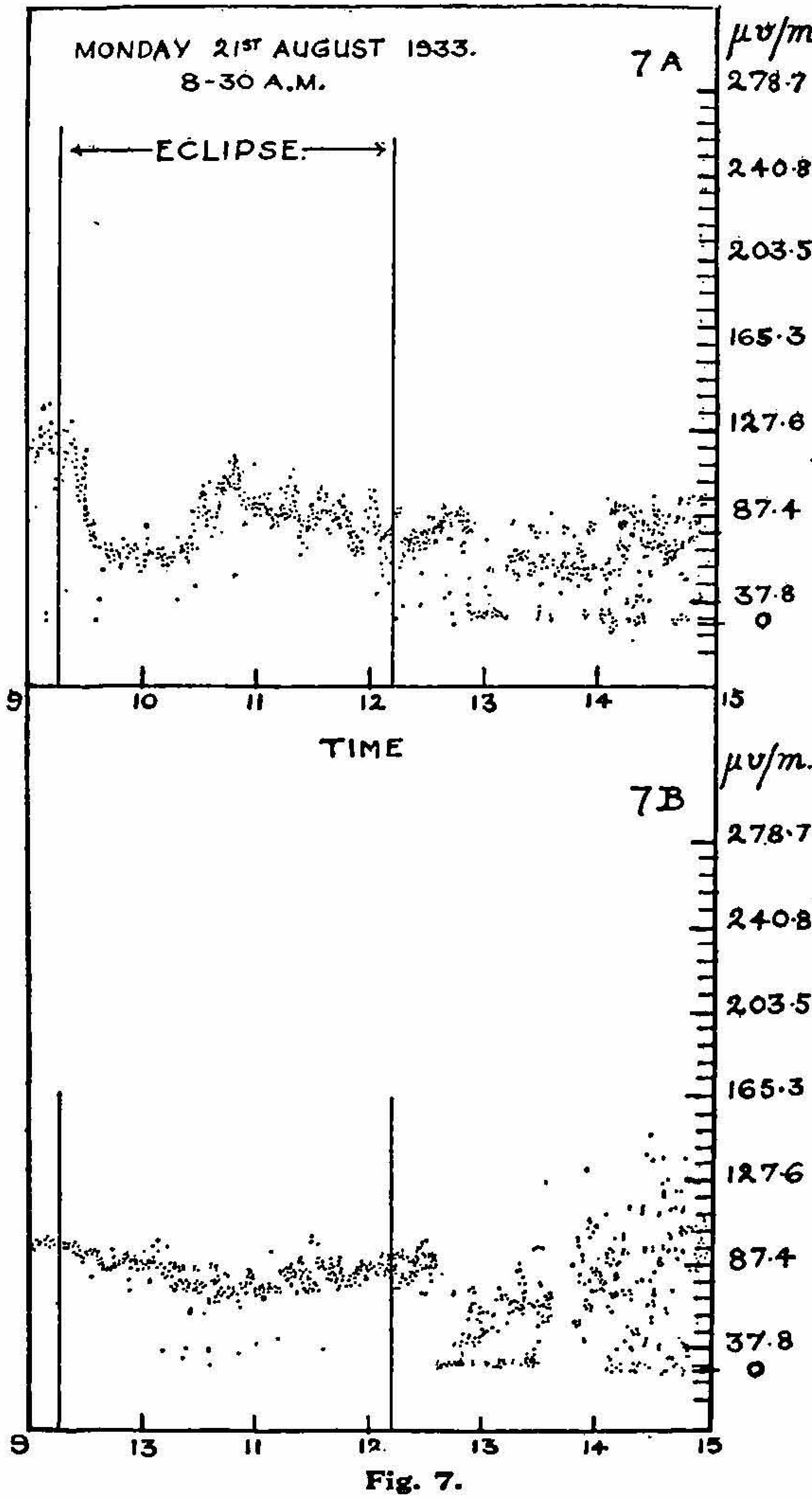

Fig. 7.

variations of Madras during the partial solar eclipse on 21st August 1933, and Fig. 7b shows a record taken on the following day for the purpose of comparison. There is a small but definite decrease of intensity during the first half of the eclipse, followed by a gradual increase during the second half.

Observations made on medium wave-lengths in England during the eclipse of 29th January 1927 (*Jour. I.E.E.*, 1928, **66**, 876) and in America on 24th January 1925 (*Proc. I.R.E.*, 1925, **13**, 539) show a rise instead of a fall in the intensity charts during the first half of the eclipse.

MEASUREMENTS ON RUGBY AND NAUEN.

Atmospheric disturbances on these wave-lengths are very severe and often cause instability in the receiving set. Sensitivity had, therefore, to be sacrificed in order to secure stable working. The intensity variations of the low frequency distant stations are much less prominent than those of the 75 kc/s transmissions from Madras. However, an interesting feature is a gradual increase and fall of the intensity between 0600 and 0700 appearing as a hump which can be seen on the chart for Rugby shown in Fig. 8.

MEASUREMENTS ON BOMBAY AND COLOMBO BROADCAST STATIONS.

The arrangement and operation of apparatus for measuring the signal intensities of the broadcast stations at Bombay and Colombo are, in principle, the same as for low frequencies. Fig. 9 gives the diagram of connections.

Aerial.—The vertical frame aerial had an area of about 1·4 sq. metres and consisted of 6 turns of 7/22 stranded copper wire wound over porcelain combs fixed at the corners of the frame.

