AN ANALYSIS OF SHORT PERIOD (10 - 30 SECONDS) GEOMAGNETIC MICROPULSATIONS

by

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ABSTRACT

Geomagnetic micropulsations are described and possible origins discussed. Previous work in Canada is reviewed with particular attention to the normal daytime Pc oscillations with periods from 10 - 30 seconds. A description is given of the work done correlating the amplitude and direction of the exciting vector at two stations.

Field work at Ralston, Alberta during July - August 1959 is described in detail. A digital computer is used to obtain the auto-correlation coefficient and the covariance of the horizontal components of the vector. From these two paramenters the dominant frequency, amplitude, and polorization of the vector are obtained.

The conclusion is reached that normal daytime Pc's seem to occur in a small band centred around a dominant frequency. Two such dominant frequencies may occur simultaneously and the vectors can have different polarization. The amplitude and direction of a given Pc seems to follow a closed diurnal pattern reaching a maximum slightly before local noon.

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CHAPTER I

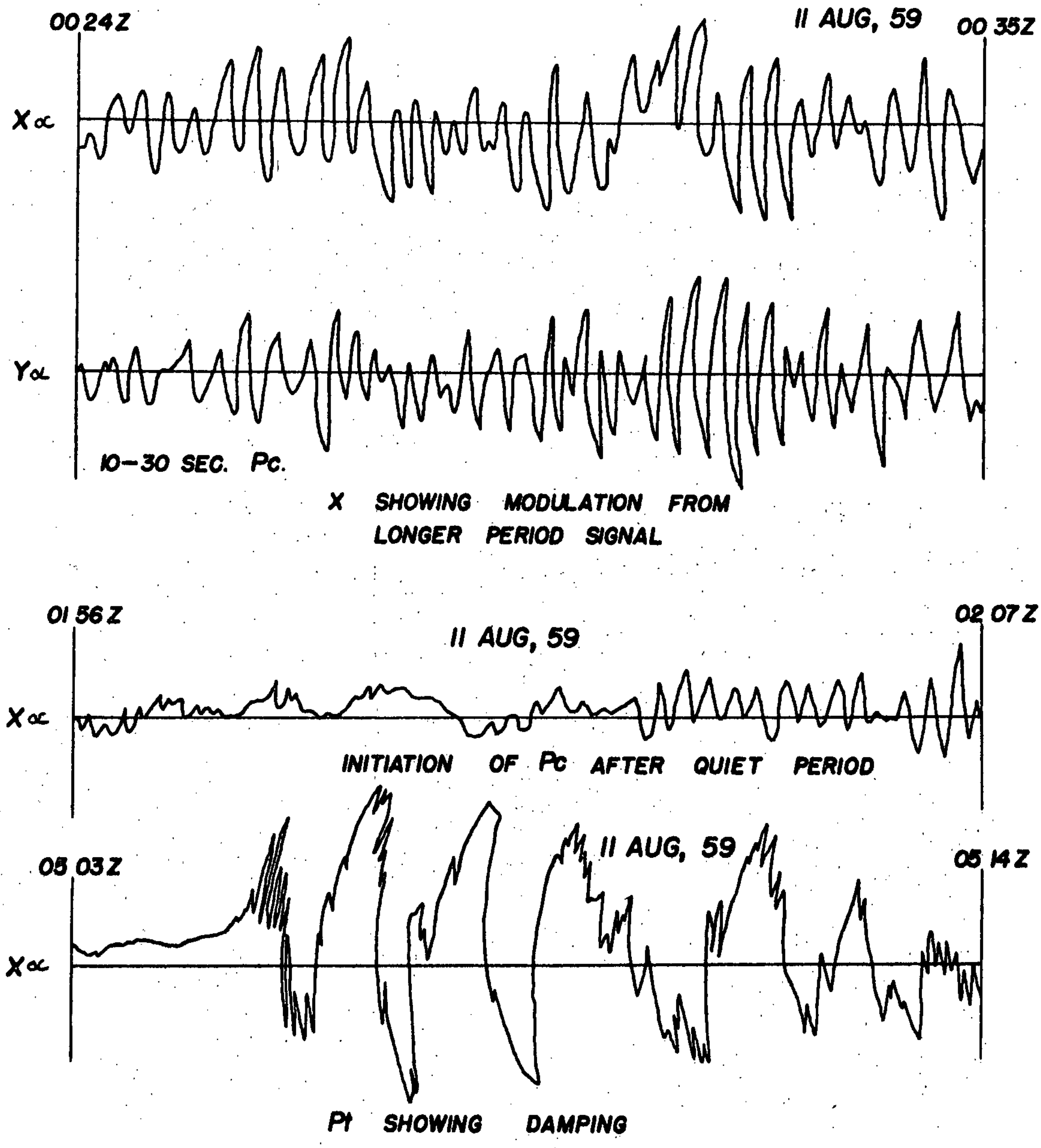
INTRODUCTION

Morphology of Geomagnetic Micropulsations

Geomagnetic micropulsations are small scale periodic changes in the earth's magnetic field. The amplitudes of these fluctuations have an order of magnitude of 0.1γ to, on occasion, as much as 20 or 30γ (1γ = 1 gamma = 10^{-5} oersted). They occur throughout a frequency range of from about .001 cps up to about several cps. Such micropulsations have been known since 1861 and some observational studies were made during the first half of this century, although most experimental and theoretical work has been carried out during the past ten years.

Micropulsations have been broadly classified into three groups but recent data obtained during the I.G.Y. (Jacobs 1960) indicate that these classifications are too general and further sub-classifications possibly using different criteria than in the past, may be necessary. These three types of micropulsations are Pc's (pulsations continuel), Pt's (trains de pulsations), and Pg's (giant pulsations). In addition to any observed signal there is always a general background made up, partly of instrumental noise, partly of induced power frequency sub-harmonics, and partly of very low amplitude Pc's. When discussing a particular frequency especially towards the higher end of the frequency spectrum it is well to remember that a signal is not usually made up of the one

FIG. 1 TYPICAL SIGNAL
BASE STATION RALSTON, ALTA



discrete frequency but of a small band centred around this dominant frequency.

Pc's as their name suggests are continuous wave trains with amplitudes a few tenths of a γ and periods from about ten seconds to under a minute. They occur most frequently during daylight hours particularily during the late morning and a series of Pc's may cover a time period lasting several hours. (See figure 1)

