THESIS

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I

AN INVESTIGATION OP MICROPULSATIONS IN THE EQUATORIAL REGION

ABSTRACT

As an introduction to the thesis, an account is given of the previous observational studies of geomagnetic micropulsations at all latitudes but special attention is given to low latitude studies. Results obtained from both magnetic and earth current records are given in the survey. Reference is made to existing theories concerning the production of micropulsational phenomena,

An account is given of the experimental methods for the study of micropulsations and the theory of the action of the high permeability core magnetometer, the type used in Zaria, is given in some detail. This is followed by the experimental particulars and the results of the analysis on pc 3, pc 4 and pi 2 band micropulsations obtained on the rapid-run magnetograms at Zaria for the months of July and August 1967. The. main results includes-

(1) The dominant periodic times of pc 3 and pc 4 are (38 -+ 3) sec, and (60 -+ 5) sec, and that of pi 2 is (60 -+ 5) sec.

(2) Pc 3 occurs at all local times with two peaks in occurrence; one in the morning and the other in the evening, the morning peak at about 06 hrs, (L,T) being more pronounced. Its peak amplitude is near

local noon.

(3) Pc 4 is essentially a daytime phenomenon with peak occurrence and amplitude near local noon,

(4) Pi 2 is essentially a night time phenomenon with •peak occurrence between 22 and 23 hrs (LIT.)

(5) Micropulsation activity is enhanced during magnetically disturbed periods and the amplitude is larger in the H than in the D component.

(6) Pc 3, pc 4 and pi 2 micropulsations are linearly polarized along the magnetic meridian.

The observed periods are compared with resonant periods predicted by some resonance theories for low latitudes. Also, the results obtained on pc 3, pc 4 and pi 2 band micropulsations are compared with those previously obtained at low latitudes.

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GLOSSARY OF TERMS.

Auroral regions: The parts of the earth between geomagnetic latitudes 70° and the poles which have maximum auroral activity.

Conjugate points: The points on the earth's surface which mark the ends of a magnetic field line.

The Dip (or inclination): The angle which the lines of force make with the plane of horrizon.

Dip Equator (or Magnetic equator): At the dip equator, the dip is zero.

Equatorial Station: Stations which are within $\pm 4^{\circ}$ or 5° of the dip equator.

Fan-shaped Structure: A form of pc1 micropulsations which consists of varying rate of change of frequency with respect to time during the course of an event as seen on a sonagram.

Low Latitude Station: Stations within $\pm 30^{\circ}$ of the dip equator.

Sonagrams: Frequency - time display records.

1.0 A REVIEW OF OBSERVATIONAL STUDIES OF GEOMAGNETIC MICROPULSATIONS WITH SPECIAL REFERENCE TO LOW LATITUDE FEATURES.

1.1 Introductory remarks.

In this thesis, micropulsations will be defined, following common practice, as those natrural fluctuations of the earth's magnetic field whose amplitudes range from a fraction of a gamma (1 gamma = 10^{-5} oersted) to as much as a few tens of a gamma and have periods in the range 0.3 to several hundred sec. On the short period side, micropulsations are bounded by the Extra Low Frequency region of the spectrum. The boundary at longer period side lacks a convenient definition. In the thesis, no special attention will be given to bays, sudden impulses or other morphological features commonly studied from normal rapid run magnetograms. Moreover, while experimental work presented in this thesis deals with micropulsations in the period range 10 to 150 sec. only, in this review, the properties of other micropulsations in the period range 0.3 to 10 sec. and 150 to 600 sec. will be given. Micropulsations of the magnetic field will be discussed but reference will also be made to results obtained from the induced earth current measurements.

Micropulsation phenomena are investigated in order to understand processes transpiring in the local ionosphere and the distant magnetosphere. Even though some of the signals

in the equatorial region might have unique characteristics which could resolve source and propagation mechanism, the progress of equatorial studies on micropulsations has been relatively slow compared to those for middle and high latitudes, largely due to the lack of wide-spread equatorial geophysical observation necessary for this type of study. There has been, however, an increase in the study of micropulsation phenomena in the equatorial region in the past few years and this is likely to receive much more attention in the future. Since the dissertation which follows is on results obtained from an equatorial station, it will be worthwhile first to review the main experimental results obtained so far in this region and to examine the relationship between the equatorial and non-equatorial phenomena.

1.2 Classification of geomagnetic micropulsation

Many attempts have been made by various authors to classify micropulsations with the subsequent result that the literature on micropulsations has been plagued with a multiplicity of nomenclature (Matsushita, 1963). This makes it difficult to compare one paper with another. In 1957 the International Association of Geomagnetism and Aeronomy (IAGA) adopted names to be applied to different types of activity, but even these names are used with great flexibility and some of them are hardly used at all. Names which have been used frequently in early literature include Pc (or Pc - 1) for regular pulsations with

periods 10 - 60 sec; Pc° (or Pc - II) for continuous pulsations with period 60 - 150 sec; Lpc (or Pc - III) for continuous pulsations with period from 2 to 7 minutes. The term Pg (giant pulsations) has also been used for Lpc while the terms SIP and Pt have been used for short irregular pulsations with period about 6 sec and for pulsation trains (Pt) which consist of a series of damped oscillations usually lasting less than one hour with period from 40 sec to a few minutes. The short period pulsations with period 0.3 to 5 sec have been termed pearls (suchsdorff, 1936, Troitskaya, 1961); PP (Troitskaya, 1961); type A (Benioff, 1960); and hm-emission (Tepley, 1961). The International Association of Geomagnetism and Aeronomy (IAGA) at their Berkeley meeting in 1963 agreed on a system of classification which divided micropulsations into regular and irregular categories, and subdivided these by period. This classification is now being employed generally and is the one that will be used in this thesis. The classification is as follows:-

Regular:	Pc 1	0.2 to 5	sec period
	Pc 2	5 to 10	" "
	Pc 3	10 to 45	" "
	Pc 4	45 to 150	" "
	Pc 5	150 to 600	" "

Irregular: Pi 1 1 to 40 sec period

Pi 2 40 to 150 sec period

These boundaries are rather arbitrary and Kato and Saito (1964) have challenged the boundary between pc 2 and pc 3. However, they afford a more convenient classification system for micropulsation than that used before.

1.3 Properties of Pc I micropulsations

In recent years, this has been the most widely studied type of micropulsations (Tepley, 1964; Campbell and Stiltner, 1965; Dawson, 1965; Hirasawa, 1965). They are generally found in the period range of 0.2 to 5 sec with typical amplitudes rising to 10 and 100 milligamma. The distinguishing feature of Pc I is a fine-structure consisting of rising tones repeating at regular intervals as seen on sonagrams. Most often the tones are rising, but sometimes they are vertical and occasionaly falling tones are observed. The amplitude traces have a beat-like appearance which results, in part, from the overlapping rising frequency structure.

There isageneral linear relationship between the recurrence period of emission T(sec) and the average period T(mid) so that T(sec) = 86 T(mid), (Campbell and Stiltner, 1965). These authors also report that the duration of the emission seems independent of of the location. Pc I's are essentially a night - time phenomenon

at middle and low latitudes, but occur during the day at high latitudes. Wentworth (1964) suggested that this may be due to differences in ionospheric attenuation. He argued that though the maximum production of Pc I is probably in the afternoon, higher ion densities at that time greatly attenuate the waves responsible for the generation of the pulsations. At the auroral latitudes, however, ionospheric attenuation will be much less and the waves can get through at the time of their maximum production. But many researchers have failed to relate experimentally Pc I's and ionopheric activity. Most of the work reported has been done at the high latitudes. Wentworth, however, has predicted strong ionospheric attenuation at low latitudes so that it will be worthwhile to investigate the question of correlation of Pc I and the various ionospheric parameters in the low latitude region. The local time variation of the mid-frequency appears to be similar at middle and higher latitudes, with higher frequencies predominating during the early afternoon.

When simultaneous sonagrams for conjugate points are compared, it is found that between hemispheres, the fine-structure is displaced by half the repetition rate (Tepley, 1964; Campbell and Stiltner, 1965). On the other hand, simultaneous sonagrams from two stations in the same hemisphere do not show

such 180° phase shift in the fine-structure. Tepley also reports that at the equatorial station of Canton Island sometimes the records show a doubling of the fine-structure indicating that at Canton Island occasionally one can receive signals generated in both hemispheres. Separate studies by Tepley (1964) and Campbell and Stiltner (1965) have indicated that pc I events are wide spread in the low latitude regions but are fairly localized in the high and middle latitudes. Roquet (1966) has also indicated that when simultaneous records from Addis Ababa, a low latitude station and Garchy, a middle latitude station, were examined, none of the few occurrences of pc I at Addis Ababa coincided with the occurrence of pc I at Garchy.

Polarization studies of pc I show that the magnetic perturbation vector is confined to a plane perpendicular to the earth magnetic field line. Both left and right-handed elliptical as well as linear polarizations have been observed and in many cases, the sense is found to reverse itself in the middle of a beat. It has also been reported that polarization of pc I events is randomly orientated in the northern mid-latitudes (Dawson, 1965; Lacourly and Goukhberg, 1966). To the best of the author's knowledge, no polarization studies have yet been reported for the equatorial regions for pc I micropulsations.

Benioff (1960) and Heacock and Hessler (1962) have found pc I

occurrence to favour magnetically quiet days and Smith (1964) found the activity to be enhanced on quiet days about five to seven days following Kp indexes of solar terrestrial disturbances. Also Wentworth (1964) and McPherson (1965) have indicated that pc I occurrence is greater at, and immediately after, storm sudden commencements. These facts imply that magnetic disturbances promote the production of pc I events, whereas the appearance at ground level requires that the ionospheric electron density be low. The correlation between pc I activity and other geomagnetic phenomena has not, however, been reported for the low latitude stations.

Wentworth and Tepley (1962a), and Heacock and Hessler (1962) have suggested that pc I are produced by bunches of electrons oscillating along the field lines with a period equal to that of pc I and drifting around the earth with the spacing period. The observation by Smith (1964) of a west-ward drift of pc I occurrence seems to confirm this theory but the theory fails to explain the 180^{o} phase shift between conjugate stations. There have been other hypothesis as to the originating source of these pulsations. The resonance type features of the event and the high latitude conjugate station coincidence encourage the presently popular hydromagnetic models of the phenomenon with propagation along the high L field lines. It is assumed that

the energy comes from the solar wind and that the necessary conditions for the resonant propagation must be established several days after the on-set of the solar-terrestrial disturbance. Ionospheric absorption of the energy in these frequencies is predicted by most models but has escaped measurement.

Equatorial studies of these events are very scarce and workers engaged in the equatorial studies of micropulsations find it difficult to detect pc I. The most rudimentary features of pc I such as diurnal variations in frequency of occurrence, amplitudes and periods are unreported. Campbell (1966) has suggested that a major contribution to the understanding of the phenomenon can be made by determining the method of arrival of the fluctuations into the equatorial regions, whether guided by the earth's field lines (Sugiura, 1965; Dawson, 1965) or from the high latitudes within a hydromagnetic duct above the ionosphere (Tepley and Landshoff, 1966; Manchester, 1966).

1.4 Pc 2 and Pc 3 Micropulsations

These pulsations are observed in all latitudes with amplitudes and activity increasing with latitude (Jacobs and Sinno, 1960). They are found to have typical amplitudes rising above 0.3 gamma in size, and have periods within the range 5 to 45 sec. Their period is found to have little or no dependence on latitude (Ellis, 1960; Saito, 1962). There is a diurnal variation of the

period at middle and high latitudes and the period often rises to about 25 to 35 sec in the daytime hours and falls to about 5 to 15 sec at night. The variation changes gradually over many days (Saito, 1962; Campbell, 1959). Saito (1962) indicated that a similar distribution of period should be expected at equatorial stations. Fernando (1966) observed at Colombo, a station near the geomagnetic equator, pc 3 with dominant period of 38 sec. whose amplitude is enhanced during the local daytime and particularly during magnetically disturbed periods. Hirasawa (1965) showed similar distribution in pc 2 and pc 3 pulsations at low latitudes with pc 2 having a double maximum in occcurrence frequencies, one during the morning hours and the other during the evening hours, but with pc 3 having a maximum in amplitude near local noon.

The diurnal variation in the frequency of occurrence of the pulsations has been studied by many workers. Hutton (1960) using earth current records in Ghana found that during the IGY there were three maxima in the occurrence frequency of the pc 3 pulsations, the evening one being the most pronounced. Romana (1962) summarised the IGY results obtained at four equatorial stations — Ghana, Paramaribo, Bangui and Hollandia. At Paramaribo and Bangui, there are two maxima in the daily variation of pc 3 frequency of occurrence, and at Legon, Ghana, and Hollandia the evening maximum predominates. The time at which maxima

occur at the four stations differ slightly from one station to another. Romana also gave results for diurnal variation in activity of the pc 2 and pc 3 pulsations for four sub-equatorial regions and these showed differing times of peak activity. The morning maxima at Tamanrasset and Port Moresby were more pronounced than the evening ones while the evening maxima at M'Bour and Apia were more pronounced than the morning ones. There are thus differing results for the diurnal variations of activity of the pulsations at low latitudes stations.

Roquet (1967) using magnetic records taken simultaneously at two equatorial stations: Parakou (100 Km south of the dip equator) and Louma (430 Km north of the dip equator) found that there was amplification of pc 3 and pc 4 amplitudes by a factor of about 3 at Parakou compared with the amplitude of the pulsation at Louma. This tends to confirm the enhancement of long period pulsations in the equatorial electrojet region as originally reported by Jacobs and Sinno (1960) in their morphological study of micropulsations. Further work is now needed to confirm this property of pc 3 and pc 4 micropulsations in the equatorial region.

The occurrence frequency of pc 2 and pc 3 is minimum in summer and winter months with peak occurrence in the equinoxes

(Glover 1963; Saito, 1964). Hutton (1962) also found that the daily variation of occurrence of pc3 varied from season to season at Legon (Ghana), during the IGY, and that the evening maximum of pc3 occurrence was greatest in the December solstice.

Kato et al (1956) and Campbell (1959, 1962) found a 27 - day recurrence tendency for pc2 and pc3 in the high and middle latitudes. Saito (1964c) found a correlation of pc2 and pc3 with the strength of solar wind. Pc2 and pc3 occurrence is also related to the local Kp index (Campbell 1959, 1962); to changes in the F - layer (Campbell, 1959; Saito, 1962) and to auroral pulsations. Very few attempts have been made to study the correlation between pc2 and pc3 activity with the other geomagnetic and ionospheric phenomena at low latitudes. Hutton (1962), however, found a significant correlation between the magnitude of the disturbance daily variation S_D of earth currents at Legon (Ghana) and the onset of micropulsations at that station. She also indicated that pc2 were observed predominantly during night hours and during periods of above average magnetic activity. The excellent correlation of daily amplitude values with magnetic disturbance places pc2 and pc3 phenomena in the solar terrestrial disturbance family. Saito (1964) showed that the activity level of pc3 has correlation coefficient of 0.8 with satellite determinations of the solar wind velocity. It is generally assumed that the

pulsations have hydromagnetic origin within the magnetosphere. Further investigations are necessary at low latitudes to relate the diurnal and latitudinal dependence of pc3 amplitude to ionospheric conditions, as has already been done at high and mid-latitudes. Also the possibility of an ionospheric current mechanism for the transport of high latitude pc3 phenomena to the equatorial region should be examined.

1.5 Pc4 and Pc5 Micropulsations.

These two distinct forms of micropulsations with typical periods 45 - 150 sec. (pc4) and 150 - 600 sec. (pc5) have been identified at various world stations (Kato, 1961; Matura, 1961; Saito, 1962; Hutton, 1965; Jacobs and Sinno 1960, Hirasawa 1965, Roquet 1966, etc.)

Pc4 micropulsations have been reported as day - time pulsations with occurrence maximum near noon at all latitudes and with amplitudes often rising above 10 gamma. Osborne and Rivers (1963) detected pc4 on normal magnetograms at Tamale (Ghana) and Freetown (Sierra Leone), both of which are equatorial stations. The pulsations had a period of about 2 minutes and amplitude of approximately one gamma; their duration was from several minutes to several hours. Glover also detected pc4 in the Phillipines and Hutton, using earth currents, in Ghana. Glover summerised his results on a contour plot which illustrates the

seasonal changes in the daily variation of activity. The season during which at his station a single maximum occurs appears to differ from that at Tamale and Freetown. Hutton (1965) indicated that there was an increase in occurrence frequency of pc4 as sunspot minimum was approached and that there was a midday maximum of occurrence frequency of the pulsations. These results agree well with those obtained by Glover and Rivers. Hutton also reported that on a few occasions at Legon (Ghana), radiostar scintillations of the same frequency accompanied pc4, but confirmation of the relationship between these phenomena is, however, needed.

Other research workers who have recently contributed to our knowledge of pc4 and 5 pulsations at the low latitudes are Fernando (1966), and Roquet (1966 and 1967). Fernando (1966) working at Colombo near the geomagnetic equator indicated that the total activity of pc3 and pc4 reaches a maximum just before noon; and that there is a good positive correlation between daily variation of pc3 and pc4 micropulsation activity with Kp index; and the observed activity in pc3 and pc4 band micropulsations is mainly confined to periods lying between 30 and 70 sec. with peak activities at 38 + 5 sec. and 60 + 3 sec. There is an indication of a small peak around 120 sec. Hirasawa working at Kakioka, a low latitude station reported, amongst other things, the appearance of pc4 and pc2 at any local time, exact coincidence of the funda-

mental component of pi2 to the spectral trend of pc4 and a slight dependence of pc4 period on local time and storminess of the day. Hirasawa also indicated that pc2, pc3 and pc4 micropulsation activity increased immediately after a storm commencement (Sc) and that high activity persisted during the initial, the main phases and the early stage of the recovery of the magnetic storm. Roquet (1967) compared results obtained simultaneously from two equatorial stations, Parakou in Dahomey and Louma in Niger Republic. She indicated that the amplitude of pc4 at Parakou (100 Km south of dip equator) was relatively larger than that obtained at Louma (430 Km north of the dip equator). This indicates the enhancement of pc4 amplitude in the equatorial electrojet region. Roquet also reported a maximum near local noon in the activity of pc4 micropulsations; that the amplitude of both pc3 and pc4 micropulsations is greatest in the morning or early afternoon hours and that the amplitude of the pulsations is larger on the H component than on the D component of the magnetic field.

There is a latitudinal variation in the amplitude of both pc4 and pc5 as indicated by Jacobs and Sinno (1960) with the amplitude of the pulsations increasing with latitude and with a possible enhancement in the equatorial electrojet region. There is also a latitudinal variation in the plane of polarization of the pulsations with the oscillations perpendicular to the geomagnetic field

lines at high latitudes but parallel to the field line at equatorial locations (Saito, 1964). However, the results need further confirmation since very few reports have been received of measurements of pc4 & 5 in the equatorial region.

Matura (1961) analysed samples of simultaneous pc5 pulsations at various world locations. He showed that the amplitude of the pulsations decreases with decreasing latitude but again with enhancement of the amplitude in the equatorial regions. He also indicated that the pulsations on the Z component have comparable amplitudes both at the auroral zone and at the magnetic equator. It would, however, be interesting to investigate the latitudinal variation of pc5 amplitude across the equatorial electrojet as has been attempted by Roquet for pc4. It is probable that a similar latitudinal effect would be obtained. A closely spaced chain of stations across the dip equator will be necessary, however, if a reliable estimate of the correlation of the amplitude of both pc4 & 5 pulsations and the properties of the equatorial electrojet is to be obtained.