Receiver.—The receiver had two transformer coupled screen grid stages for radio frequency amplification; the third was a triode for rectification and the fourth a pentode for amplifying the audio frequency output from the rectifier. Each stage was screened from the other by suitable partitions. Any tendency to instability was prevented by reducing the filament current or altering the bias by the potentiometer P. Small signal intensities of the order of 3 to 5 μv/m. could be recorded without risk of self-oscillation.

Calibrating equipment.—The calibrating oscillator was similar to those used for the low frequencies, but the output was taken from a small coupling coil C with a thermo-junction T.J. and a radio frequency potential divider R.

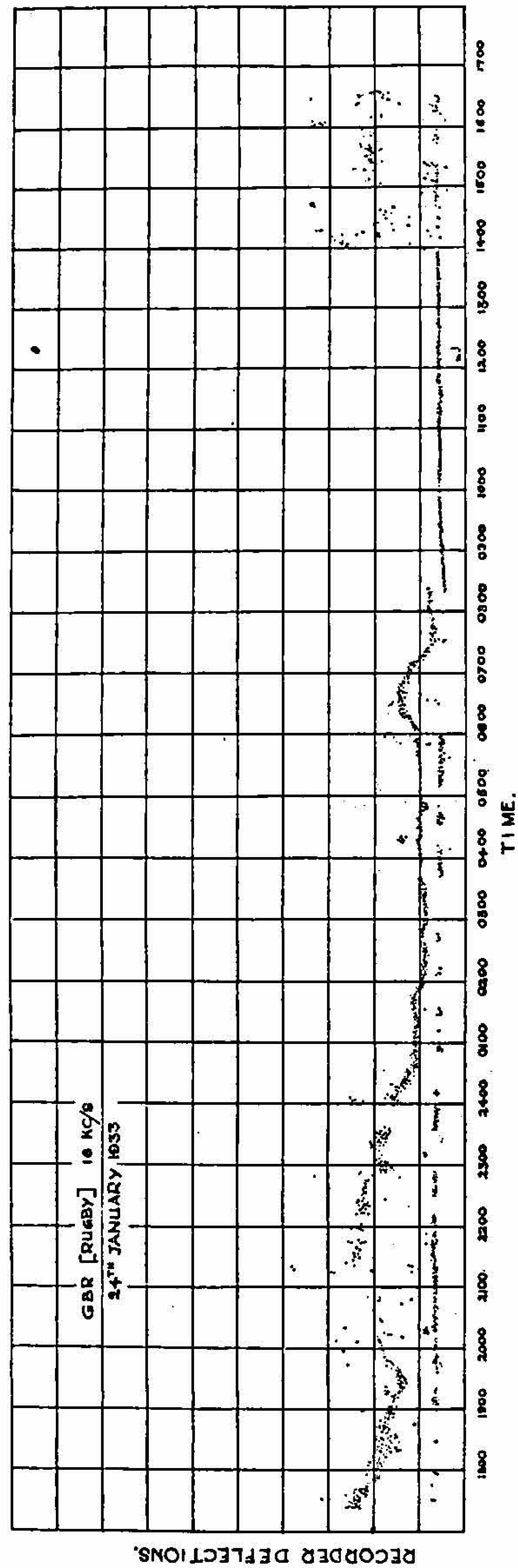
GBR [RUGBY] 16 KC/S
24TH JANUARY 1933
TIME.
RECORDER DEFLECTIONS.

Fig. 8.