Pt's usually occur as a series of oscillations and appear to be well damped with larger amplitudes and longer periods than Pc's. They appear in groups at night with a total duration of from ten minutes to less than an hour. Amplitudes are around one half gamma and periods of the order forty seconds to several minutes. (See figure 1).

Pg's are series of regular pulsations with large amplitudes up to tens of gammas and periods of a few minutes occurring only in the auroral zones.

The pulsations described cover the frequency spectrum up to 0.1 cps. From 0.1 to 10 cps the observed pulsations are in general very weak although there are characteristic trains of oscillations, which have been called "Pearls" by Troitskaya (1957). Still higher frequencies are caused for the most part by lightning discharges (Goldberg 1956) or arise from man-made background of electromagnetic radiation.

Despite the large amount of recent work on micropulsations it is difficult to draw more than very general conclusions about such properties as frequency of occurrence, diurnal and seasonal variation, latitude dependance, and whether the incidence of a given pulsation is local or widespread. Often the experimental data reported by different observers is contradictory or seems to fit no regular pattern. Among the possible reasons for this is the use of instruments with different sensitivities, and recording for periods of too short a duration.

Another difficulty is the choice of method for analysis of data and choice of criteria for differentiating between the different types of micropulsations. In this respect it now appears likely that Pg's can be divided into two groups depending on the wave form and time of maximum frequency of occurrence. Also a group of Russian investigators (Jacobs 1960) suggest the division of Pc's into three groups with periods in the range from 5 - 15 seconds, 20 - 40 seconds, and 50 - 90 seconds.

Origin of Micropulsations

There is little doubt that the source of the disturbance which causes micropulsations is either in the earth's ionosphere, in the outer atmosphere extending out to several earth radii, or in both depending on the type of pulsation. It is also generally accepted that these variations are due to a flux of solar particles, probably ionized hydrogen, which are incident upon the earth's atmosphere either in the form of an ionized cloud or as a steady jet whose intensity and velocity depend on the state of the sun's corona. Apart from these rather general ideas, there are several conflicting theories dealing with the exact cause of the micropulsations themselves.

Bennett and Hulburt (1954) have suggested that these streams of protons from the sun undergo magnetic self-focusing and spiral in towards the earth along the magnetic lines of force causing the aurora when stopped by collisions with the heavier gas molecules. Micropulsations might be caused by ionized particles following orbits in the earths magnetic field.