There is a peak to peak correlation at conjugate points in pc4 and pc5 activity at high and middle latitudes (Saito, 1964; Nagata, 1963). Heirtzler (1966) comparing results obtained from two equatorial conjugate stations of Amapa and Barbecena in eastern

Brazil showed that pc4 and pc5 micropulsation activity at both stations was correlated in great detail but with a phase lag of about 60°, i.e. a time lead of about 13 sec. for Amapa (about 280 Km north of dip equator) with respect to Babercena (about 280 Km south of dip equator). Reports of conjugate points studies of pulsations in this period range are, however, scarce.

A consistent longitudinal variation in pc micropulsations has not been established in the low latitudes. Hutton (1965), however, reported that on more than 50 percent of the occasions when large pc3 occurred at Legon (Ghana), at least 5 other stations widely spaced in longitude and latitude showed simultaneous pc3.

In non-equatorial regions, pc4 and pc5 micropulsations have been shown to correlate with measurable ionospheric parameters such as f_0F_2, $f_{min.}$ or riometer absorption. Micropulsation activity increases with decreasing solar activity (Saito, 1964). A negative correlation with Kp index has been demonstrated by Maple, 1969, and Hirasawa (1965) has shown a correlation between pc5 period and positive and negative sudden impulses. An association of pc4 and pc5 micropulsations with X-ray bursts and auroral radar echoes has also been reported at high latitudes. Such correlation studies between pc4 and pc5 micropulsations and ionospheric and other geophysical phenomena have not been carried out on a large scale at low latitudes.

However, Hutton (1965) noted a dependence of the frequency of occurrence of pc 4 on solar activity in Ghana and Fernando (1966) and Hirasawa (1965) gave indications of a correlation between pc 4 and Kp index. Hutton (1965) also indicated that maximum occurrence of pc 4 is in December solstice.

Some pc 4 and pc 5 micropulsation phenomena have been explained on the theory that they are caused by hydromagnetic tosional standing oscillations of the geomagnetic field lines (Kato and Watanabe, 1956; Obayashi and Jacobs, 1958). In 1966 Campbell argued that if all surface measurements are measures of arriving hydromagnetic waves, then the nature of an equatorial enhancement of amplitude needs clarification.

Pulsations with irregular forms - pi I and pi 2

These are the irregular pulsations usually found in the period ranges 1 to 40 sec (pc 1) and 40 to 150 sec (pi 2). Their amplitudes range from a few hundred gammas to the lower limit of the recording system.

At high latitudes pi 1 are usually found as the micro-structure of bays, pi 2 etc and occur during the main phases of geomagnetic storms. They have maximum amplitude and activity in the auroral zones (Campbell and Matsushita, 1962) and are found to have a 27-day recurrence tendency. They are observed mainly in the morning and evening hours (Heacock and Hessler, 1962). No seasonal variation in occurrence frequency

was found by Heacock and Hessler but, a tendency towards equinoctial maxima in occurrence frequency has been reported by Campbell and Matsushita (1962). Both pi 1 and pi 2 are found to have a clear association with ionospheric phenomena. Great similarities and also some differences have been found in events measured at conjugately located stations (Campbell, 1965).

Pi 2 consists of series of damped oscillations usually lasting less than one hour. Early observers have termed them as "pulsational sudden commencements" (P.S.C.) to indicate their burst beginnings. Others referred to them as pt or "pulsation trains" or "pulsation temporares" to indicate short duration. They are observed in all latitudes more or less simultaneously and always accompany bays (Duncan, 1960; Kato and Ossako, 1952). They are essentially a night-time phenomena. Troitskaya (1953) reported a G.M.T. dependency with the occurrence maxima occuring between 18 and 19 hours G.M.T. Other observers have shown that both pi 1 and pi 2 occur most frequently about 22 - 23 hours local time (Billaud, 1953; Kato et al 1953) while others added that the maximum occurrence is found near mid-night, although longitudinal scattering is observed (Benioff, 1960; Romana and Cardus, 1962; Kato and Saito, 1961). In the equatorial region, Hutton

(1965) indicated similar diurnal variations in pi 2 at Legon, and equatorial station, and stated that the maximum in the occurrence frequency was found between 22 and 23 (L.T.). Fernando working at Colombo, also an equatorial station reported a maximum in the occurrence frequency between 22 and 23 hours (LST) and that 60 sec was the dominant peak in the period spectra. Hirasawa (1965) obtained exact coincidence of the fundamental frequency component of pi 2 and pc 4 micropulsations at a low latitude station and found that pi 2 and pc 4 are sometimes accompanied by very short period pulsations with period in the range 1 to 5 sec. (pi 1). Roquet (1966) reported that pi 2 occurred simultaneously at Addis Ababa and Parakou (two equatorial stations) and at Garchy in France (a middle latitude station), with similar amplitudes for the H component. Amplitudes for the H component at the low latitude stations are normally greater than those of the D component. Saito (1961) also found pi 2 to be synchronous in low latitudes but Rostoker, (1965) indicated a phase shift of the order of a few seconds between stations separated by a few kilometers along an East-West line for high and middle latitude stations. Heirtzler (1966) observed a phase shift of about 13 seconds for pi 2 between two low latitude conjugate stations. Low latitude conjugate station studies of pi 2 are, however, rare.

The dependence of pi 2 amplitude on geomagnetic latitude has been reported by many observers who indicated that the amplitude appears to decrease with decreasing latitude (Kato and Saito, 1961; Jacobs and Sinno, 1960), with a possibility of enhancement in pi amplitudes in the equatorial electrojet region. Roquet (1967) did not find such an enhancement.

The rotation of pi 2 micropulsation polarization has been reported to have a diurnal variation, being counter-clockwise before midnight and clockwise after midnight (Kato and Saito, 1961). No clear polarization measurements for pi's have yet been reported for low latitude stations.

With regard to the seasonal variation of pi occurrence it has been found that they occur most frequently in the spring equinox with a second maximum in the autum equinox at high and middle latitudes (Kato and Akasofu, 1956). Yanagihara (1957) has found that the number of occurrences of pi 2 is inversely proportional to the sunsport number. TroitsMaya reported the minimum amplitude of pi 2 in summer months while Benioff (1960) obtained the minimum amplitudes in the equinoxes.

Pi's have been shown to correlate with solar activity and with ionospheric phenomena at high and middle latitudes. Pi 1 is well correlated with auroral fluctuations (Campbell, 1959; Troitskaya, 1961), with ionospheric absorption of cosmic noise and with occurrence of X-ray bursts (Anger et al 1963).

Troitskaya also reported that pi 2 amplitude and frequency of occurrence decrease as solar activity increases and that moderately disturbed days favour pi 2 occurrence. Fernando (1966) and Hirasawa (1965) reported pi 2 occuring more frequently after a storm sudden commencement at low latitudes and Fernando also obtained a strong positive correlation of pi 2 activity with Kp index.

1.7 The lack of sufficient detail of equatorial features

It is significant to note that magnetic observatories at low latitudes are few and those recording micropulsations are even fewer. Consequently, there has been a gap in our knowledge of magnetic micropulsations in the equatorial region. In particular, the most basic features of pc 1 such as diurnal variations in frequency of occurrence and of amplitudes are unreported. More effort is essential in order to find out and ascertain the basic properties of pc's and pi's in the equatorial region. Such investigations should include the study of:-

(a) the polarization properties of micropulsations

(b) low latitude conjugate point relations

(c) diurnal, seasonal and solar cycle variation of activity of all types of micropulsation.

(d) the effect of the equatorial electrojet on micropulsation properties.

(e) the correlation between the micropulsation phenomena and the ionospheric and other geophysical phenomena.

(f) spectral content of the micropulsations.

The main results already obtained for the low latitude region are summarised in Table I .

TABLE I

Main experimental results on micropulsations obtained at low latitudes

ro-sations	Time of peak activity	Seasonal Variations	Correlation with ionospheric and other Geomagnetic parameters	Other remarks
Pc 1	1. Essentially night time events (Roquet, 1966 Wentworth, 1964)		1. Strong ionospheric attenuation predicted (Wentworth, 1964)	1. Widespread events in low latitudes but localised in the middle and high latitudes (Tepley, Campbell and Stiltner, 1964 and 1965, Roquet, 1966)
Pc 2	1. Evening (around 18 hrs L.T.)(Hutton, 1960; Romana, 1962) 2. Morning (around 06 hrs L.T.) (Romana, 1962)	1. Occurrence predominates in Dec. solstice. (Hutton, 1962)	1. Occurrence favours magnetically disturbed periods (Hutton, 1962; Hirasawa, 1965) 2. Positive correlation with magnitude of disturbance daily variation S_D (Hutton, 1962)	
Pc 3	1. Morning (around 06 hrs L.T.) (Roquet, 1966; 1967; Romana, 1962) 2. Evening during IGY (around 18 hrs L.T.) (Hutton, 1960; Romana, 1962) 3. Just before local noon (Fernando, 1960)	1. Maximum occurrence in the equinoctial months (Glover, 1963	1. Activity favours magnetically disturbed periods (Hutton, 1962; Hirasawa, 1966) 1. Good positive correlation with Kp index. (Fernando, 1966)	1. Amplitude enhanced in the equatorial electrojet region (Roquet, 1967) 2. Amplitudes are larger on H than on D component (Roquet, 1967) 3. The 38 sec. period is the dominant peak activity. (Fernando, 1966)

TABLE I (continued)

Pc 4	1. Near local noon (Hutton 1965; Fernando 1966; Heitzler 1966; Glover, 1963; Osborne, and Rivers, 1963)	1. Maximum Production in Dec. solstic. (Hutton, 1965) 2. Maximum occurrence in the equinoctial months (Glover, 1963)	1. Positive correlation with Kp index (Fernando, 1966) 2. Activity favours magnetically disturbed periods (Hutton, 1965; Hirasawa, 1965) 3. Activity decreases with increasing solar activity (Hutton, 1965; Hirasawa, 1965)	1. Amplitudes are larger on H than on D component (Roquet, 1967) 2. Radio Star scintillations may accompany pc 4 (Hutton, 1965) 3. Slight dependence of period on local time and on storminess of the day (Hirasawa, 1965) 4. Exact coincidence of pi 2 and pc 4 fundamental components. (Hirasawa, 1965) 5. Peak activity at 60 + 5 sec. with a minor peak at 120 sec. (Fernando, 1966; Heitzler, 1966) 6. Amplitude enhanced in the equatorial electrojet region (Jacobs and Sinno, 1960; Roquet, 1967) 6. Oscillations parallel to magnetic field lines (Saito, 1964) 7. Conjugate point activities correlate well (Heitzler, 1966).
Pc 5				1. Amplitude enhanced in the equatorial electrojet region. (Matura, 1961; Jacobs & Sinno, 1960) 2. Comparable amplitudes on Z component at the auroral and magnetic equator (Matura, 1961) 3. Oscillations parallel to magnetic field lines (Saito, 1964)

TABLE I (Continued)

Pi 1	Night time events. (Roquet, 1966)			
	1. Near local midnight. (Roquet, 1966; Hirasawa, 1965)	1. Maximum occurrence during the equinoxes. (Hirasawa, 1965)	1. Occurrence favours magnetically disturbed periods. (Hirasawa, 1965)	1. The dominant period is the 60 sec spectra (Fernando, 1966)
	2. Between 22 and 23 hrs (L.T.) (Hutton, 1965; Fernando, 1966)		2. Strong positive correlation with Kp index (Fernando, 1966)	2. Polarization vector counter-clockwise before midnight and clockwise after. (Saito and Kato, 1961)
				3. Phase shift of about 13 sec. two conjugate stations. (Heitzler, 1966).
Pi 2				4. Events synchronous at low latitudes. (Saito 1964)

2.0. DEVELOPMENT OF THEORIES TO EXPLAIN GEOMAGNETIC MICROPULSATIONS.

Many theories have been proposed to explain the rapid variations of the earth's magnetic field, such as po and pi, but there is as yet, no generally accepted theory of the phenomenon. Three main theories have been under consideration. These are :-

(1) Stormer's theories (1955) in which clouds of charged corpuscles are thought to be executing periodic orbital motion in the magnetic dipole field of the earth,

(2) theories which assume the existence of hydromagnetic waves within the ionosphere (Kato and Watanabe 1955; Lehnert, 1956; Coulomb, 1959) and

(3) theories which postulate the existence of hydromagnetic waves in the earth's outer atmosphere (Dungey 1954; Kato and Akasofu 1956; Tamoa, 1959). Akasofu (1956), Watanabe, (1957) and Dawson (1965) have also considered the problem of propagation of the hydromagnetic waves in the exosphere through the ionosphere and the possibility of the ionosphere having a screening effect on the waves.

From experimental and other theoretical considerations there is a tendency at present to discard Stormer's theory. In order that the values of the period and amplitude of the pulsations obtained from his theories should agree with the experimental values,

it is necessary to assume either that the periodic trajectories exist at a very great distance from the earth or that the energy of the charged particles is great. From other considerations, neither of these assumptions is regarded as reasonable.

When the second theory, in which it is assumed that standing waves are set up between layers of the ionosphere, is considered there is a lack of agreement between the calculated and experimental values of the period and amplitude. But Coulomb (1959) working on the suggestion by Dessler (1958) that there are longitudinal hydromagnetic waves in the equatorial belt, has postulated the existence of standing waves being reflected between the upper and lower boundaries of the F_2 layer of the ionosphere and having a wavelength of approximately 100 km. On this assumption, the period of the waves would be of the order of one second or less. The theory then excludes the long period pulsations.

The third theory is receiving much more attention at the present time. In this the nature and mechanism of pulsations are thought to be caused by hydromagnetic waves which can be generated on the boundary of the magnetosphere and within it. The waves then propagate in the magnetosphere along (toroidal pulsations) and across (poloidal pulsations) the lines of force to the lower limit of the ionosphere where they are transformed into electro-

magnetic waves which are observed on the surface of the earth as pulsations of the magnetic field and of the earth currents.

The mathematical analysis of these modes - toroidal and poloidal was first conducted by Dungey (1954) and applied by him to a preliminary interpretation of micropulsations. This work was extended by Obayashi and Jacobs (1958) and more recently in much greater detail by MacDonald (1961). In the latter analysis, attention was focused on a third type of resonance, which results from a ducting of wave energy between the earth's surface and the relatively low magnetospheric height - 1000-2000km- where the speed of hydromagnetic propagation reaches a maximum.

Little progress has been made in correlating the different types of resonant modes with the different kinds of micropulsation. The periods of resonant toroidal oscillations increase with latitude as indicated by the equation

$$T = \int_{-\lambda_0}^{+\lambda_0} \frac{1}{V} \frac{ds}{d\lambda} \, d\lambda$$

where s is the arc, v, the wave velocity, λ the geomagnetic latitude and $\pm \lambda_0$ the limits, and the reported observational increase in the periods of pc and pi with latitude may be explained on this basis. But the enhancement of long period pc and pi in the equatorial electrojet region has not yet been explained satisfactorily.

In the recent years much attention has been given to the

theoretical interpretation of the shortest period micropulsations, pc1. Prominent among the various workers who have attempted to explain the properties of pc1 are Tepley and Wentworth (1962), Jacobs and Watanabe (1962); Stefant (1965); Gendrin (1965); Cornwall (1965); Landshoff (1965); and Dawson (1965). Most of the available evidence seems to indicate that pc1 are caused by a magnetic disturbance at about five or six earth radii in the vicinity of the equatorial plane. A reasonable hydromagnetic model for the propagation of the pulsations is one in which Alfven (left hand) waves travel along field lines to reach the earth's surface at auroral latitudes and then propagate equatorward as modified Alfven (right hand) waves just above the ionosphere. The isotropic right-hand wave is constrained to a duct between 400 and 2000 km above the earth by refractive processes. It has been shown that many of the observed properties of pc1 can be related to such a model.

There has been much speculation about the mechanisms for the generation of pc1 micropulsations. Jacobs and Watanabe (1962) postulated that the interaction of the solar wind with the magnetopause would generate noisy fluctuations which propagate as left-hand waves along the magnetic field lines down to the ionosphere at high latitudes. They also suggested that standing waves are established between the top of the ionosphere and the height of

of the proton model, whose bounce period was equal to the observed repetition time. This would account for 180° phase shift.

Of the several resonance theories, that which has been found to be most partinent to equatorial micropulsations has been worked out by Prince and Bostick (1964). Their work is an extension and elaboration of similar treatment carried out by Jacobs and Watanabe (1962, 1964). Jacobs and Watanabe suggested means by which hydromagnetic waves reaching high latitudes could be responsible for micropulsations observed at the equator. Table 2 summarises the predictions of resonance periods applicable to the high and middle latitudes.

Table 2

(from Westphal and Jacobs, 1962).

Latitude, deg	80	70	60	50	40	30	20
Period, sec	111	124	252	245	159	69	46

Table 3 shows the resonance periods predicted by Prince and Bostick (1964) for equatorial micropulsations which fall within the period range of interest of the present thesis. The results obtained will be compared with these. The resonances are for sun-spot minimum conditions under which the experimental data was collected.

Table 3

(from Prince and Bostick, 1964).

Day Sec	140	70	45	25	20	10*
Night Sec	120	60	37	20	16	4.5*

* Strongest of all the predicted resonances.

It can be seen from the graph that α should be of the order of 20 for a suitable system to be used to detect micropulsations over a fairly wide frequency band.

In order to increase the induced voltage, μ, n and A should be large but because of construction and portability considerations a compromise is necessary. The detecting coil together with the galvanometer amplifier should be of a size and weight compatible with the requirements of installation and portability. The coil should be placed some distance from the recording building and from vehicular traffic, and preferably buried to minimize wind motion. The impedance of the coil should be such that the signal can be transmitted over several feet to the recording equipment using coaxial cable.

The sensitivity of the coil as a detector is given by

$$V = n \pi R^2 \frac{dB}{dt}$$

where R is the radius of curvature of the coil and n the number of turns,,and its self inductance, L will be given by

$$L = n^2 \mu_0 R \left\{ \log_e \frac{8R}{r} - \frac{7}{4} \right\}$$

where μ_0 = permeability of free air

and r = cross-sectional radius of coil

Thus the sensitivity increases as the square of R, and self inductance only linearly as R, implying advantages in using coils of large radius of curvature. This is useful when air

cored coils are used as detectors.

Although the sensitivity of induction coils may be increased by filling the coil with a high permability substance, this may increase the self-inductance and will change the frequency response significantly as a result of eddy currents and hysteresis losses. This effect may be minimized by using a laminated core. Within the winding itself, proximity effect, distributed capacity and wire resistances contribute to losses in the coil. Hill and Bostick (1962) have shown that skin effect is negligible.

Mumetal is the most commonly used core material which satisfies most of the conditions stated above but due to the large demagnetizing factor of the long rods, the effective permeability is not strongly dependent on the true permeability provided the permeability is a few thousand (Bozorth, 1951). The effective permeability is more dependent on the length to diameter ratio of the rod. In order to avoid saturation in the earth's ambient field, the field in the bar should be less than 1000 gauss. It has been shown that for an ambient field of about 0.5 oersteds, this leads to a permeability between 1000 and 2000 and a length to diameter ratio of between 70 and 100 will produce the desired permeability. The induced voltage decreases

toward the end of the rods rather parabolically resulting in optimum winding cross-section being parabolic as indicated on fig. 3. When this is so the ratio of flux to resistance per turn is also kept constant.