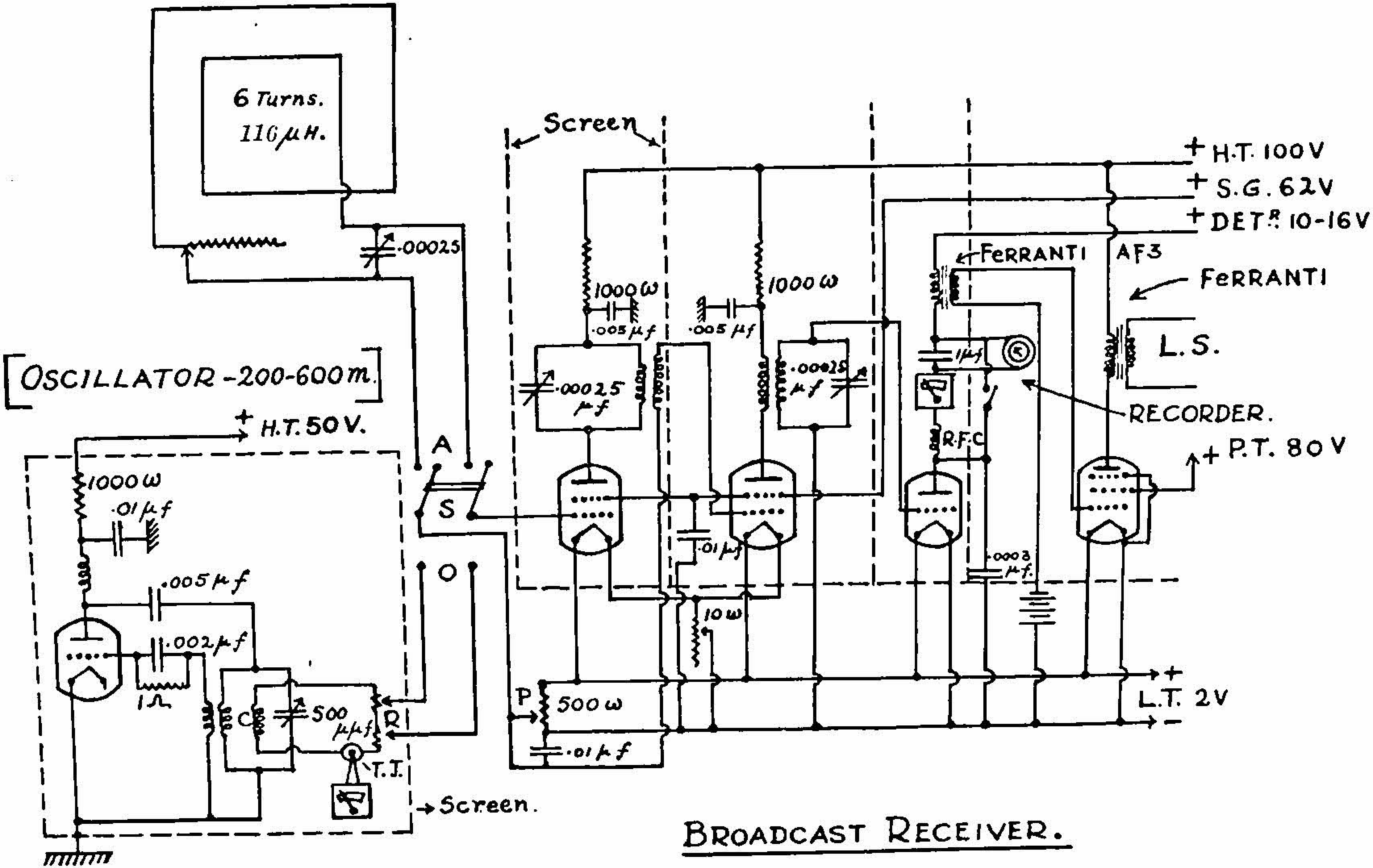

Fig. 9.

Medium Frequencies—Measuring Equipment.

Procedure.—The method of operation and measurement was exactly the same as that for low frequency observations. As both laboratory and atmospheric disturbances affected smooth working, sensitivity had to be sacrificed a little in order to secure stability. The routine programmes from the transmitting station constituted the signal and, as this was generally unsteady, measurements of effective resistance were carried out on a local signal tuned exactly to the frequency of the station.

Results of observations.—Fig. 10a gives the signal intensity variations of the Bombay broadcasting station. It shows the deep and rapid fading of the Bombay transmissions at Bangalore, a change from zero to maximum often occurring within the short period of 30 seconds. The actual deflections of the recorder indicated that the fading was often of shorter duration. When the aerial was rotated about the vertical axis and kept at various positions the minima obtained were never sharp nor steady. A three hours' record, obtained with the plane of the aerial perpendicular to the direction of transmission, is shown in Fig. 10b. This shows that the horizontal electric vector of the down-coming ray is also subject to violent fluctuations of intensity.

The mean average value of the intensity recorded between the hours 2100 and 2300 during the months of July, August and September is 87·5 $\mu v/m$ and is shown on Fig. 11. During the day the transmissions from Bombay can be heard but faintly on infrequent occasions. It has never been possible to observe the signal on the recorder.

A record of the Colombo transmissions is shown in Fig. 12. Fading is as severe as with the Bombay transmissions. During the day this station has been heard on the receiver when adjusted to a sensitive condition. The average intensity recorded during the months of January and February was 70 $\mu v/m$ between 1930 and 2030. The day intensity is too low to be recorded with any accuracy.

Interference.—Both Bombay and Colombo stations were affected by interference from foreign stations. After about 2030 when Bombay* was tuned in, a continuous whistling was heard. The whistle varied in intensity and when it increased a European station was heard faintly in the background. With a local oscillator, the frequency of the interfering station was found to be slightly lower than that of Bombay. It was heard either when Bombay was on or when the local oscillator was working. It was not possible to measure the intensity of the foreign station.

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* Bombay has recently changed from 840 kc/s to 855 kc/s and the transmissions appear still to be affected by interference.