If an ionized cloud of solar origin enters the earths upper atmosphere then it is possible that hydromagnetic oscillations would be excited and Alfvén waves propogated along the magnetic lines of force causing micropulsations with periods comparable to those of Pt - type oscillations. Calculations based on observed data and assuming that the micropulsations are caused by Alfvén waves (Obayaski and Jacobs 1958) gives ion densities for the outer atmosphere comparable with figures obtained from other sources.

Giant pulsations may be caused by torsional oscillations in the outer atmosphere (Kato and Akasofu 1956, Kato and Watanabe 1957) and Pc's by poloidal oscillations. Pc's would then be initiated in the sunlit part of the ionosphere by turbulent shock waves from the sun's corona.

There is however some experimental data (Duffus and Shand 1958) which shows that Pc's and Pt's are often not continent-wide in occurrence, and even when widespread are often out of phase. This would not seem to favour the poloidal oscillation theory of the Japanese investigators.

CHAPTER II

PREVIOUS INVESTIGATIONS IN CANADA

Defence Research Board

A group from the Pacific Naval Laboratory (P.N.L.) at Esquimalt B.C. have been recording Pc's and Pt's since 1954. Most of their experimental work has been carried on at Albert Head, a station on the coast near Victoria, although data has also been recorded by a mobile station at various inland locations. Whenever the mobile station was operated, the base station at Albert Head recorded as well for comparison. Measurements were made of the three components X, Y, and Z where X (geographical north), and Y (east) are the components of the horizontal field H and Z is the vertical component (positive downwards).

Duffus and Shand (1958) obtained micropulsation records at Albert Head in the frequency range .001 to .1 cps on 150 days between 1954 and 1957. The magnitude and direction of the micropulsations were noted and interpretations made of the diurnal variation, the direction of the exciting vector, and its geographical distribution. The results were compared with data published by other investigators in different parts of the world (Chernosky et al 1954, Holmberg 1953, Troitskaya 1955).

Duffus and Shand found a trend for increasing amplitude with increasing period and found that the probability of occurrence depended both on frequency (and hence also on amplitude) and on L.M.T. The diurnal variations showed only general trends and often the results conflicted with those from other investigators. This is partly due to insufficient data but also, to a large extent, to different detection and amplification equipment. Often equipment will tend to discriminate against certain frequencies in favour of others or have directional characteristics thus giving incomplete results. There is also the problem of interpreting data obtained in different geographical locations particularily in different latitudes. Despite these difficulties a general peak in the Pc activity was found slightly before local noon and a peak in Pt activity before local midnight. The quietest time was from 1800 to 2200 L.M.T.

Most of the pulsations had phase differences between two or all three of the components. The general trend was for X and Z to be in phase while Y led or lagged. This was not in accord with earlier work in Japan (Terada 1917) where the horizontal components were in phase and Z lagged. The data for signals which were in phase gave a rather wide scatter for the direction of the vector as a function of frequency. There was slightly less scatter in both the azimuth and the inclination for the very low frequency end of the spectrum. It was noticeable that the greater the azimuth the greater was the angle of inclination. Inclinations ranged from 10° to 70° and azimuths from 260° to 20° true.

Little correlation was found between the vertical components at Albert Head and Halifax Nova Scotia where some data had been recorded with identical equipment. The signals were usually different in frequency and phase. When similar pulsations did occur they seemed to be either exactly in phase or 180° out of phase with some evidence of a diurnal variation. This conflicts with some observations indicating that initiation is world-wide (Troitskaya 1955).

Because of the often contradictory data from records at widely separated stations the group at P.N.L. subsequently decided to investigate short range geographical variations in micropulsations. Simultaneous records were made at two stations, the base station at Albert Head and the mobile field station which occupied various locations between May 1958 and February 1959.

Observations were initially restricted to the frequency band between 0.001 and 0.1 cps which was later extended to include frequencies up to 1 cps. Measurements were made of the three components X, Y, and Z, and analysis was by visual inspection of the amplitudes and periods on strip-chart recordings. No attempt was made to determine phase relationships. There was a selective choice of data for analysis and signals with phase differences between components of $\pi/4$ or more were not processed.

The first field station was at Bear Creek some 25 miles from Albert Head and twelve miles from the sea.