Another source of error is the generation of thermal voltages at joints in the wires, or due to small temperature changes differences along the wire. Since it is not possible to insulate the entire system thermally, negative feedback can be applied to reduce drifts and keep the recorder on scale by attenuating the low frequency response.

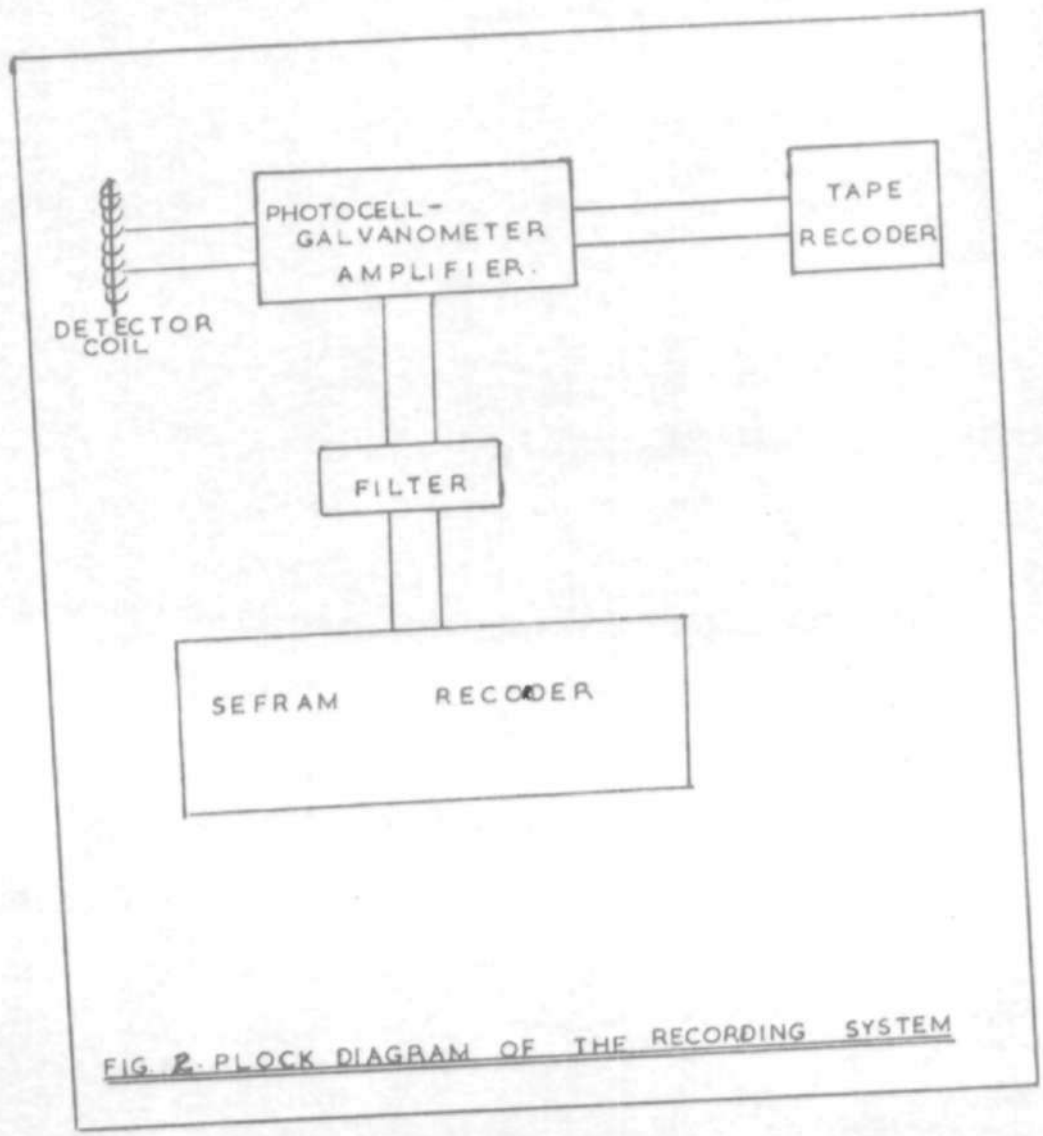


FIG 2. PLOCK DIAGRAM OF THE RECORDING SYSTEM

take the signals from the detectors to the recording equipment which was set up in a room about 300 metres from the detectors. The coaxial cables were placed in insulating pipes and buried a few cm. under the ground

4.2.1 The Detectors.

Each detector consists of coils of 10,000 turns of 34 S.W.G. copper wire wound on a mumetal bar of length 205 cm. and diameter 2.2 cm. The coil was wound in seven layers as follows:-

First layer	:	2,500 turns
Second layer	:	2,400 turns
Third layer	:	1,780 turns
Fourth layer	:	1,420 turns
Fifth layer	:	1,060 turns
Sixth layer	:	700 turns
Seventh layer	:	400 turns.

The first layer was wound on the centre of the bar leaving an allowance of 20 cm. on each end. The successive layers had an allowance of 10 cm. on both ends of the previous layers so that the detector in general had a parabolic shape as indicated in fig. 3. The layers were insulated from each other by french cloth. The feedback coils of 3,500 turns (swg 34 copper wire) were wound uniformly on top of each detector. The mumetal bar

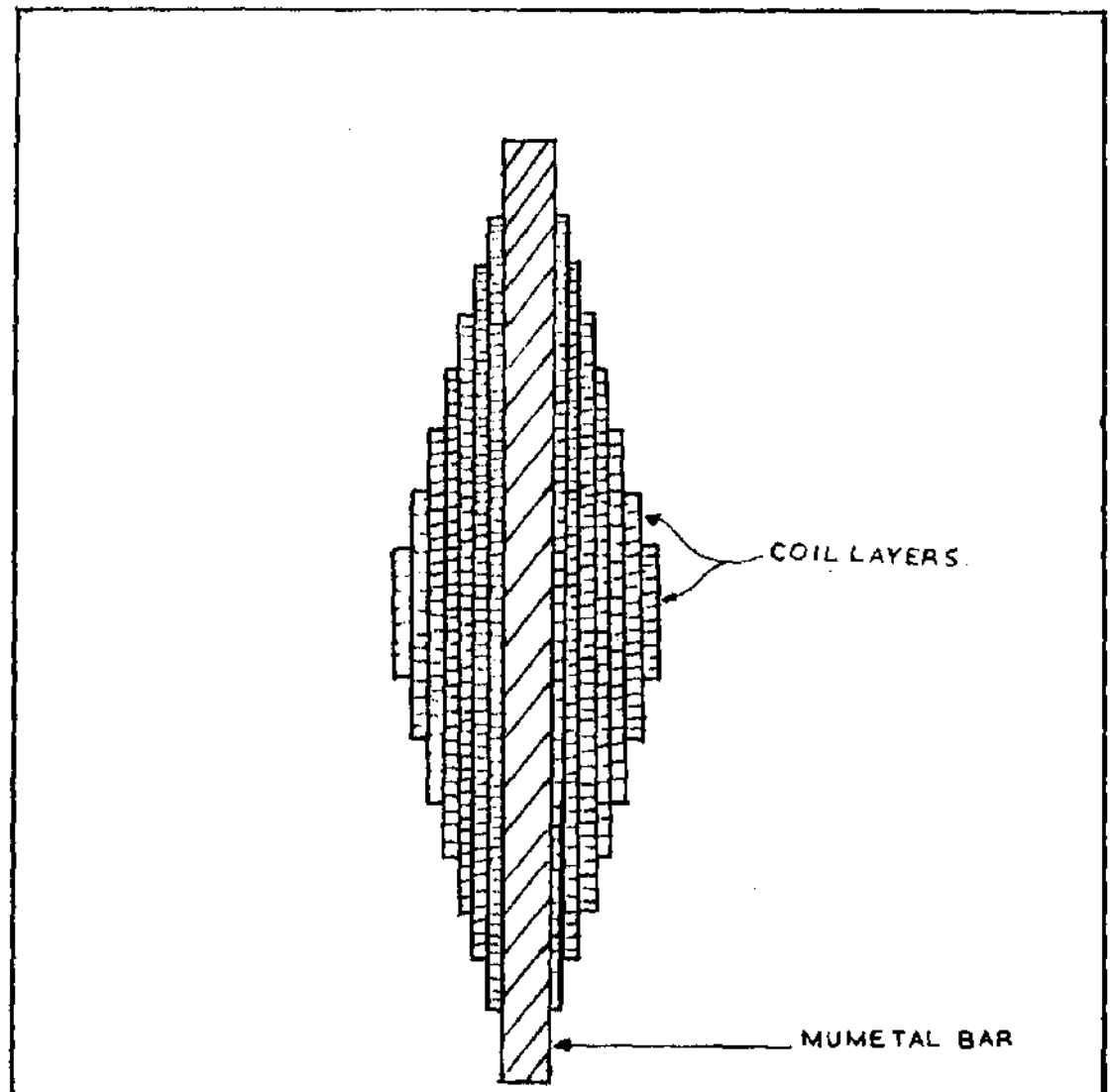


FIG. 3. SECTION OF DETECTOR

has permeability of 1000 with length to diameter ratio of 92. The total resistance of the detector is 70 ohms with an inductance of about 250 H. The coil generates an e.m.f. of 22×10^{-10} volts for a field of 1 gamma/sec.

One detector was inseted in a vertical concreter hole being shielded by a cylindrical wooden box and thin copper plates at both ends of the box. The other two detectors are placed in cemented trenches in the north - south and east-west geomagnetic directions. The three detectors were under one aluminium roof to protect them from rains and vibrations due to winds.

4.2.2 The Galvanometer - Photocell Differential Amplifier and the Sefram Recorder

The essential parts of galvanometer - photocell amplifier are shown on the circuit diagram in fig. 4 while fig. 5 illustrates the optical arrangement. The galvanometers were placed on a concrete table while the Sefram Recorder, the photoresistor bridge and the lamps were arranged on two separate tables at different elevations as shown in fig. 5. Fig. 6 is the circuit diagram of the Sefram Recorder as given by the manufacturer.

The photocell (type 1831-1831-5, French made) and the 10K Ω resistance which make up the photoresistor bridge were

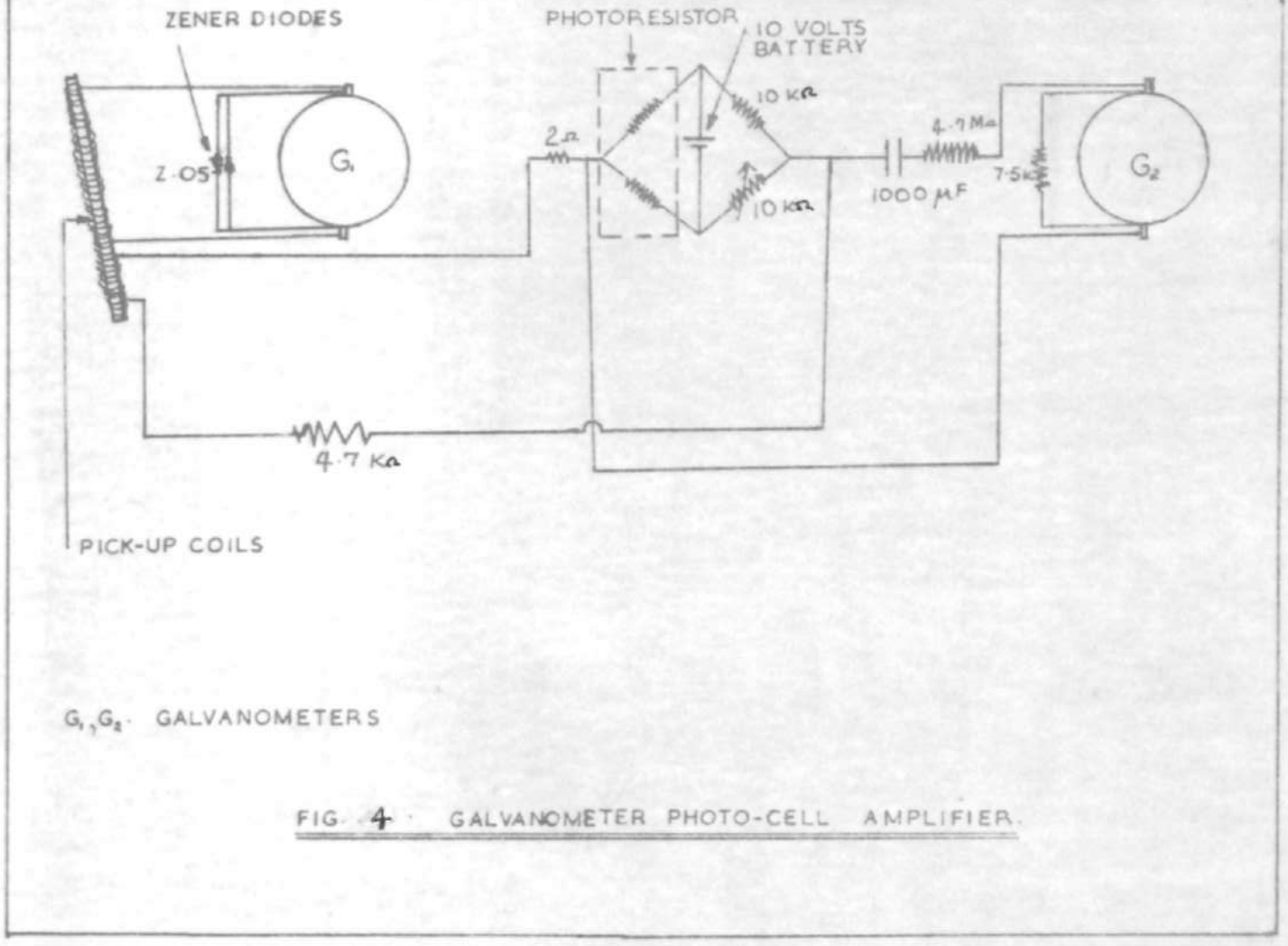


FIG. 4 GALVANOMETER PHOTO-CELL AMPLIFIER.