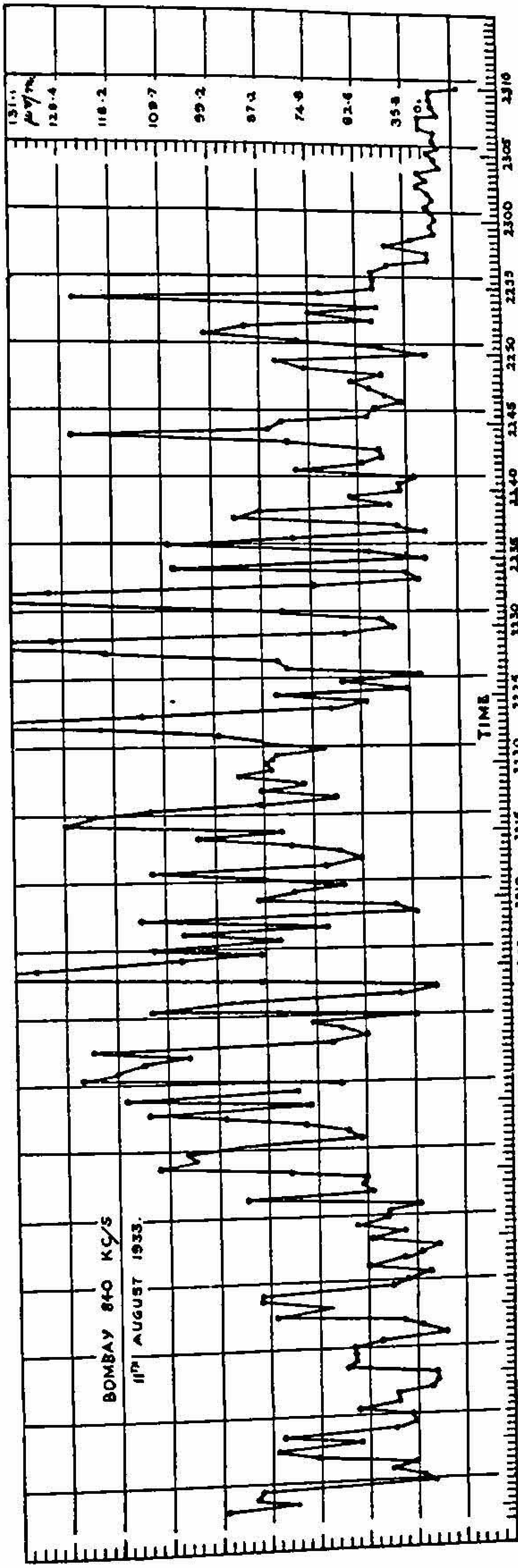

Fig. 10(a).

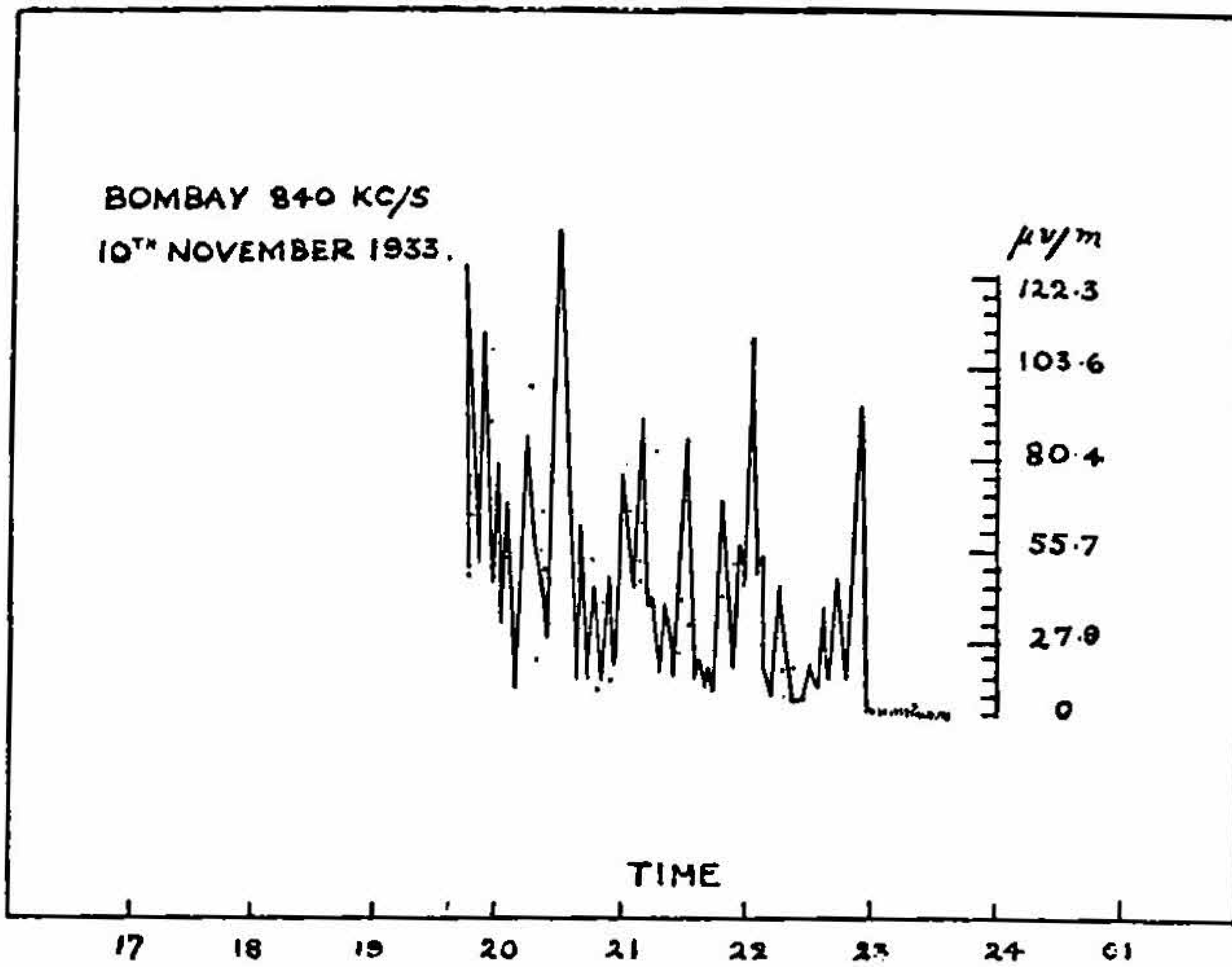

Fig. 10(b).

Coil Perpendicular to Direction of Propagation.

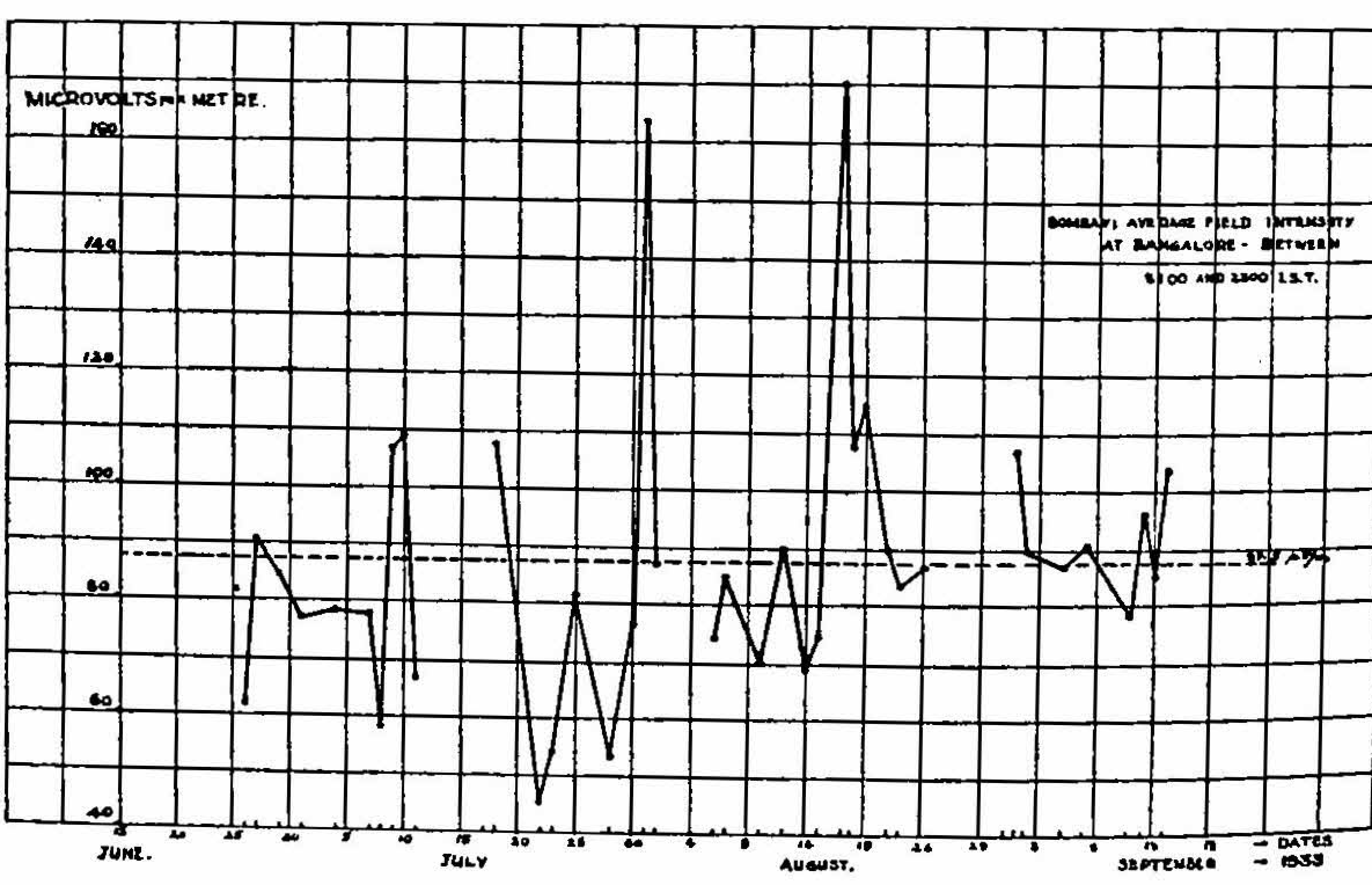

Fig. 11.