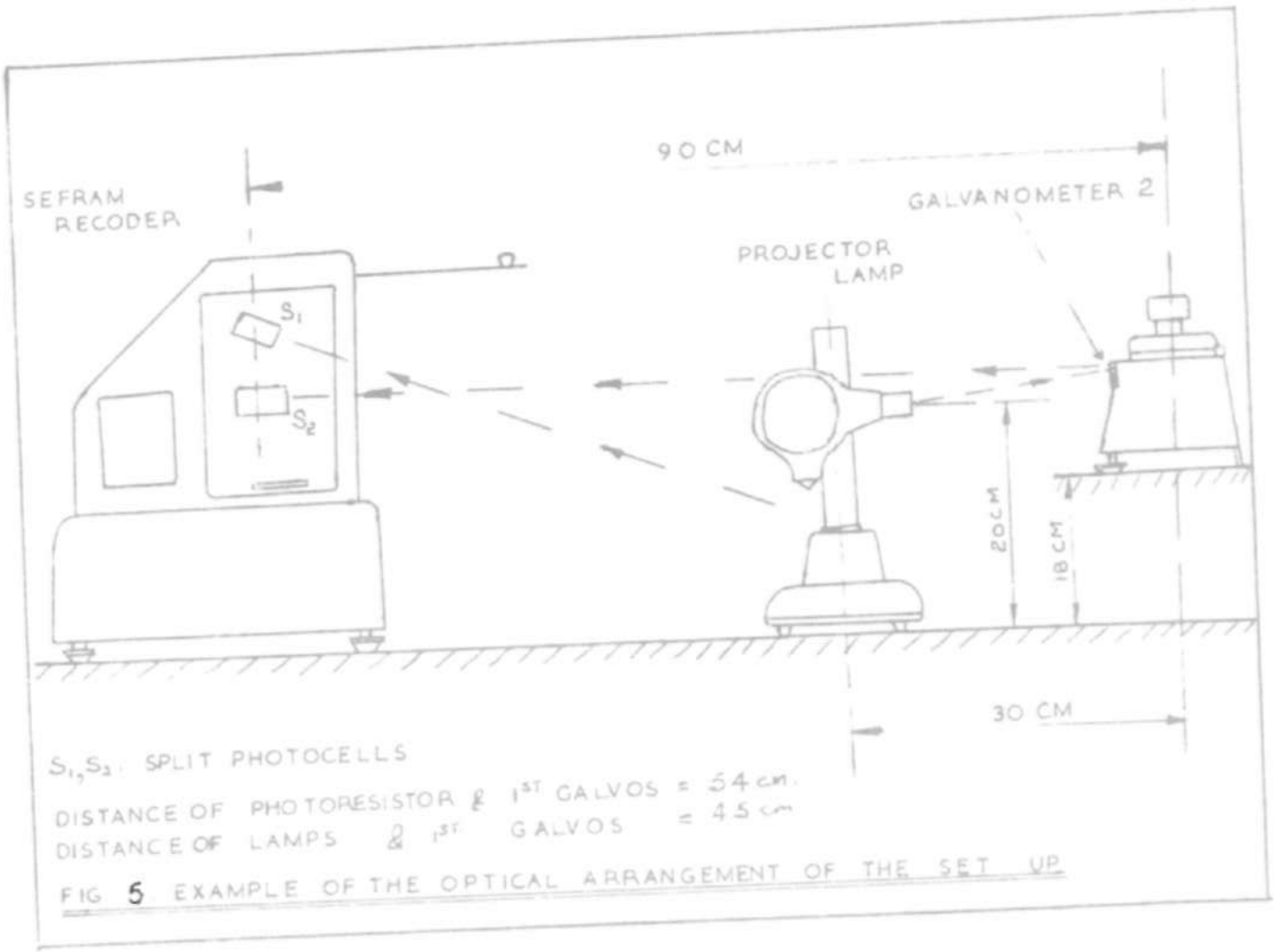


FIG 5 EXAMPLE OF THE OPTICAL ARRANGEMENT OF THE SET UP

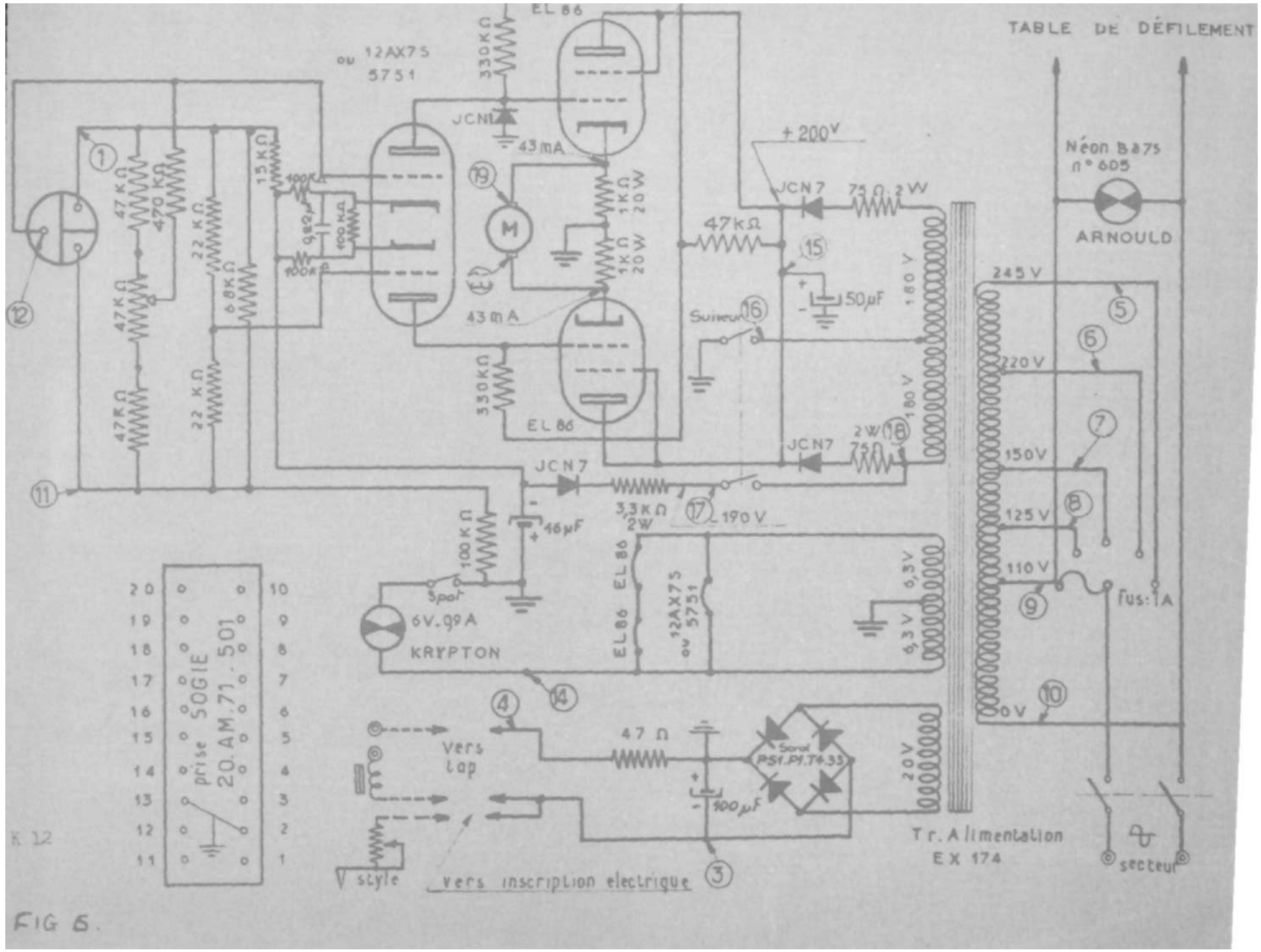

TABLE DE DÉFILEMENT
EL 86
ou 12AX75
5751
330KΩ
JCN1
43mA
+200V
JCN7
75Ω 2W
Néon Ba75
n° 605
ARNOULD
47kΩ
15
50µF
180V
245V
220V
150V
125V
110V
0V
Fus: 1A
Secteur
Tr. Alimentation
EX 174
Suiveur
16
18
17
190V
3,3kΩ 2W
100kΩ
16µF
Spot
6V.99A
KRYPTON
EL86 EL86
ou 12AX75
5751
0,3V
6,3V
20V
47Ω
Vers
tap
Pont
PS1.P1.T433
100µF
Vers inscription electrique
style
prise SOGIE
20.AM.71.501
K 12

FIG 6.

mounted on a square aluminium plate with terminals for the battery across the bridge and for the output signals from the bridge. Two such mounted photoresistor bridges were made, one for the signals from the North-South direction and the other for the East-West direction.

The signals from the two detectors (the vertical detector was not used during this preliminary investigation) were fed to the first stage galvanometers which have the following characteristics :-

Coil Resistance (ohms)	Period (Sec)	Sensitivity	Critical Damping Resistance(ohms)
519	8	0.31×10^{-3} μA/mm	10,800
514	8.3	0.278×10^{-3} μA/mm	9,800

The displacements of the first stage galvanometers were arranged to fall on the photocells of the photoresistor bridges which amplified the signals. The output from the photoresistor bridges are taken through short leads to the second stage galvanometers which have the following characteristics:-

Number	Coil Resistance	Period (Sec)	Sensitivity	Critical Damping Resistance (ohms)
182,492	147	2	550 mm/μA	3,500
182,588	149	2	550 mm/μA	3,500

The displacements of the mirrors of the second stage galvanometers were allowed to fall on the split-photocells on the Sefram Recording equipment. The Sefram Recorder contains a power amplifier which measures signals proportional to the differential light on the photocells and drives a pen recorder. There were two photocells on the Sefram Recorder so that only two elements of the signals could be recorded simultaneously. The H and D components of the signals were recorded throughout the period with which this thesis is concerned. The recorder has chart speeds ranging from o.6 mm/min to 600 mm/min. There are two time markers which can be operated by connecting two relay clocks to the Time Marker Terminals on the Recorder. Time marks were registered every minute and these were calibrated once a day with a radio receiver tuned to a standard time signal. From these time marks the chart could be divided into hourly intervals.

Power supply from ac. stabiliser was connected to

a) the four lamps which provide light spots for the galvanometers,

b) the Sefram Recorder, and

c) the tape recorder.

Arrangements were also made to take a portion of the signal from the photo-resistor bridge to a tape recorder which was set up

in an adjacent room. The tape recorder has its own power amplifier and can record signals simultaneously with the pen recorder. The tape recorder was not, however, in use during the period of the present study, as a means of analysing the magnetic tapes were not immediately available.

A 1000 μf condenser placed in the circuit helped to minimise disturbances due to 50 c/s mains pick up. The equipment was made insensitive to low period fluctuations by inserting a 4.7 K Ω resistance in series with the output so that the lack of low-band-pass filters had little effect on the long period fluctuations which are the objects of this thesis. The response curve of the coil galvanometers system used is shown on fig. 7.

4.3 Calibration

The system was calibrated by rotating a small magnet of known magnetic moment at a constant speed at a point on the axis of the coil at a fixed distance from its centre. The field induced in the coil was then given by $2M/r^3$ gauss where M was the magnetic moment of the magnet in c.gs. units and r cm was the distance from the centre of the detector to the position of rotation of the magnet. This was equivalent to a field of $2M/r^3 \times 10^5$ gamma. These artificially produced pulsations were recorded on the Sefram instrument, operating at a chart speed of 12 mm/min.

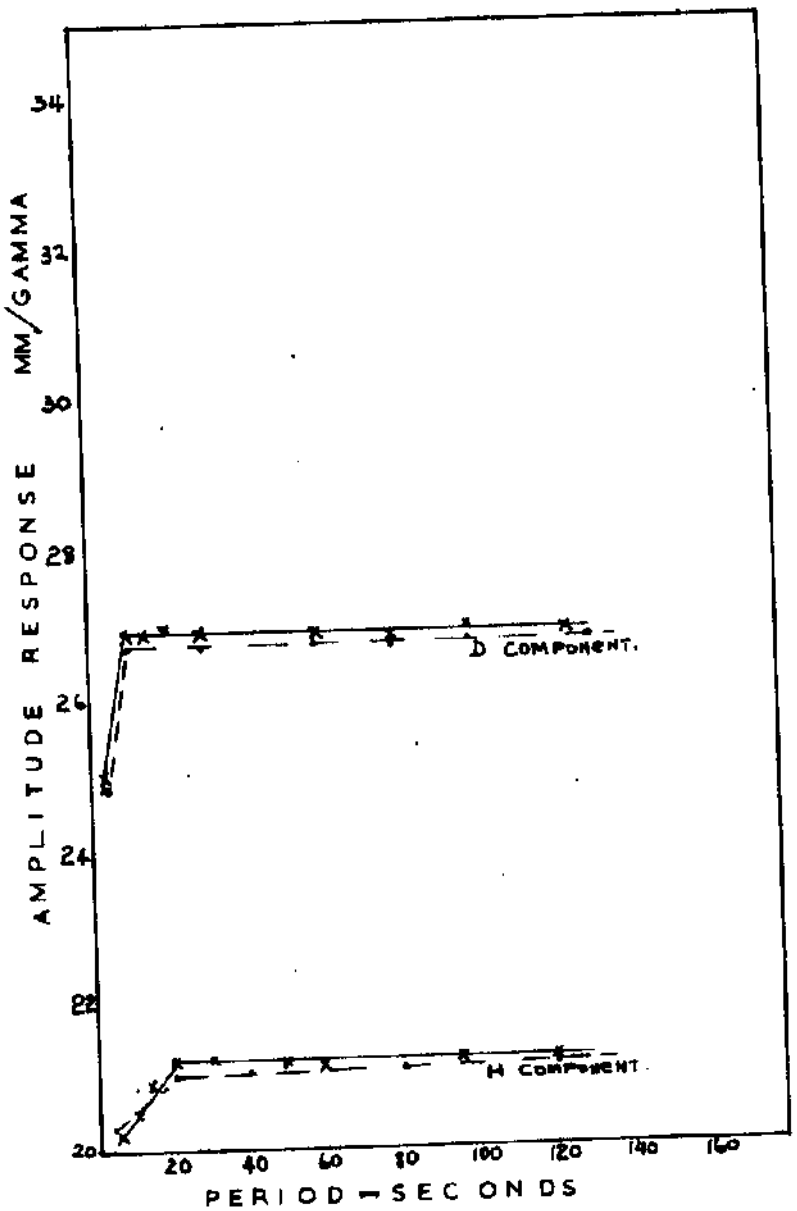


FIG. 7 . EXPERIMENTAL RESPONSE OF THE COIL-GALVANOMETER SYSTEM USED.

——— FEEDBACK IN.

— — — - WITHOUT FEEDBACK.

If A in mm is the peak-to-peak amplitude of the pulsations then

$$A = \frac{4M}{r^3} \times 10^5 \text{ gamma.}$$

Hence the response in mm/gamma could be calculated corresponding to the period of the pulsations which could be read from the chart. (M = 2620 c.g.s. units and r = 9.95m for the detector in the North-South direction and r = 10.1 m for the East-West detector). By rotating the magnet at various speeds a response curve could be plotted.

When a satisfactory experimental arrangement had been achieved, the response curves for both H and D component detectors were obtained and the following sensitivities were estimated from them in the period range 5 - 120 sec.

Duration	Element	Sensitivity
Jul.1 - Aug. 31	H	0.5 gamma/cm
July 1 - July 3	D	0.3 gamma/cm
July 4 - Aug.31	D	0.4 gamma/cm

The calibration was checked from time to time during the period of study but the response was found to be constant as all the components of the circuits were kept constant and the emf across the photresistor bridge was maintained at 10 volts. Whenever an alteration was made in the installation it was essential to check the calibration of the system. Table 4 gives

an example of the response of the system for different pulsation periods. From this information the response curves were constructed.

Table 4.

D (E-W) T =	2	sec	2.5 cm/γ
	10	"	2.69 "
	15	"	2.69 "
	30	"	2.69 "
	60	"	2.69 "
	125	"	2.70 "
H (N-S) T =	3	"	2.02 "
	10	"	2.05 "
	20	"	2.12 "
	30	"	2.12 "
	60	"	2.12 "
	95	"	2.12 "

4.4 Trial Experiments.

While the specifications of the most suitable galvanometers, viz, periodic time, internal resistance, and sensitivity, are related to the type of pulsations which one wishes to study, in this particular experiment use had to be made of galvanometers already available in the Department. From these the most suitable were chosen for inclusion in the installation.

It was also necessary to experiment with the value of resistance and capacitance to be put in series with the output

circuit to obtain a suitable sensitivity for the detection of long period pulsations in the period ranges of pc3, pc4 and pi2. Resistances in the range 2 to 5 MΩ and capacitances between 500 μF and 1000 μF were tried. The frequency response curves were obtained for the following different circuit characteristics:

(a) With and without feedback.

(b) Series resistance 2.2 MΩ , 3.36 MΩ, 4.7 MΩ and 5 MΩ with the following corresponding shunt resistances across the second stage galvanometers: 5 kΩ , 7.5 kΩ , 7.5 kΩ , 7.5 kΩ.

Series capacitances of 500 μF and 1000 μF were tried with each of the arrangements. Typical response curves are shown in fig. 7.

It was found that feedback did not alter the response very much but helped to minimise drifts due to fluctuations in the mains voltage and due to temperature variations.

It was also found that in order to maintain suitable amplitude and to minimise drifts, it was necessary to put 4.7 MΩ and 1000 μF in series with the output and 7.5 kΩ in parallel with the Tinsley galvanometers.

5.0 DATA HANDLING AND ANALYSIS

Several analytical methods were used in an attempt to bring out the main features of micropulsation activity, and in order to investigate the amount of detail which it is possible to obtain from a general analysis of this sort. Records were scaled by hand and computations carried out on an office adding machine. This was desirable because of the high degree of variability exhibited by the micropulsations, and in order to identify distinct types of events and to comment on their quality. It must be added here that visual analysis is not an ideal method particularly as regards to spectral contact of the various micropulsations. It is for this reason that it is planned to record simultaneously on magnetic tape in future experiment. These together with a precise statement of the criteria adopted in the measurement of the parameters are listed below.

The records were analysed in hourly intervals in the first instance, and pulsations occurring in each hour were classified into events in the same category i.e. as pc 3, pc 4 or pi 2. The information for each hour was tabulated and in a typical hour, many events each with a different period and perhaps showing different forms were found to occur. The approximate time of commencement of all the events was also noted.

5.1 Period (T)

Period was measured as the time between adjacent peaks in well developed waves. This was easily obtained from the knowledge of a chart speed and the graduations of the chart itself. The chart speed used throughout most of the period of study was 6 mm/minute, so that it was possible to measure a wave with an accuracy of ± 5 sec. In some cases a chart speed of 12 mm/min was used so that a wave period could be measured with an accuracy of ± 2.5 sec. Where the period was attributed to an event in a general way it was usual to measure a representative sample of the waves in the train. When a particular train of waves showed variability of period it was necessary to break the train into events of constant period or to acknowledge the period spread in the computation which followed. Events having pulsations less than three complete cycles were excluded from the final analysis.

5.2. Amplitude (A)

Peak to peak amplitude was measured first in millimetres from the scaling of the chart paper. This was later converted into gamma from the calibration curves. Again it was necessary to estimate the average amplitude to be ascribed to an event. Events having amplitude less than 0.02γ were excluded in the final analysis.

5.3 Continuity (C)

The continuity of an event was defined to be its duration in units of five minutes. Thus an event could have a maximum continuity of 12 in any hour. The approximate time of commencement of an event was first noted and from this the continuity of event was estimated. It was necessary to break an event into two where it overlaps between two adjacent hours for the purpose of the analysis.

5.4 Energy (E)

The energy ascribed to an event was computed from CA^2, where C is continuity and A amplitude and energy spectra and distribution curves were drawn. Energy is not, however, a good parameter for representing micropulsation phenomena because of the very large range of amplitude and continuity which occurs in micropulsations. A 5 gamma pulse lasting for 15 minutes is, in energy, equivalent to a perfectly homogenous continuous train of amplitude 0.2 gamma lasting for 15 hours. Considerable attention to the importance of the qualitative properties of micropulsations is necessary before broad conclusions may be drawn from information based on energy characteristics.

5.5 General remarks on the Analysis

A reasonable amount of data was obtained during the two

months of operation of the installation which was operated continuously with a chart speed of 6 mm/min. on all days. There was no interruption in the recording except for some few intermittent days when there was failure of the local electricity supply. The months during which data was obtained for the present analysis were July and August 1967. During May and June, 1967, preliminary recordings of micropulsations had been obtained both on paper chart and magnetic tape. Sonagram analysis of the tape recordings was obtained by Dr. Hutton at the Institut de Physique du Globe, Paris. She also made a preliminary visual comparrison there of the Zaria pen-recordings and similar observations from Addis Ababa, Ethopia and Garchy, France.

Both the sonagram analysis and the visual comparisons confirmed that the pulsations recorded at the Zaria station were natural pulsations of the earth's magnetic field.

5.6 Presentation of results

The results obtained were first arranged in tabular form and then plotted as described below. Examples of the traces of the various events were photographed and are presented for comparison and reference.

5.6.1 Occurrence versus time of day

From the continuity analysis, it was possible to determine the number of events which occurred during an hour of the day. The hourly values of the number of occurrences of the events pc 3, pc 4 and pi 2 were thus obtained and the diurnal variations in occurrence frequency during the period of study were obtained.

5.6.2 Amplitude versus time of day

Because of the doubt cast on the energy as a good

measure of micropulsation as stated earlier, it was thought advisable to give also the diurnal variation in amplitude of the three events studied. The hourly means of the amplitude were computed and graphs of amplitude against time of day were plotted.

5.6.3 Energy versus time of day

Graphs of energy against time of day were plotted from the hourly means of energy obtained for the two months of study. From these a measure of micropulsation activity was deduced and the result compared with that obtained from other parameters such as occurrence frequency and amplitude.

5.6.4 Period versus time of day

The average period for each hour was computed and the mean hourly values for the two months obtained. Curves showing diurnal variations in periods for some of the events studied were plotted.

5.6.5 Occurrence versus period

For each of the events pc 3, pc 4 and pi 2, the graph of occurrences against periods was plotted. From the plots the regions of peak occurrence for each of the events were determined.

5.6.6 Energy versus period

Graphs of energy versus period were plotted for the

two months of study for the different ranges of period which were chosen to correspond with the IAGA classification i.e. pc 3, pc 4 and pi 2. The difficulty due to energy range in events which occurred was minimised by excluding events of short continuity showing an energy greater than 1,000 units.

5.6.7 Polarization studies - H/D versus time of day

Graphs of H/D of pc 3 and pc 4 against time of day were plotted for the two months of study. The ratio H/D was obtained from the mean amplitude of pulsations on H and D components.

6.0 DESCRIPTION OF RESULTS

6.1 Traces

Figures 8 to 10 are examples of pc 3, pc 4 and pi 2 traces respectively as obtained on the rapid-run magnetograms at Zaria at the times indicated on the charts.

Fig. 11 shows tracings of simultaneous Zaria and M'Bour (Senegal) (14.5° N, 17.0° W Geographic and 21.2° N, 55° Geomagnetic) records which is included for comparison. For the H component, the sensitivity of the Zaria installation is 0.5 γ/cm while that of M'Bour is about 1.8 γ/cm and on D component, the Zaria installation has sensitivity of 0.4 γ/cm and M'Bour 1.4 γ/cm. The sensitivity of the Zaria installation is thus about three times that of M'Bour. The records from M'Bour, however, give a very useful comparison with what is obtained in Zaria. There is a reasonable degree of correspondence between the Zaria and M'Bour records as can be seen, making allowance for the difference in frequency response of the installations. The low frequency components which are seen on Zaria records are, however, not obvious on the M'Bour records but this is probably also due to difference in frequency response of the two installations. This may also arise from the fact that the dip latitude of Zaria is less than that at M'Bour (M'Bour is just outside the electrojet

region) so that large irregular pulsations are likely to be enhanced at Zaria with reference to M'Bour.

It is also worthwhile to add here that Dr. Hutton has compared some records obtained with the same equipment at Zaria in May, 1967, with the corresponding ones obtained with similar equipment from Garchy (France) a middle latitude station (47.3° N, 3.1° E Geographic and 49.6°, 84.8° Geomagnetic) and has found in general that there is good correspondence between the records from the two stations though there were fewer good quality pc3 micropulsations on Zaria records. This may be due to lack of equipment sensitivity or to a latitudinal effect and the masking of pc micropulsations by the enhanced irregular fluctuations observed near the dip equator.

These comparisons, particularly that between Zaria and M'Bour records which are two equatorial stations, indicate that a real geophysical phenomena is being measured, not something spurious.

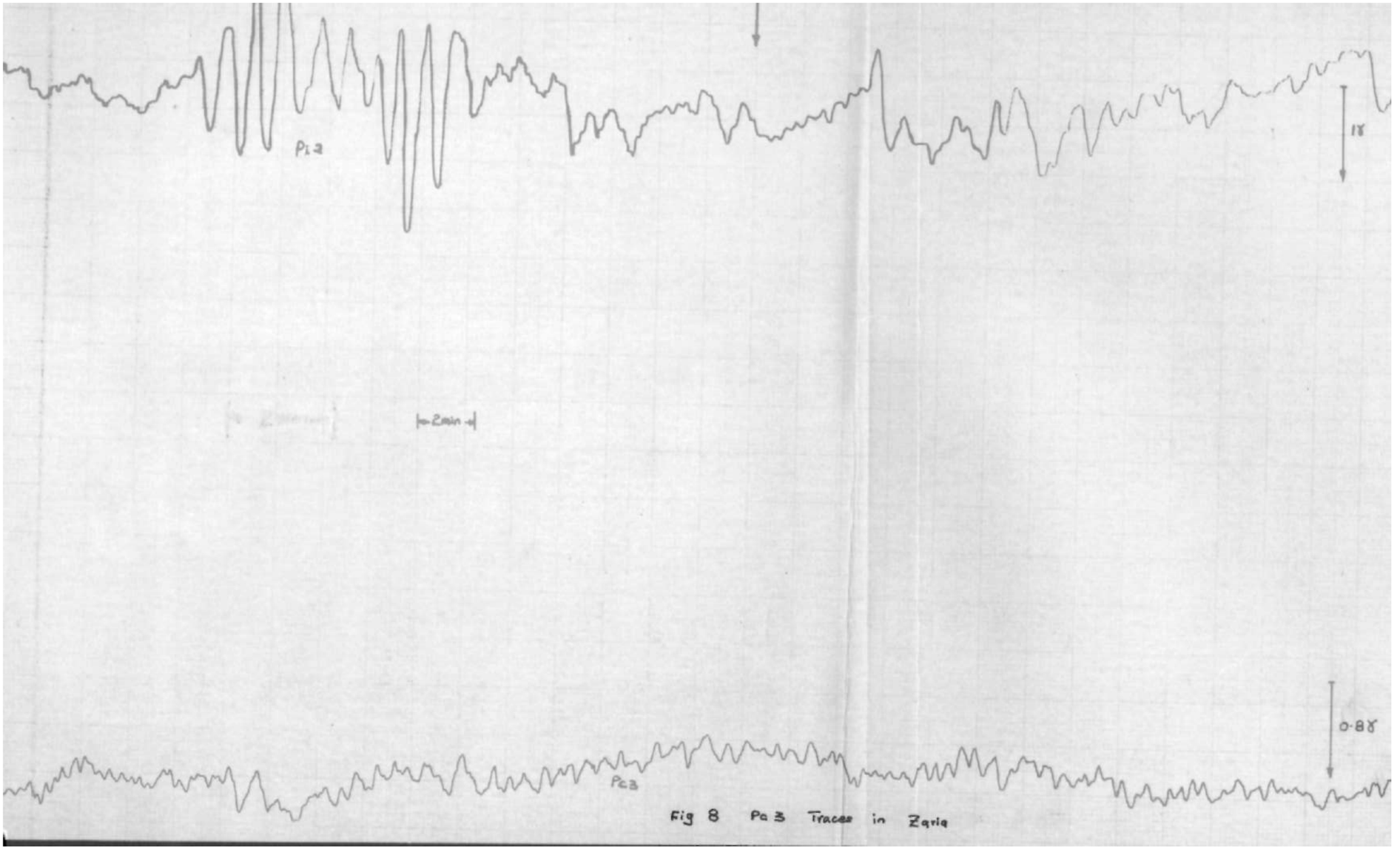


Fig 8 Pc 3 Traces in Zaria

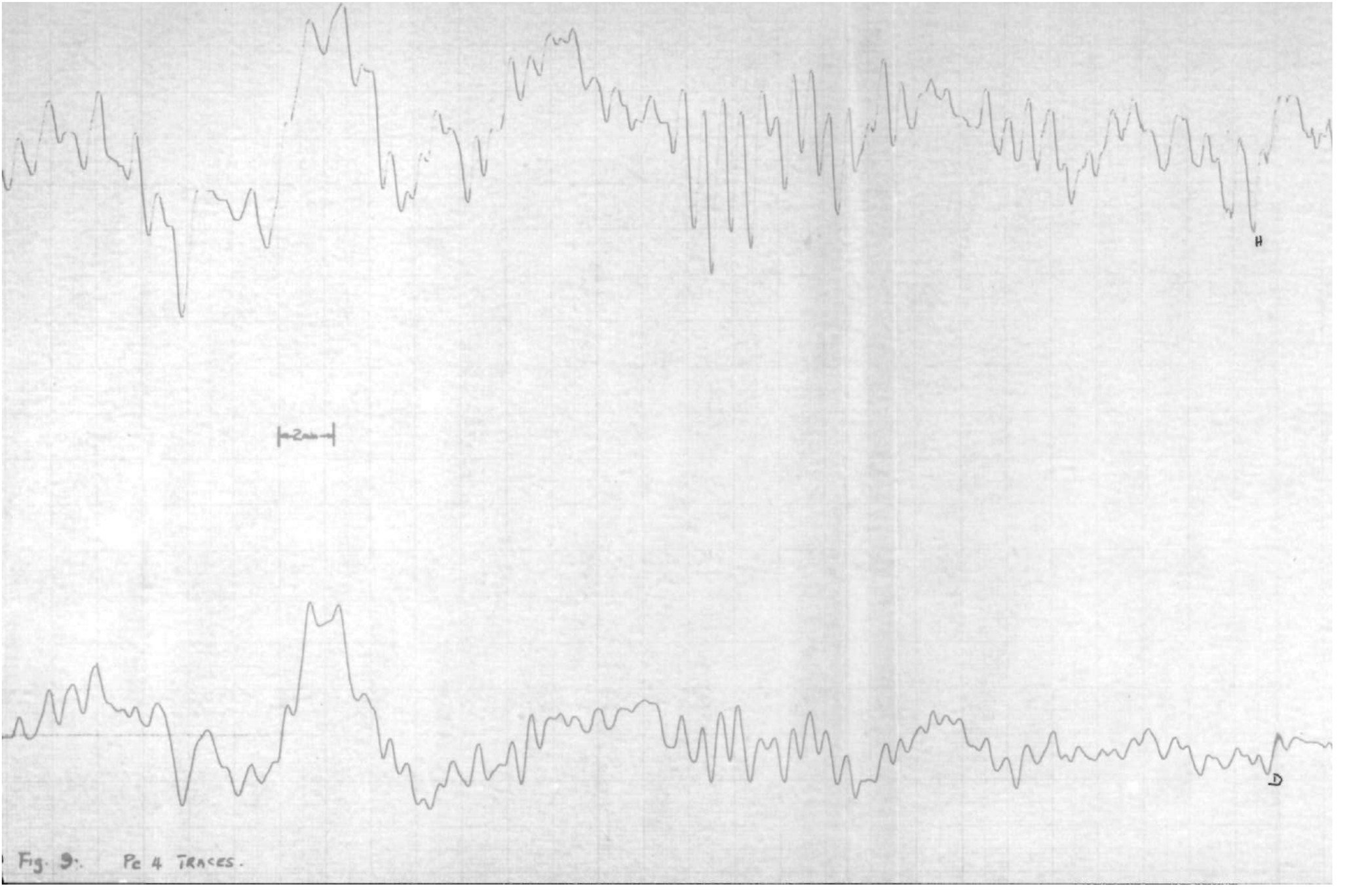


Fig. 9. Pc 4 TRACES.

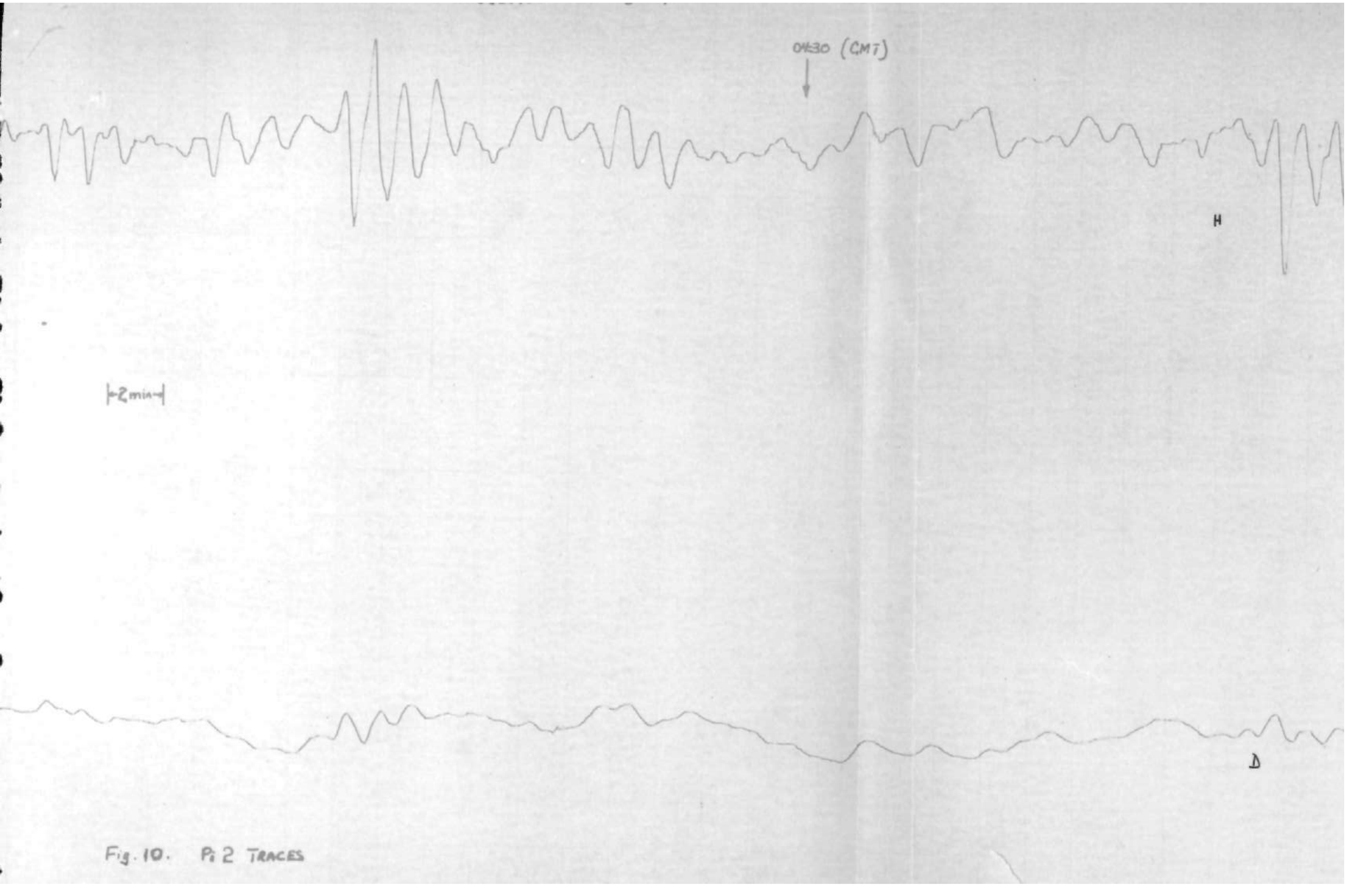


Fig. 10. Pi 2 TRACES

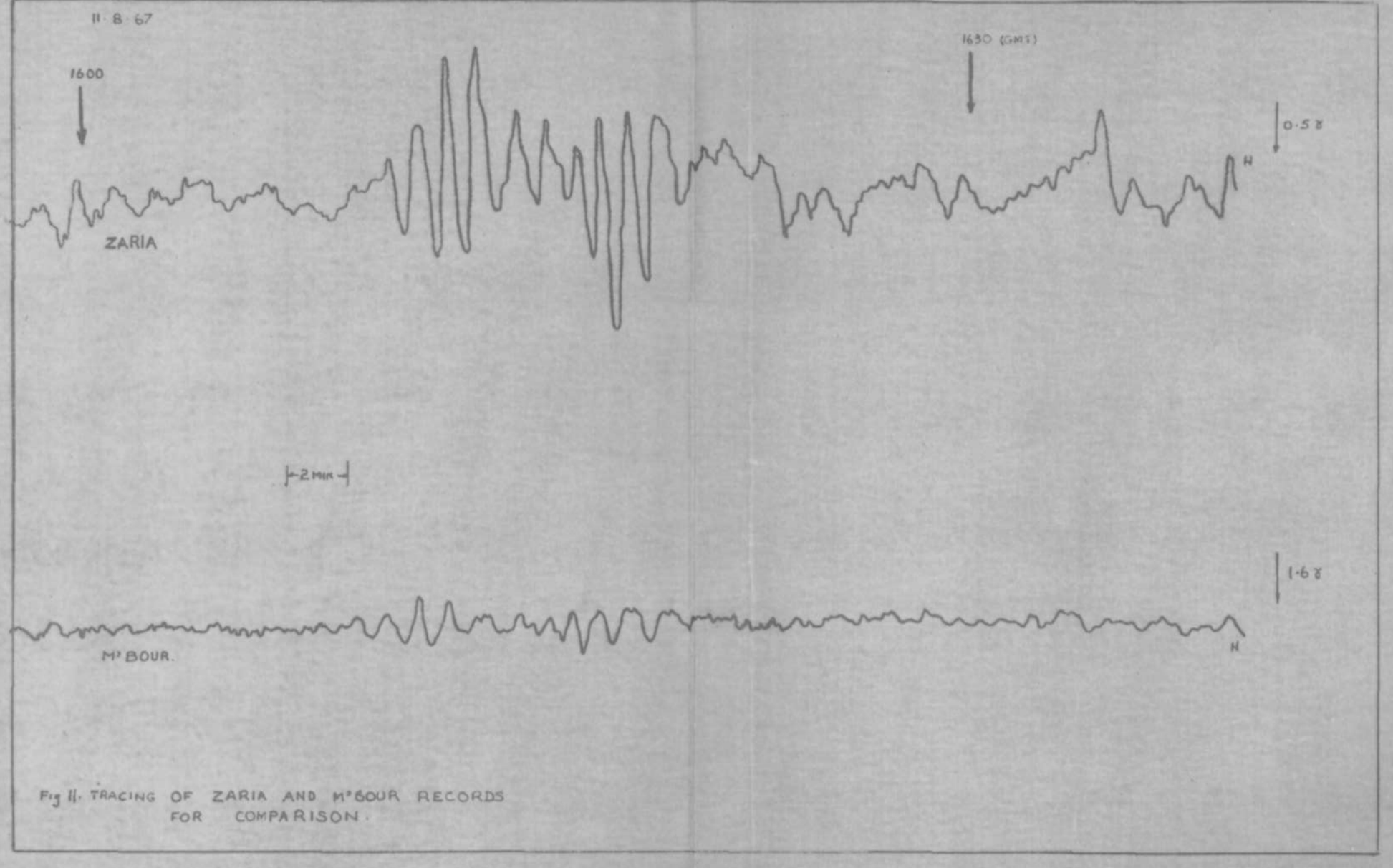


Fig 11. TRACING OF ZARIA AND M'BOUR RECORDS FOR COMPARISON.

6.2. Pc3 MICROPULSATIONS.

6.2.1 Diurnal variation in occurrence frequency.

Fig. 12 shows the diurnal variation of pc3 occurrence frequency on both H and D components. It appeared that pc3 pulsations could occur throughout the day but there was a pronounced morning peak between 04 and 08 hours (L.T.). There was little difference in diurnal variation between the two months of study but pc3 occurrence appeared to be more numerous in August than in July. During the period of study, 66 cases of pc3 were detected in July while 109 cases were detected in August. Pc3 pulsations were seen rather more frequently on the H component than on the D component (95 cases on H and 83 cases on D component).

6.2.2 Diurnal variation in amplitude.

Fig. 13 shows the plots of pc3 amplitude versus time of day for both H and D components. The plots show that there was a clear peak amplitude at about 09 hours (L.T.). The mean peak amplitude on H was 0.38γ and 0.18γ on D. In general the amplitudes were larger during the day than at night. Also the amplitude were larger on H component than for the D component by a factor of about 2.

6.2.3 Diurnal variation in energy.

Fig. 14 shows the diurnal variation in energy of pc3 as detected on H and D components. The energy variation was

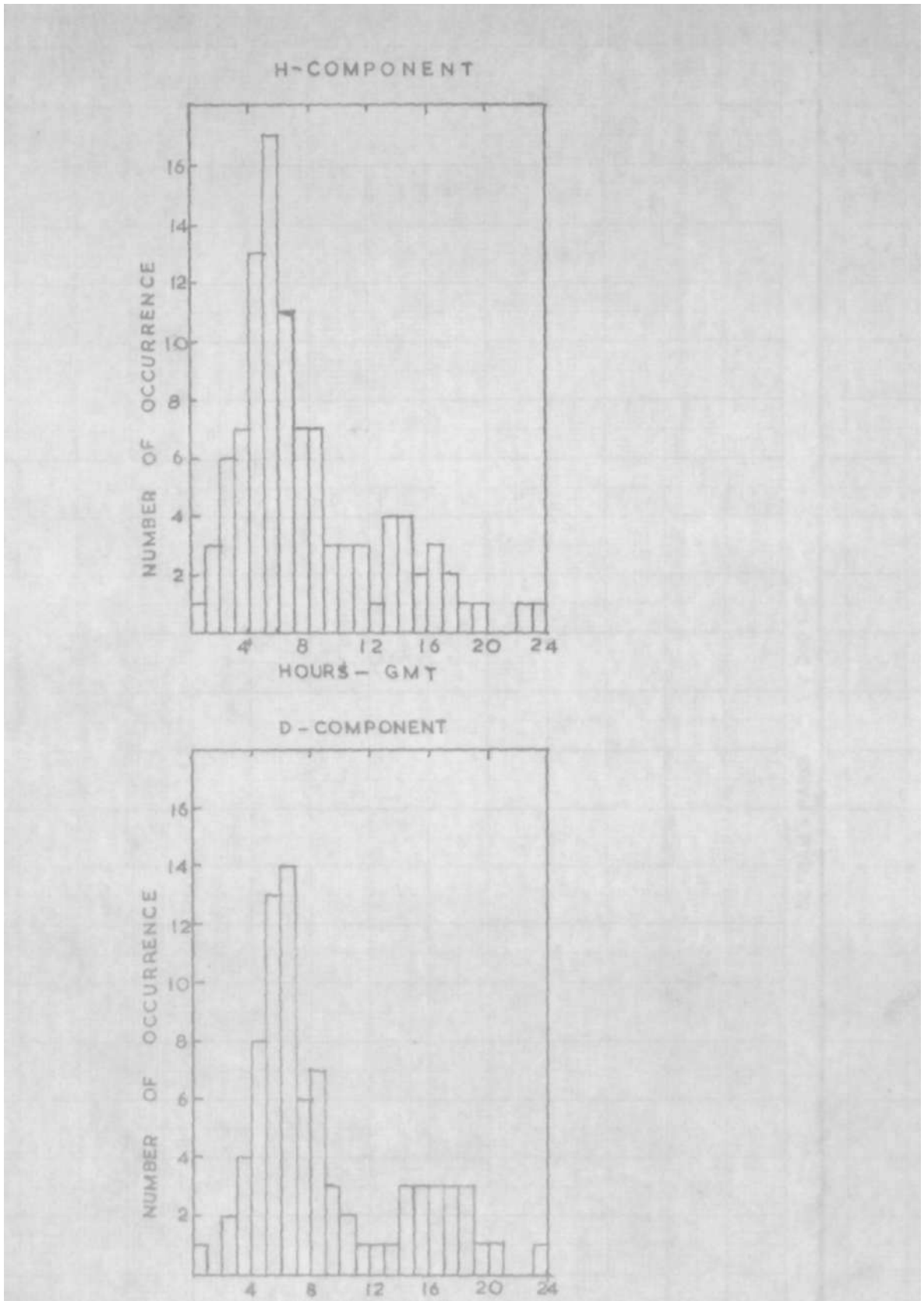


Fig No. PC 3 DIURNAL VARIATION IN OCCURRENCE FREQUENCY (JULY - AUGUST 1967)