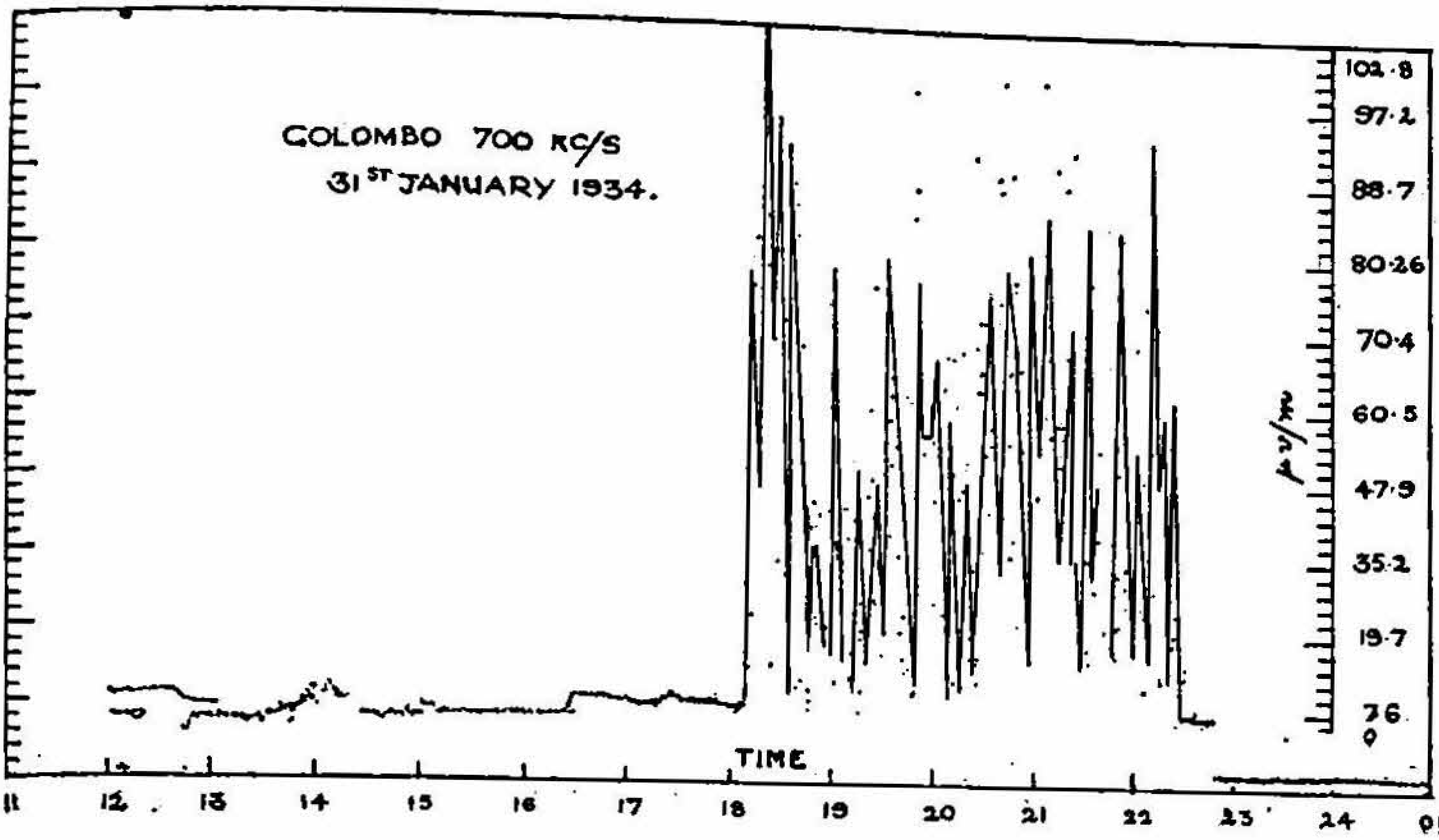

Fig. 12.

While it was sometimes possible to get Bombay free from the interfering station by increased reaction on the receiver, Colombo could not be separated out from the foreign station; but the weak interfering signal could often be suppressed by making the set less sensitive. This suggests that the station interfering with Colombo has the same or a harmonic frequency corresponding to that of Colombo.

CONCLUSION.

The above relates to part of the programme of work undertaken during the Polar Year 1932–1933. My best thanks are due to Mr. K. Sreenivasan for his valuable guidance and help at every stage of the work. Thanks are also due to the Director of Wireless with the Government of India, for kindly arranging special experimental transmissions from Madras. To Prof. F. N. Mowdawalla my thanks are due for his interest in the work and the discussion of the results.

APPENDIX I.

The following table gives the details of the stations on which observations were taken :—

Station	Call Sign	Working Wave-length	Location	Great Circle Distance from Bangalore	Bearing from Bangalore
Bangalore	..	..	12°–57′N 77°–35′E	..	..
Madras	VWO	4000 m (75 kc/s)	13°–4′N 80°–15′E	289·1 Km.	88°–48′ E of N
Bombay	VUB	357·1 m (840 kc/s)	18°–53′N 72°–48′E	825·2 Km.	37°–30½′ W of N
Colombo	..	428·5 m (700 kc/s)	6°–55′N 79°–53′E	700·2 Km.	158°–44′ E of N
Rugby	GBR	18,750 m (16 kc/s)	52°–23′N 1°–16′W	5049 Km.	39°–10′ W of N
Nauen	DFY	18,130 m (16·545 kc/s)	52°–37′N 12°–49′E	4458 Km.	37°–29′ W of N

APPENDIX II.

The details of the frame aerials are given below :—

No. of Coil	Wave-length range in metres	Shape	Area in sq. m.	No. of Turns	Spacing in cm.	Inductance in μH.
1	250–500	Rectangular	1·4	6	1·35	116·6
2	3,000–5,000	Square	3·21	20	1·30	1500
3	15,000–20,000	Square	3·21	50	0·62	7620

APPENDIX III.

The inductance of the coil aerial was calculated from the graph showing the relation between λ^2 and added tuning capacitance for different values of λ. The curves, plotted for the three coils, are shown in Fig. 13. The inductance is given by the formula $L=\frac{\lambda_2^2-\lambda_1^2}{3\cdot 55\,(C_2-C_1)}$ in micro-henries, where λ_2 and λ_1 are any two wave-lengths in metres and C_2 and C_1 the corresponding values of the tuning condenser in micromicrofarads.