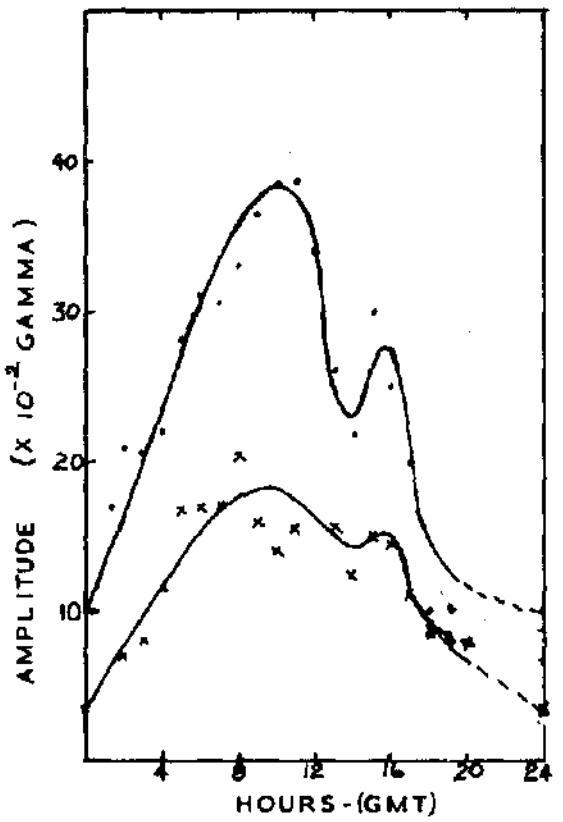


FIG. 13. Pc 3 DIURNAL VARIATION IN AMPLITUDE. (JULY-AUG 1967)
.. H COMPONENT
xx D COMPONENT

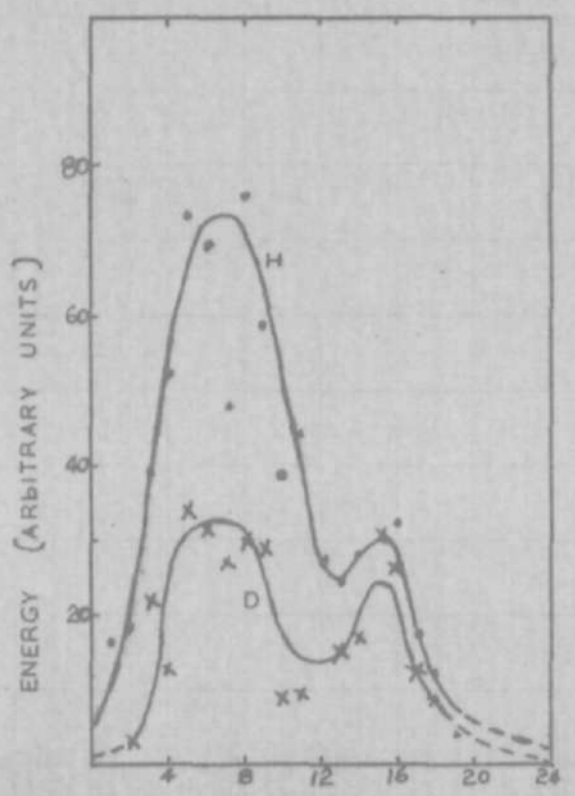


FIG 14. Pc3 DIURNAL VARIATION IN ENERGY. (JULY - AUG. 1967)

·· H COMPONENT

x× D COMPONET

similar to the amplitude variation but peak energy occurred at about 06 hours (L.T.) i.e. at the same time as peak occurrence frequency.

6.2.4 Diurnal Variation in Period.

Fig. 15 shows the diurnal variation in period of pc3 events during the period of study. It had a U-shaped type variation with minimum period occurring at about 16 hours (L.T.).

6.2.5 Occurrence versus Period.

Fig. 16 shows the variations of pc3 spectrum at Zaria. The histograms show that the basic spectral shape remained the same on both components. The maximum frequency of occurrence was in the period range (37.5 ± 2.5) sec.

6.2.6 Energy versus Period.

Fig. 17 shows the plots of energy versus the period of pc3 micropulsations. No consistent trend is visible.

6.2.7 Polarization.

The fact that the amplitudes were larger on H than on D component showed that pc3 micropulsations were linearly polarized in the north-south direction. Fig. 18 shows the plot of ratio of amplitude on H to D versus time of day. The plot showed that the ratio remained constant at about 2 throughout the day.

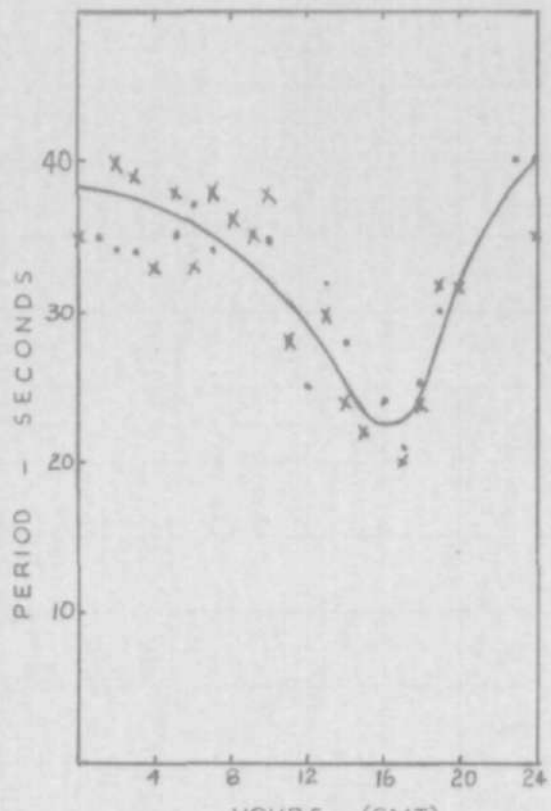
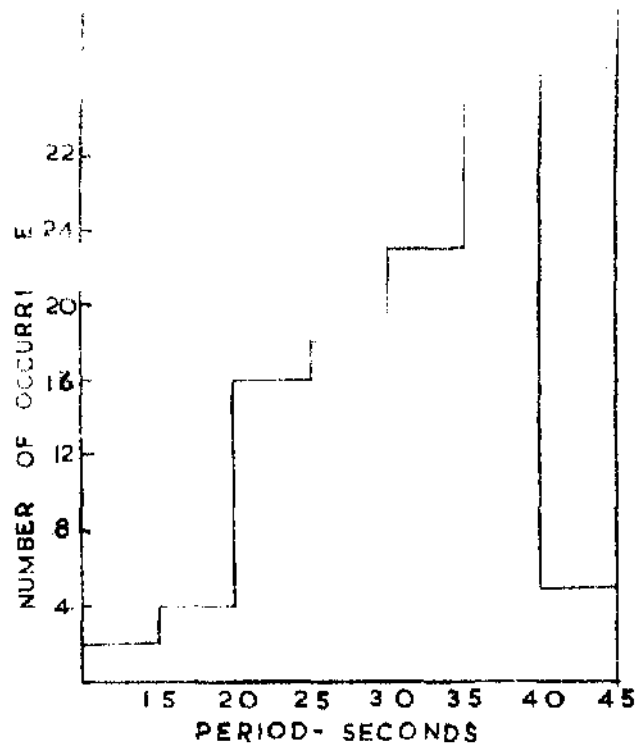


FIG. 15 Pc 3. DIURNAL VARIATION IN PERIOD. (JULY - AUG 1967)
.. H COMPONENT.
xx D COMPONENT.



D- COMPONENT

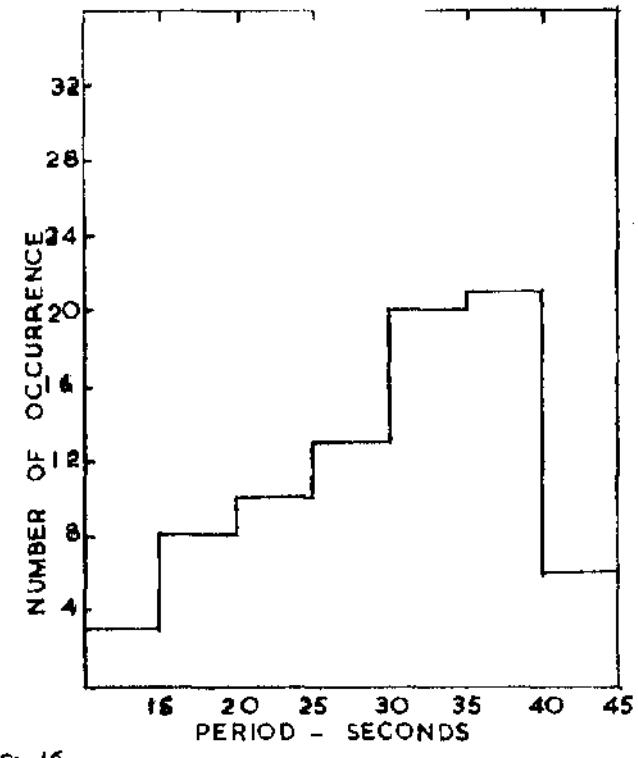


Fig 16. PC 3 PERIOD SPECTRA
(JULY– AUGUST 1967)

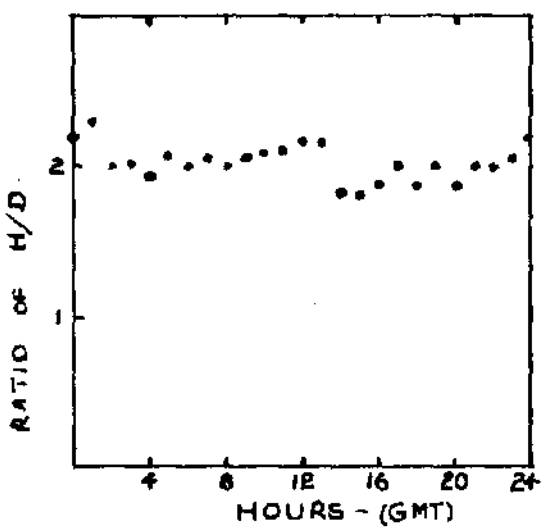


Fig 18 Pc3 AMPLITUDE RATIO
H/D VERSUS TIME OF DAY.
(JULY - AUG. 1967)

6.30 Pc4 MICROPULSATIONS

6.3.1 Diurnal variation in occurrence frequency.

Fig. 19 shows the plots of number of occurrences of pc4 micropulsations versus the time of day. It appeared that pc4 micropulsations occurred mainly during the day with peak occurrence at about 11 hours (L.T.). During the period of study, 142 cases of pc4 were detected in July and 91 cases in August while 152 cases were on H component with 81 cases on D component.

6.3.2 Diurnal variation in amplitude.

Plots of the amplitude of pc4 micropulsations versus time of day are shown on fig.20 for both H and D components. There was a clear diurnal variation in amplitude of pc4, with peak amplitude at about 11 hours (L.T.) on both components. The amplitude was bigger in size on H component than on D component by a factor of about 4. The mean peak amplitude on H was 0.88γ and on D 0.25γ .

6.3.3 Diurnal Variation in Energy.

Fig. 21 shows the graphs of energy of pc4 versus time of day for both H and D components. The diurnal variation in energy were similar to the diurnal variation in amplitude. The peak energy occurred at 12 hours local noon

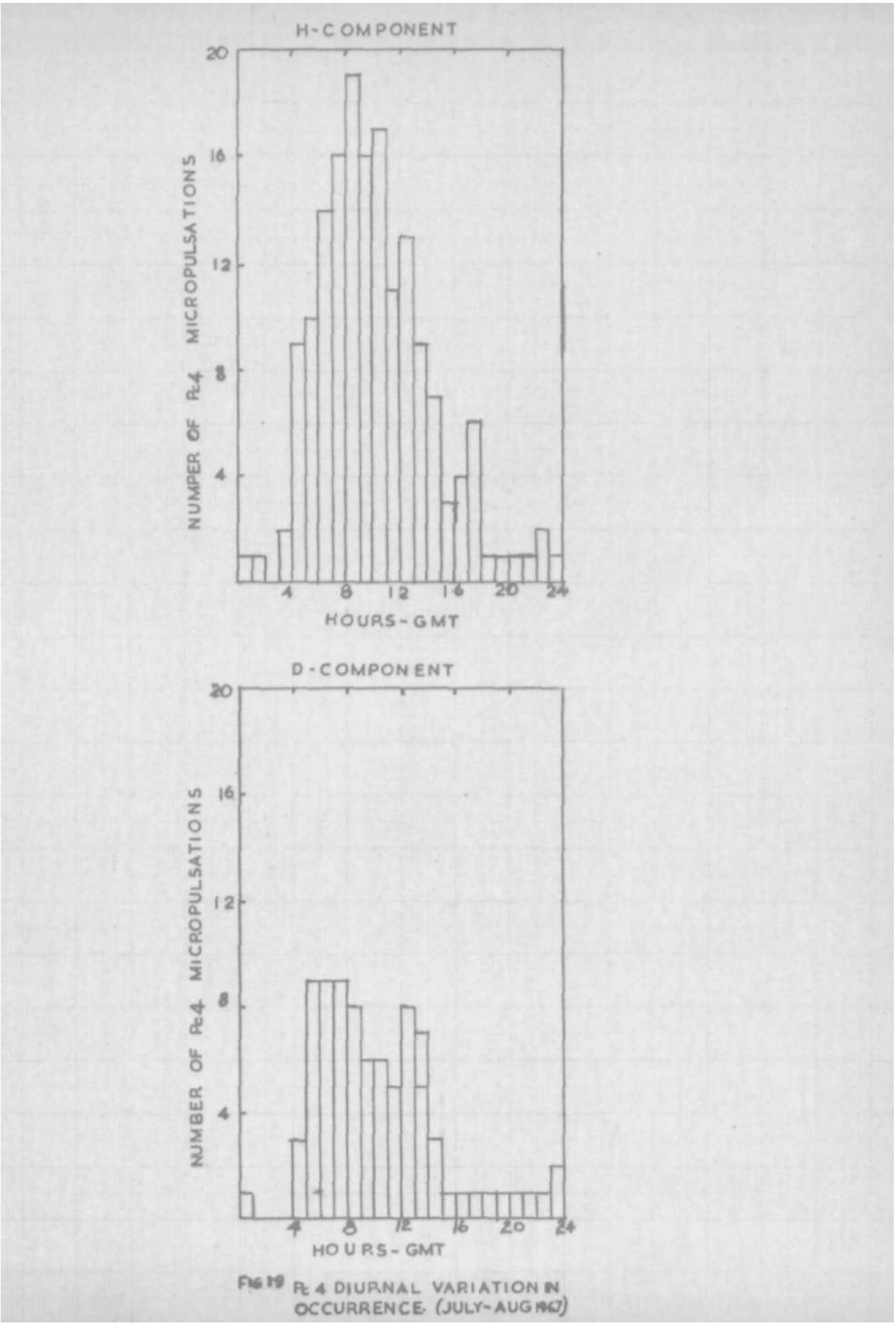


Fig 19 Pc 4 DIURNAL VARIATION IN OCCURRENCE (JULY-AUG 1967)

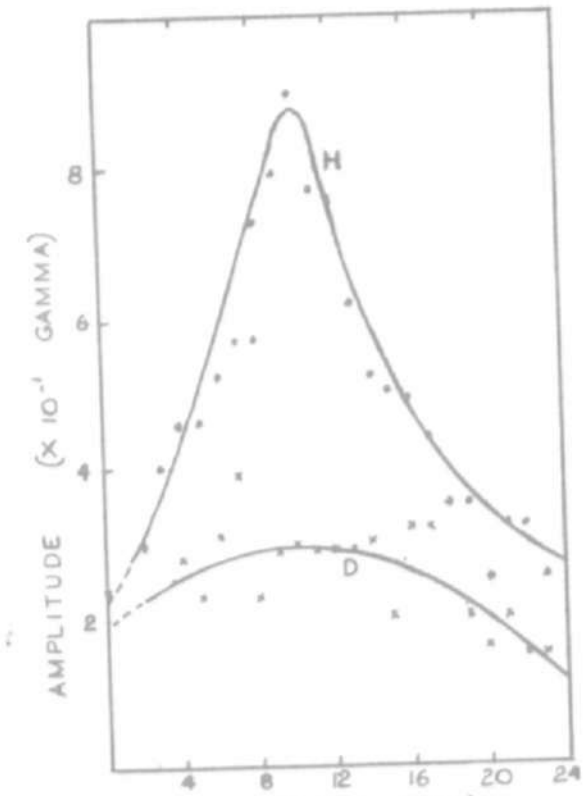


FIG-20 Pg 4 DIURNAL VARIATION IN AMPLITUDE. (JULY - AUG. 1967)

.. H COMPONENT

xx D COMPONENT

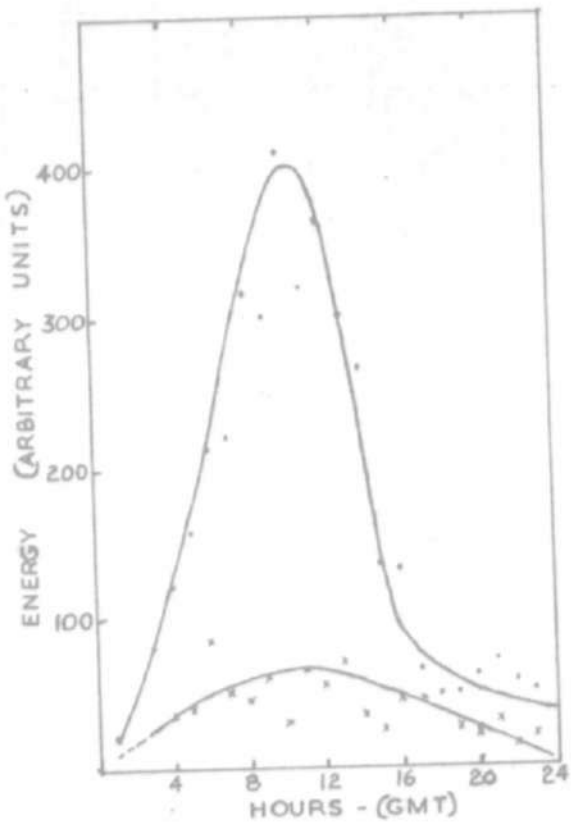


FIG 21. Pc 4 DIURNAL VARIATION IN ENERGY. (JULY - AUG. 1967).

.. H COMPONENT.

xx D COMPONENT.

as indicated on the graphs for both components.

6.3.4 Diurnal Variation in Period.

It was not necessary to plot graphs of periods versus time of day for pc4 as the variation was very irregular and it would not be possible to make any useful deductions.

6.3.5 Occurrence versus Periods.

The histograms on fig. 22 show the July - August pc4 period spectra on both H and D components. The spectral shapes on both components are similar with maximum occurrence frequency at (60 ± 5) sec. There appeared to be a minor peak in the region of (100 ± 5) sec.

6.3.6 Energy versus Period.

Fig.23 shows the graphs of energy versus period of pc4 on both H and D components. No consistent trend is visible.

6.3.7 Polarization of pc4 pulsations.

It was seen that the amplitudes of pc4 on H component were greater than those on D component and on many occasions when pc4 were detected on H, no simultaneous pc4 were seen on D. These facts might show that pc4 were linearly polarized in the north-south direction i.e. along the magnetic meridian. The ratio of amplitude of pc4 on H over D was plotted against the time of day as shown on fig. 24. The ratio varies with time of day and had peak near local noon indicating that pc4 had tendency to be strongly linearly polarized along the magnetic meridian during the day.

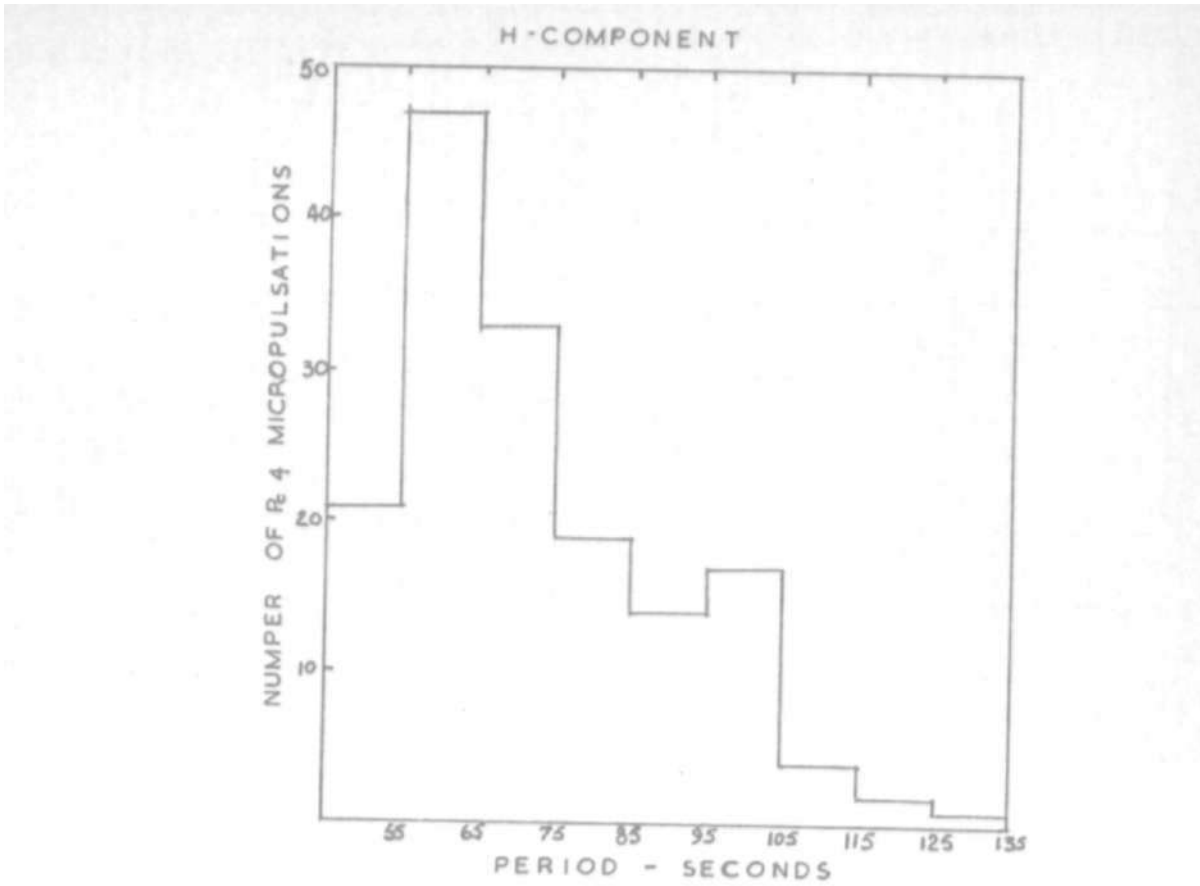


Fig 22 Pc 4 PERIOD SPECTRA (JULY-AUG 1967)

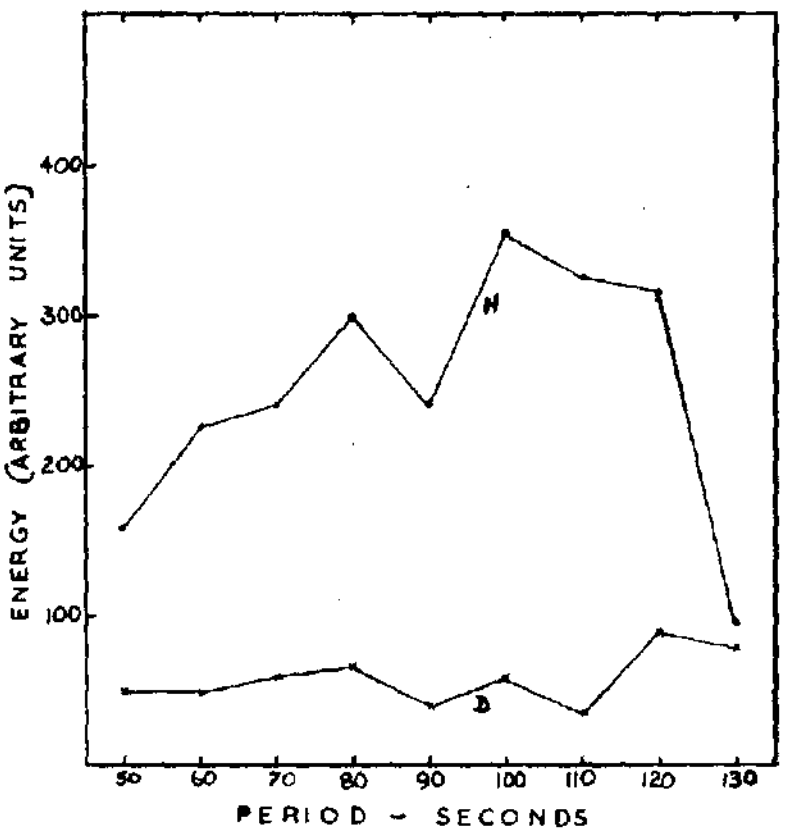


FIG 23.P.4 ENERGY VERSUS PERIOD.
(JULY - AUG. 1967)
.. H COMPONENT.
xx D COMPONENT.

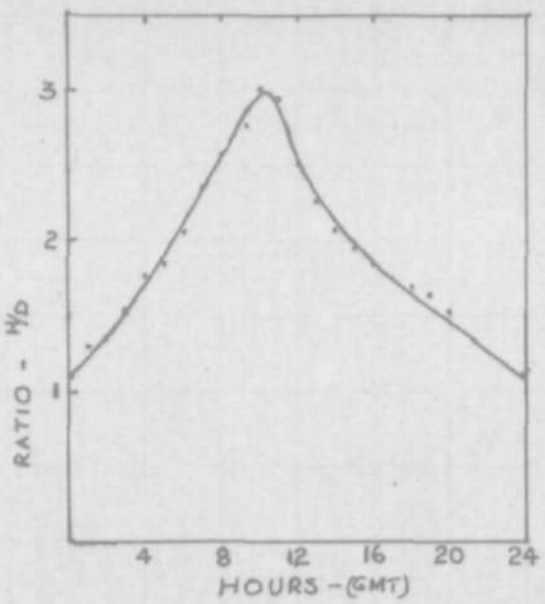


FIG 24. PL 4. AMPLITUDE RATIO H/D
VERSUS TIME OF DAY. (JULY-AUG. 1967)

6.4.0 Pi2 MICROPULSATIONS

6.4.1 Diurnal variation in occurrence freuqency.

Fig.25 shows the plots of occurrence frequency of pi2 versus time of day as detected on both H and D components. The plots indicate that pi2 occurred mainly during the night hours with peak occurrence between 22 and 23 hours (L.T.). During the period of study 97 cases of pi2 were detected in July and 134 cases in August. Of these 138 cases were recorded on H component and 73 cases on the D component.

6.4.2 Diurnal Variation in Amplitude.

Table 5.

Time (hrs.L.T.)	Mean Amplitude ($\times 10^{-1}\gamma$)	
	H	D
0-4	11.4	3.9
4-8	13.5	3.5
16.20	11.0	4.1
20.24	13.9	4.1

Table 5 above shows the variation of amplitude of pi2 with the time of day. The variation is not significant although it appeared that longer amplitude pulsations occurred near the mid-night. Amplitudes are greater on H than on D component by a factor of about 4. Peak amplitude on H was 1.8γ and on D 0.5γ.

6.4.3 Diurnal Variation in Period.

Table 6.

Time (hrs.L.T.)	Mean Period (Sec)	
	H	D
0-4	73	79
4-8	70	67
16-20	69	72
20-24	83	83

Table 6 above shows the variation of period of pi2 with time of day. It appeared that the longer period pi2 micropulsations occurred between 20 and 24 hours (L.T.)

6.4.4 Occurrence Versus Period.

Fig.26 shows the plots of number of pi2 micropulsations against the period. The histograms show that the region of maximum occurrence was in (60 $\pm$ 5) sec. on both H and D components.

6.4.5 Amplitude Versus Period.

Because of the short duration of pi2 trains and because of the definition of the energy used here ($E = CA^2$ where C is continuity in units of five seconds and A the amplitude in gamma) it was found more useful to plot the amplitude rather than the energy versus the periodic time. Fig 27 shows the plots for both H and D components. No consistent trend is visible.

6.4.6 Polarization of pi2.

It was found that the amplitudes of pi2 on H component were larger than those on D component. This might indicate a north-south polarization of pi2 micropulsations.

6.5.0 Sudden Commencements and Storm Time Pulsations.

A sudden commencement (Sc) occurred at 0557 (GMT) on the 11th of August 1967, as indicated on fig.28 on Zaria rapid-run magnetograms. The Sc was also clearly seen on M'Bour records and on the normal slow - run magnetograms at Zaria. Immediately after the Sc. and for some days after, it was noticed that the amplitude and continuity of the irregular perturbations were greatly enhanced. Also both the pc and pi micropulsations occurred more regularly, with larger amplitudes and continuity during the storm period. Table 7 is given for comparison of storm time pulsations with non-storm time ones for the month of August 1967.

Table 7

	5 storm days	26 non-storm days
Mean number of pc3 & 4 occurrences	10	6
Mean number of pi2 occurrences	6	5
Mean amplitude of pc3 and 4	0.46 gamma	0.15 gamma
Mean amplitude of pi2	0.54 gamma	0.31 gamma

It was also found that the periods of the pulsations were larger at storm times, as indicated in table 8.

Table 8.

Pulsations	Period (Storm time)	Period (non-storm time)
pc3	37 sec.	32 sec.
pc4	70 sec.	69 sec.

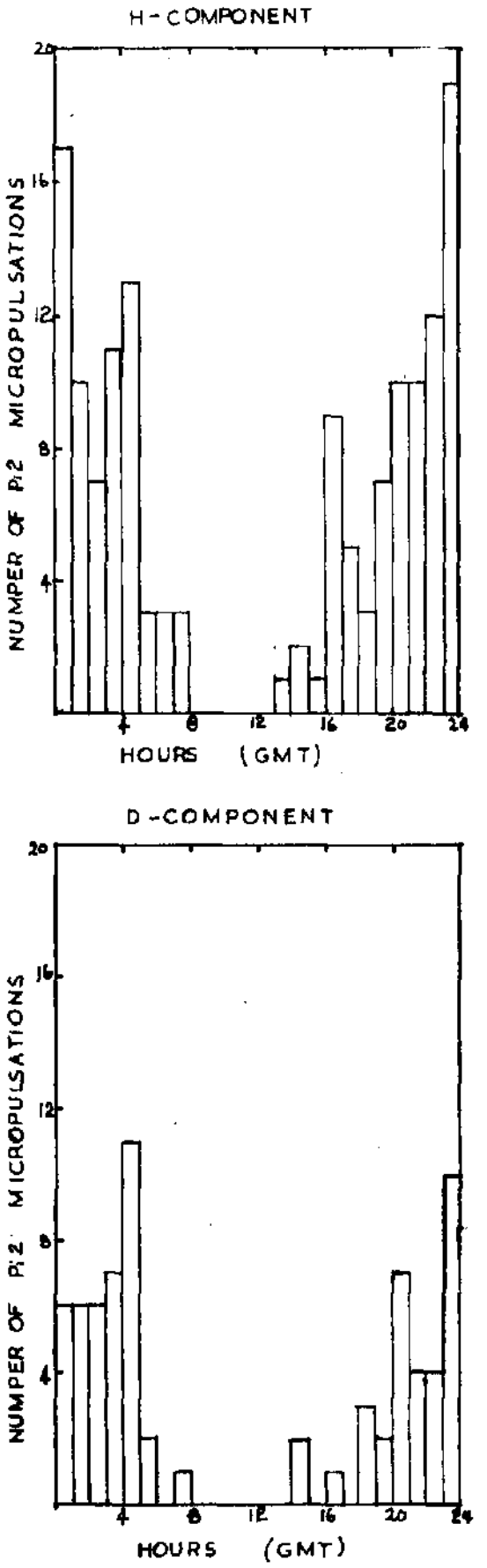


Fig 25 Pi 2 OCCURRENCE VERSUS TIME OF DAY. (JULY - AUG 1967)

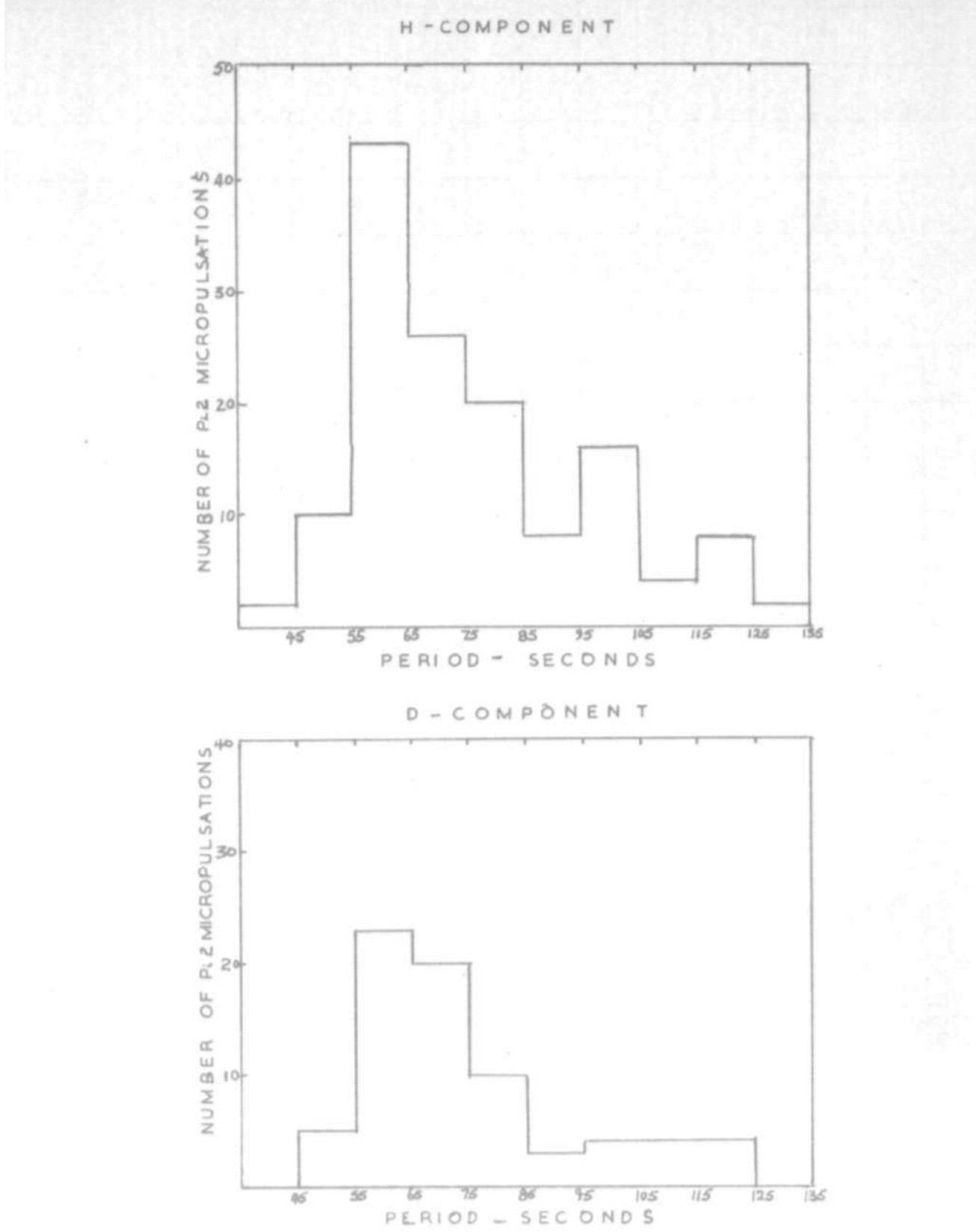


Fig 26 Pi 2 PERIOD SPECTRA (JULY-AUG. 1967)