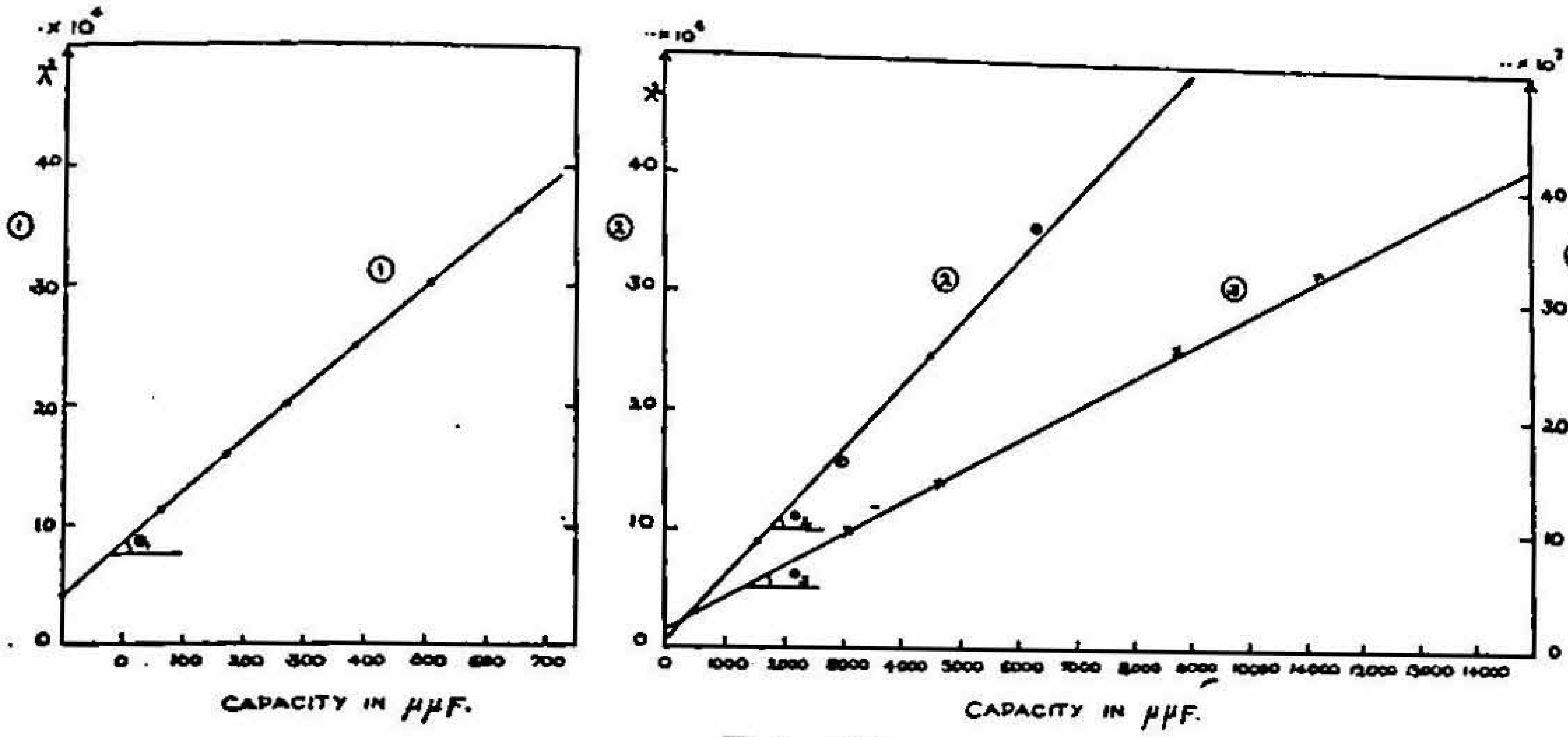

Fig. 13.

$$\text{Tan}\ \theta = \frac{\lambda_2^2-\lambda_1^2}{C_2-C_1} = 3\cdot 55\ L_{\mu H.}$$

$$\text{Tan}\ \theta_1 = \frac{26\cdot 5\times 10^4}{640} = 3\cdot 55\ L_{\mu H.} \quad (1)$$

$$\therefore\ L = 116\cdot 6_{\mu H.}$$

$$\text{Tan}\ \theta_2 = \frac{34\cdot 1\times 10^6}{6400} = 3\cdot 55\ L_{\mu H.} \quad (2)$$

$$\therefore\ L = 1501_{\mu H.}$$

$$\text{Tan}\ \theta_3 = \frac{33\times 10^7}{12200} = 3\cdot 55\ L_{\mu H.} \quad (3)$$

$$\therefore\ L = 7620_{\mu H.}$$

APPENDIX IV.

The method of calculating the field intensity is as follows:—The voltage developed in a coil aerial of area a, and number of turns n, by field intensity F is $\frac{2\pi a n \omega L}{\lambda R}F$, where ω is the angular frequency, λ the wave-length, L the inductance of the coil, and R the effective resistance of the aerial. In the calibrating arrangement let i_1, i_2 be the currents and n_1, n_2 the number of turns in the transformer primary and secondary, respectively. Also let r_1 be the resistance of AB and r_2 the resistance of CD (Fig. 14). C.T. being the current transformer previously mentioned (Dye, *Jour. I.E.E.*, 1925, **63**, 597), we have,

$$i_2 = i_1\frac{n_1}{n_2}.$$

$$\text{Voltage across AB} = i_2 r_1 = \left(i_1\frac{n_1}{n_2}\right) r_1.$$

$$\text{Voltage across CD} = \left(i_1\frac{n_1}{n_2}\right) r_1 \frac{r_2}{r_1} = i_1\frac{n_1}{n_2} r_2.$$