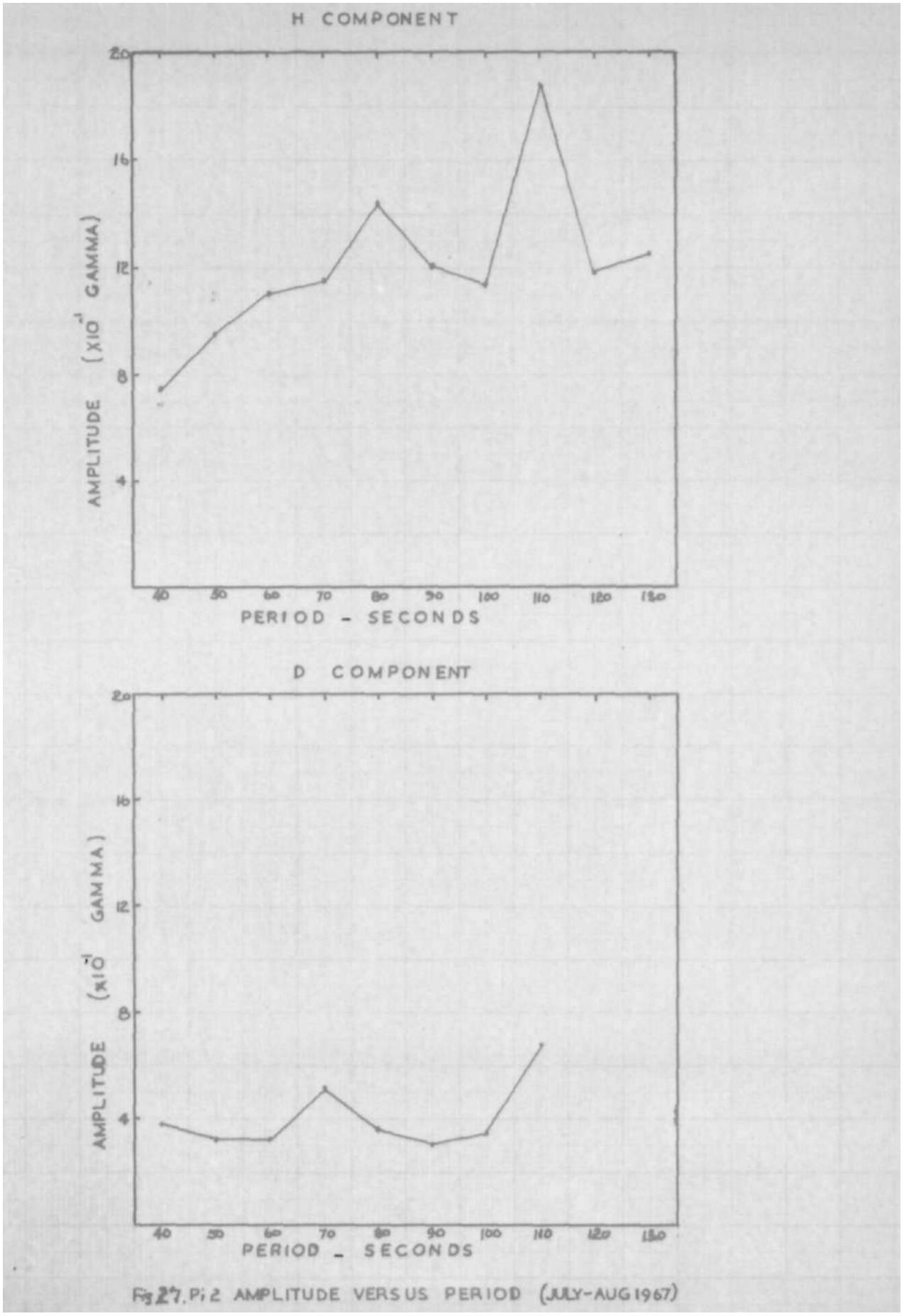


Fig 27. Pi 2 AMPLITUDE VERSUS PERIOD (JULY-AUG 1967)

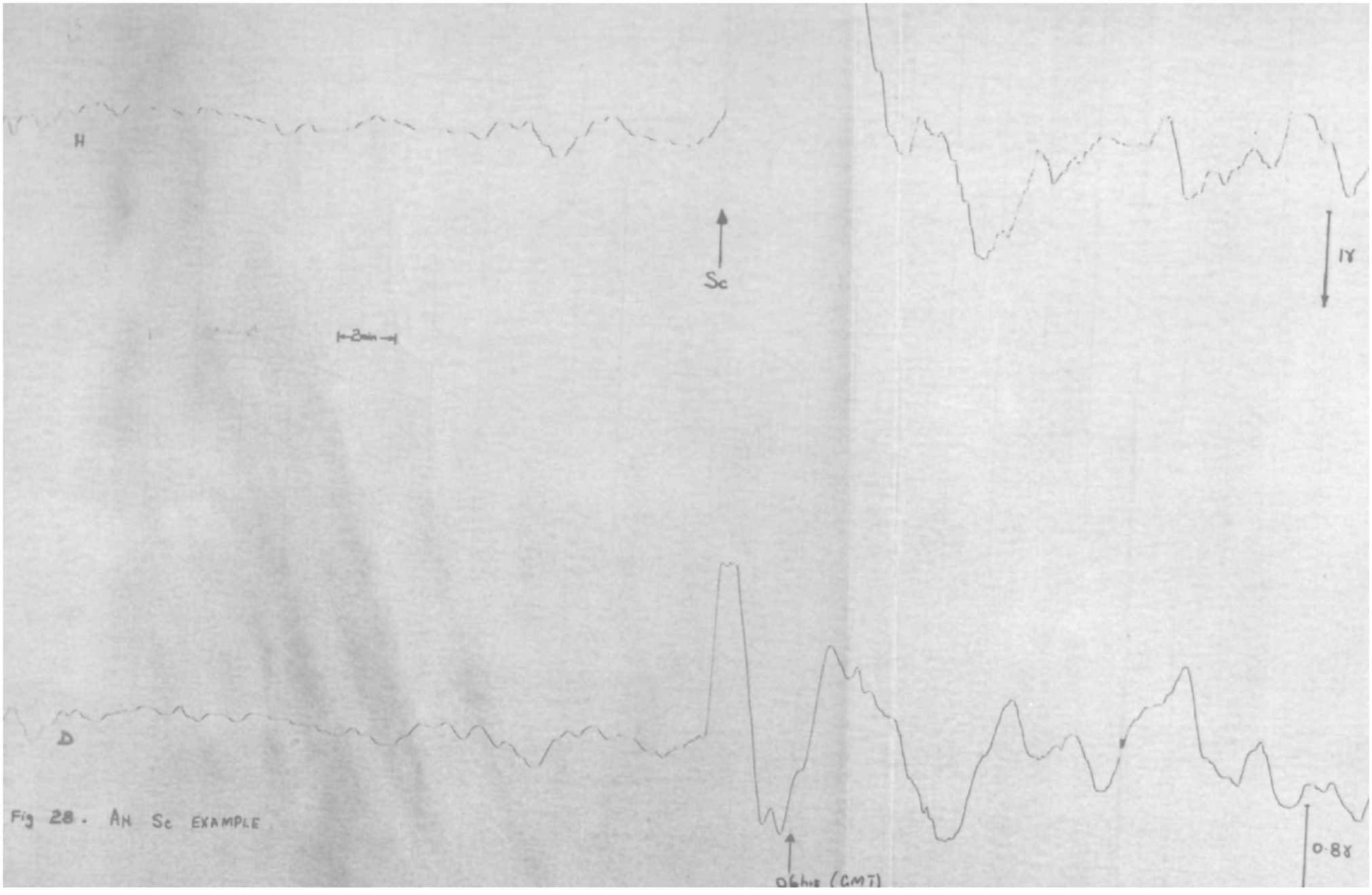


Fig 28. AH Sc EXAMPLE

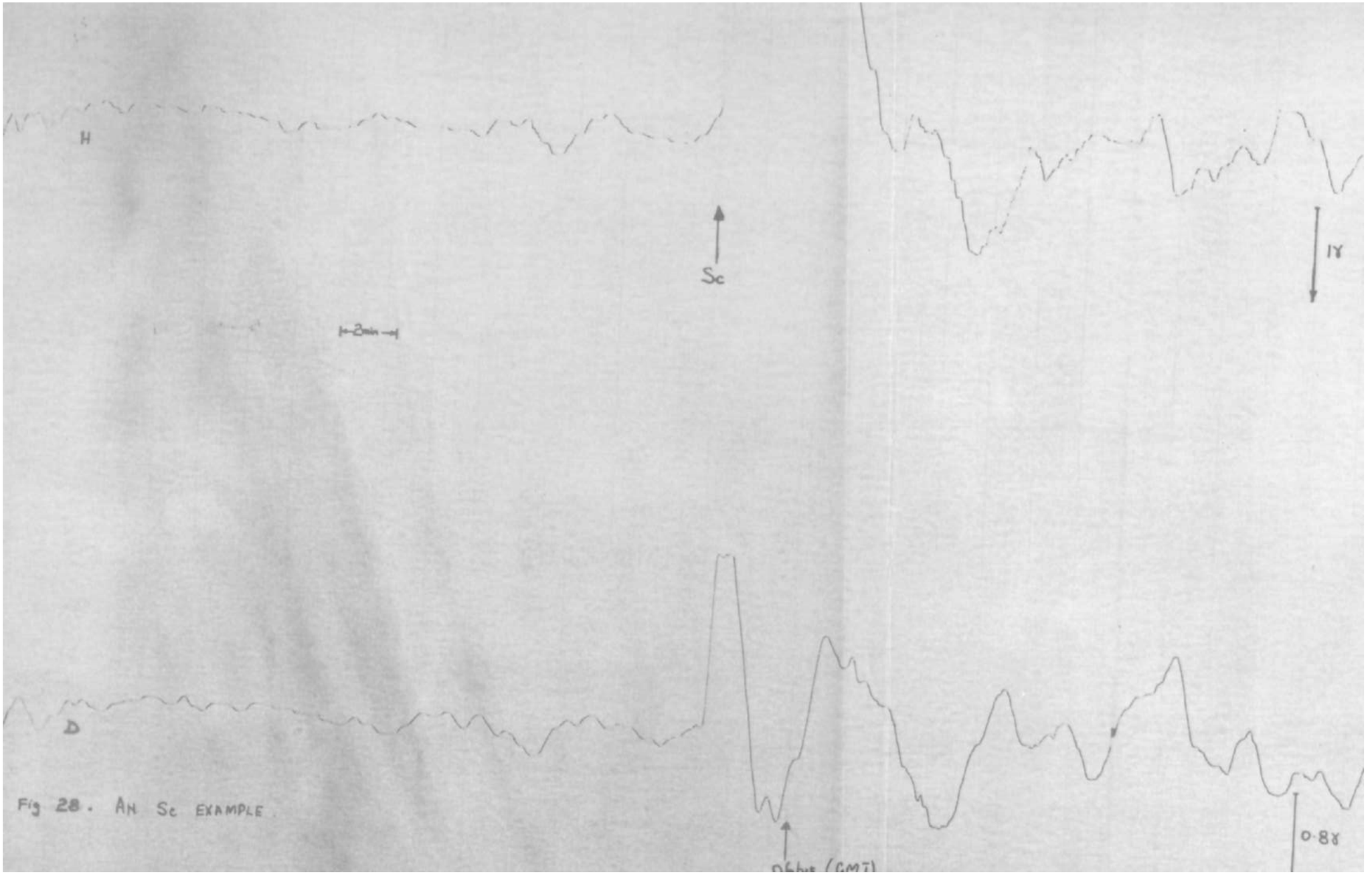


Fig 28. An Sc example.

7.0 PRINCIPAL CONCLUSIONS AND DISCUSSIONS

7.1 Some General Comments

The analysis is based on rather limited data, and hence, one must be careful as to the conclusions which can be drawn. Broad features are clearly evident and emphasis will be placed on them in the following discussion. The statistical sample is too small to make meaningful deductions about some of the detailed phenomena described in the previous chapter.

7.2 Principal conclusions

The main characteristics of pc 3, pc 4 and pi 2 band micropulsations observed at Zaria during the months of July and August, 1967 are as follows:-

1. Pc 3 micropulsation had a mean diurnal variation in occurrence frequency and amplitude. The occurrence frequency had a main peak around 06 hrs (L.T.) with a secondary minor peak in the evening. Peak amplitude occurred at about 09 hrs (L.T.). Roquet (1967) and Fernando (1966) gave similar results for equatorial stations. But Hutton (1961), Cardus (1962) and Romana (1962) observed greater evening peaks in occurrence frequency and amplitude during the IGY. Can these discrepancies be simply attributed to any error in the individual method of analysis? If they are real then there seems to be a strong solar

cycle effect on pc 3 micropulsations. These discrepancies can only be solved if the number of stations operating rapid-run observation are increased in the equatorial region so that research in the micropulsation band is carried out on a larger scale over many years.

2. Pc 4 micropulsation was essentially a daytime phenomena with peak occurrence frequency and amplitude just before local noon. Osborne and Rivers (1963), Fernando (1966), Glover (1963) and Roquet (1966) have given similar results for pc 4 in the equatorial stations. Workers in high and middle latitudes also gave similar results.

3. The pi 2 micropulsation was found to be essentially a night time phenomena with peak occurrence frequency between 22 and 23 hrs (L.T.). Other workers who have found similar results for pi 2 at the equatorial stations are Hutton (1965), Fernando (1966), Roquet (1966), Legeat (1967, private communication). Workers at high and middle latitudes also gave similar results for pi 2 (Campbell and Matsushita,

1962; Heacock and Hessler, 1962; Billaud, 1953; Kato et al, 1955; Benioff, 1960; Hirasawa, 1965; Romana and Cardus, 1962)

4. The amplitude of pc 3, pc 4 and pi 2 pulsations were larger in size on the H than on the D component and in general pulsations were more numerous on H than on D component. Saito (1964) and Roquet (1966) indicated similar results. These facts indicated that the pulsations were linearly polarized in the north - south direction i.e. along the magnetic meridian. Pc 4 tended to be strongly linearly polarized along the magnetic meridian near the local noon but pc 3 did not show such diurnal variation in polarization.

5. The pulsations studied were more numerous in the month of August than in July. This might indicate that equinocial months are more favourable than the June solstice.

6. The periods of pc 3, pc 4 and pi 2 showed a slight dependence on the time of day. Pc 3 had a U -type diurnal variation in period with shorter periods occurring during the afternoon hours.

7. During magnetic storms, micropulsation amplitude and frequency of occurrence were increased while

irregular perturbations were greatly enhanced in amplitude and occurrence. There was a slight increase in period of the pulsations at storm times.

8. The observed pc 3 and pc 4 micropulsation bands were mainly confined to periods lying between 20 and 80 seconds with dominant periods at (38 ± 3) sec. and (60 ± 5) sec. The dominant period of pi 2 was (60 ± 5) sec.
9. There was an exact coincidence of the fundamental components [(60. ± 5) sec] of pi 2 and pc 4.

The main results obtained are summarised in the following table 9 and these are compared with those previously obtained at the equatorial stations.

TABLE 9

Pc 3	Zaria 1967 results	Previous results
Time of maximum occurrence	Around 06 hrs (L.T.)	18 hrs (L.T) (Hutton 1960 during the IGY)
Maximum amplitude	0.50γ on H, 0.18γ on D	0.95γ on H, 0.15γ on D (Roquet, 1966), 0.5γ (Hutton, 1965)
Time of peak amplitude	09 hrs (L.T.)	During the morning hrs (Roquet, 1967)
Time of peak energy	06 hrs (L.T.)	---
Dominant period	(38 ± 3) sec.	(38 ± 5) sec (Fernando, 1966)

Table 9 (continued)

Pc 3	Zaria 1967 results	Previous results
Polarization	Linearly polarized along the magnetic meridian	Fernando (1966), Saito, (1964)
Pc 4		
Time of maximum occurrence	11 hrs (L.T.)	Near local noon (Hutton, 1965; Fernando 1966; Roquet, 1966; Glover, 1963; Heitzler 1966)
Maximum amplitude	1.5 γ on H, 0.58γ on D	1.4γ on H, 0.9 γ on D (Roquet, 1966)
Time of peak amplitude	11 hrs (L.T.)	Between 09 and 10 hrs (Roquet, 1966)
Time of peak energy	12 hrs (L.T.)	-
Dominant period	60 $\pm$ 5 sec.	(60 $\pm$ 5) sec (Fernando, 1966)
Polarization	Linearly polarized along the magnetic meridian	Fernando (1966), Saito, (1964)
Pi 2		
Time of maximum occurrence	Between 22 and 23 hrs (L.T.)	Between 22 and 23 hrs (L.T.) (Hutton, 1965) (Fernando, 1966) Near mid-night. (Roquet 1966.)
Maximum amplitude	1.4γ on H, 0.4γ on D	-
Dominant Period	(60 $\pm$ 5) sec.	(55 $\pm$ 10) sec. Fernando, (1960)

Table 9 (continued)

Pi 2		
Polarization	Linearly polarized along the magnetic meridian	Fernando (1965) Saito (1964)

7.3 Discussion

Hydromagnetic oscillations of the plasma in the atmosphere have been proposed to account for both pc and pi magnetic pulsations. There are two modes of propagation; the Alfven and the modified Alfven commonly known as left-hand and right modes respectively. The left-hand mode propagates along the field lines while the right-hand mode propagates isotropically.

The hydromagnetic model commonly considered is that of a standing left-hand mode oscillation of a whole line of force. It is exited by hydromagnetic disturbances due to solar wind interacting with the magnetosphere on the day light side of the earth (Jacobs and Watanabe, 1962). The line of force in the plasma is considered to act like a string under tension and the period of the fundamental wave is

$$\int_0^l \frac{2ds}{V(s)}$$

where l is the length of the field line and V(s) is the velocity at the line element ds

$$V(s) = H(s)\left[(\mu / P(s)\right]^{\frac{1}{2}}$$

where H(s) is the magnetic field intensity, μ is the permeability of the medium and P(s) is the mass density at s.

Jacobs and Watanabe (1964) considered another model in which they assumed a current vortex system where the hydromagnetic waves on the sun-earth line induces electrojets in the ionosphere at high latitudes. The oscillating charge then produced 'leaks' to lower latitudes to form an oscillating current vortex. The current system is fixed on the sun-earth line. Geomagnetic micropulsations, at least, in the high and middle latitudes are claimed to be due to such current systems.

A layered ionosphere model, based on rocket and satellite data, has been used by Jacobs and Watanabe (1962) and Prince and Bostick (1964) for theoretical calculations of wave transmissions. The right-hand mode is assumed to be dominant in the lower latitudes and the left-hand mode in the high latitudes. The resonance periods predicted by Prince and Bostick (1964) which are applicable to lower latitudes are shown in table 3.

Table 10 is given to indicate the comparison between the predicted resonances and the dominant periods of the pulsations studied in Zaria.

Table 10.

Predicted	Observed experimentally
70 sec. (Day)	(60 $\pm$ 5) sec. (Day)
45 sec. (Day)	(38 $\pm$ 3) sec. (Day)
60 sec. (Night)	(60 $\pm$ 5) sec. (Night)

This comparison shows that the agreement is quite good inspite of the uncertainties in the ionospheric parameters. This is an indication that the micropulsations detected at the equatorial stations originate, at least primarily, from the hydromagnetic waves propagated in the right-hand mode and at right angles to the field lines. The polarization of the micropulsation vector as observed is along the magnetic meridian and this too is consistent with such a mode of propagation.

Hirasawa (1965), Fernando (1966) and Saito (1967) have indicated the resemblance between the period spectra of pc 4 and pi 2 micropulsations. Saito (1967) inferred that it was quite possible that both pc 4 and pi 2 which he referred to as psc are caused by the same hydromagnetic resonance system involved in the earth's magnetosphere. It seems possible that at least part of pc 4 is a superposition of many damped oscillations like pi 2. The exact coincidence of the fundamental components of pc 4 and pi 2 micropulsations obtained at Zaria supports this inference. It seems likely that pc 4 and pi 2 arriving at the equatorial region are caused by the same phenomenon.

8.0 AN OUTLINE OF FURTHER RESEARCH

The study of micropulsations already carried out for the two months of July and August 1967 suggests the need for the work to be continued in the following main directions.

(1) The continuation of the Zaria recording to obtain a sufficiently long and complete set of data to facilitate detailed statistical study of micropulsation activity in the equatorial region.

(2) The establishment of a permanent earth-current recording system at Zaria so that the relation between the earth currents and the magnetic field can be determined.

(3) The establishment of micropulsation recording system at about three stations spaced in a north-south direction across the equatorial electrojet so that a study of the variation of micropulsation activity across the electrojet can be carried out. Stations such as Ibadan, Zaria and Sokoto would be some ideal ones in Nigeria.

(4) Any further study of micropulsation activity would also include the relationship of micropulsation parameters with ionospheric parameters and the Kp index, and the investigation of the polarization of the micropulsation vector which have not been carried out in the present study.

(5) Spectral analysis of semultaneous magnetic tape recordings.

(6) Adjustment of the frequency response of the installation to enable the study of shorter period phenomena - pc2, pc1 and pi1.

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