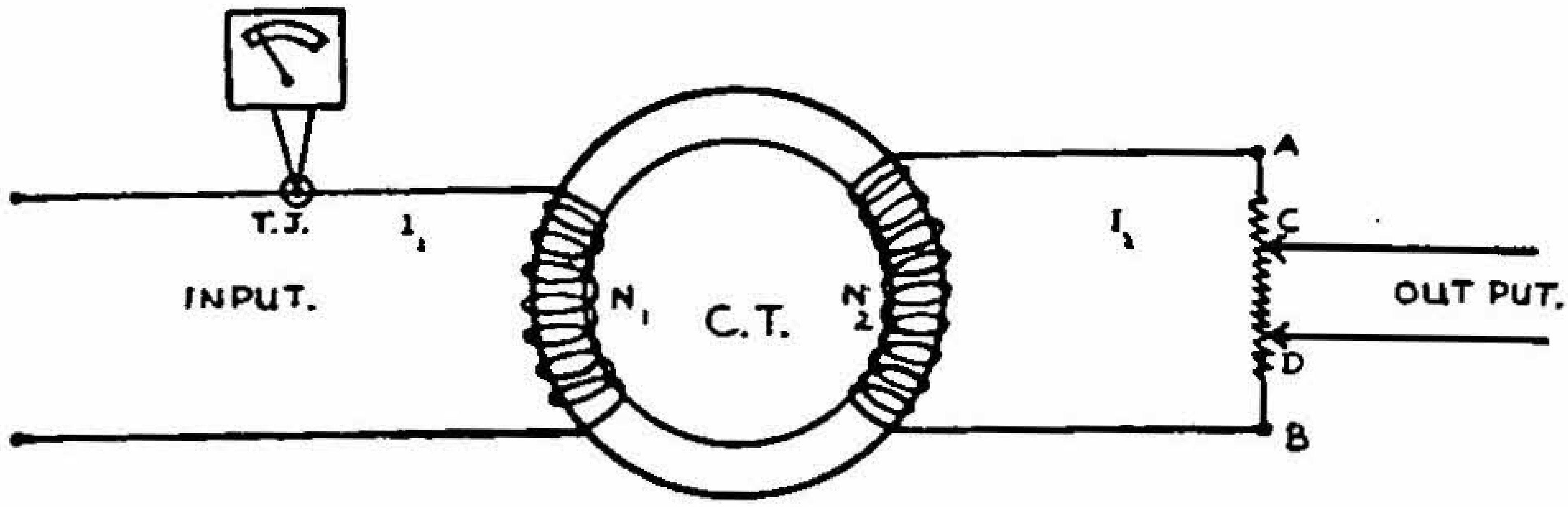

Fig. 14.

The method of measuring the field intensity F consists in adjusting r_2 to produce the same deflection as that due to F. Hence

$$V = \frac{2\pi a n \omega L}{\lambda R} F = i_1 \frac{n_1}{n_2} r_2 \quad .. \quad .. \quad .. \quad (1)$$

$$F = \frac{\lambda}{2\pi a n \omega L} \times \frac{n_1}{n_2} \times R\, i_1\, r_2 \quad .. \quad .. \quad .. \quad (2)$$

Here F is in volts/cm. when L is in henries, λ in cm., R in ohms, and i in amperes. Expressing F in microvolts/metre the above equation is written as

$$F_{\mu v/m} = \frac{n_1}{n_2} \cdot \underset{\text{ohms}}{r_2} \cdot \underset{\text{ohms}}{R} \cdot \underset{\text{m.a.}}{i} \left[\frac{\lambda_m \times 10^3}{4\pi^2 a_{sq.m.} n f L_{\mu H.}} \right] \quad .. \quad .. \quad (3)$$

Substituting the corresponding values for λ, a, n, F and L, the above expression for $F_{\mu v/m}$ can be written as follows:—

For observations on

Madras Fort Radio, $F_{\mu v/m} = \frac{n_1}{n_2} r_2 R\, i_1 \times 14{\cdot}05$

Rugby ,, $\frac{n_1}{n_2} r_2 R\, i_1 \times 24{\cdot}3$

Nauen ,, $\frac{n_1}{n_2} r_2 R\, i_1 \times 22{\cdot}72$

Bombay ,, $r_2 R\, i_1 \times 11{\cdot}05$

Colombo ,, $r_2 R\, i_1 \times 15{\cdot}92$

r_2 and R are expressed in ohms and i_1 in milliamperes. (*Note:* the calibrating oscillator for Bombay or Colombo does not have a current transformer as can be seen from Fig. 9.)

APPENDIX V.

Measurement of Effective Resistance.

R of the equations in Appendix IV is the effective resistance of the aerial and the amplifier. Equation (1), $\left(i_1 \frac{n_1}{n_2} r_2 = \frac{2\pi a n \omega L}{\lambda R} F\right)$, may be written as $K_1\, r_2 = K_2/R$ where K_1 and K_2 are constants depending on the working values of the corresponding terms during experiment. The resistance variation method adopted in the present observations consists in the introduction, while the signal is on, of different additional resistances in the aerial circuit by means of a switch included in the circuit. The deflections in the recorder being noted, the value of R can be calculated from the observations. If R_n and R_m be any two known values of the resistance added to R and the corresponding values of r_2 to produce the same respective deflections be r_n and r_m, we have

$$\frac{K_2}{K_1} = r_2 R = (R + R_n) r_n = (R + R_m) r_m = \text{Constant.}$$

Simplifying, $R = \dfrac{R_m r_m - R_n r_n}{r_n - r_m}$.

The observations were made with a steady signal, obtained from the local oscillator tuned correctly to the station. The deflections on a galvanometer, included in the rectifier circuit, were noted as different resistances were introduced. The double throw switch was next thrown over to the local oscillator and the deflections in the galvanometer were again noted as the resistance r_2 of the potential divider was varied.

A graph, connecting r_2 and galvanometer deflections, was plotted; the resistances $r_n, \ldots, r_m$ were read corresponding to the deflections obtained as $R_n, \ldots, R_m$ were introduced in the aerial circuit. Four known resistances were added to R and hence five values for r_2 were read from the graph corresponding to R, $(R + R_n), \ldots, (R + R_m)$. Taking each pair, ten values were obtained for R and the average of these was taken as the effective resistance.

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