Duffus et al (1959) found that for periods under two minutes the X component at Bear Creek was as much as 50 per cent larger than X at Albert Head while the Y and in particular the Z component at Bear Creek became smaller with increasing frequency. If the amplitudes of the three components are summed vectorially the "total pulsating vector" is obtained. The amplitude of the total pulsating vector at Bear Creek was less than that at Albert Head for periods under 50 seconds but greater for periods over 100 seconds.

Thus the vector at the station by the sea had a much greater inclination and its azimuth was more westerly than that at the inland station. Also with increasing frequency the amplitude by the sea became greater than the amplitude inland. It seems probable that these effects are due to the higher electrical conductivity of the sea.

The second field station was set up at Summerland B.C. 250 miles from Albert Head and 185 miles from the sea. Records from Summerland differed from those at Albert Head much more than those at Bear Creek (Shand et al 1959). There were still however many similarities and corresponding sections of the records could be compared.

The X and Y components at Summerland were similar to those at Albert Head except that amplitudes at Summerland averaged 50 per cent higher. The Z component at Summerland was very different in appearance and had a much smaller amplitude. At Summerland the inclination was much less and the azimuth slightly more northerly than at Albert Head. The amplitude for the total vector was about the same at each station.

A third field station was established at Ralston, Alberta 515 miles from Albert Head and 470 miles from the sea. The number of record sections which could be compared was relatively few although the onset and disappearance of bursts of activity appeared simultaneously and the envelopes of a series of pulsations were similar at the two stations.

The X components were similar in appearance with the amplitude at Ralston usually about double that at Ablert Head. The Y components were only seldom similar although again the signal at Ralston was usually double that at Albert Head. The Zcomponents were dissimilar with a much lower amplitude at Ralston, particularily at the higher frequencies. The azimuth was a little more northerly at Ralston than at Albert Head and the inclination much less -- even less than that at Summerland. The mean amplitude of the total vector at Ralston was 50 per cent greater than at Albert Head.

When trains of Pc activity were compared between Ralston and Albert Head they almost always occurred simultaneously despite a difference in longitude of 13°. There was also no indication of any diurnal variation in the amplitude of the total vector at Ralston as compared to Albert Head.

The fourth and last field station in this series was established at Borrego Springs, California, 960 miles from Albert Head and only 70 miles from the sea. The signal at Borrego, the lower latitude station, was simpler in form to that at Albert Head and the X and Y components showed fewer phase differences. Individual pulsations at the two stations were seldom similar but again the envelopes of series of pulsations were very similar.

The amplitudes of the X and Y components at Borrego averaged 3/4 those at Albert Head. The Z component at Borrego was much smaller than that at Albert Head. There were large and frequent changes in azimuth at Borrego - the preferred direction of the total vector was northeast with a slight inclination.

Summarizing the data from the four field stations and the base station at Albert Head, it seems feasible to divide the signal into three bands with periods in the ranges 1 - 8, 10 - 30, and above 40 seconds. The lower limit of 1 second is an instrumental limitation. The group above 40 seconds would include Pt's. The group from 10 - 30 seconds occurred most regularily and included Pc's recognized as the normal daytime signal. Almost without exception this group occurred simultaneously at both the field station and at Albert Head. The total vector for this middle group of Pc's maintained a preference for direction, time of day, and amplitude at the field station different to that at Albert Head.

Total Pc activity does not appear to be related solely to L.M.T., despite the preference for daytime of the 10 - 30 second group. The station at Ralston which was closest to the auroral zone and furthest inland, and situated in the most uniform topography had the smallest Z component and the largest amplitude of the total vector. The station at Borrego furthest from the auroral zone had the smallest amplitude for the total vector and was the only station with a noticeably different azimuth. The station at Albert Head by the sea and also in non-uniform topography had the largest Z component.

Subsequent Investigations by P.N.L.

Continuation of the research into short range geographical variations of the character of micropulsations has been carried out by P.N.L. It was suspected that earth currents (Cagniard 1960) accompanying Pc's and Pt's might affect the amplitude, direction, and even phase of the magnetic vector. This would be particularily true for a station by the sea or in mountainous terrain and it was decided to correlate data from two stations over a magnetically homogeneous area. The site chosen was near Ralston in eastern Alberta. This thesis is mainly concerned with the analysis of some of the data obtained on this investigation.

Records were made of the three components X, Y, and Z over the frequency range .01 to 30 cps. A permanent base station was established and a mobile field station in a truck set up at gradually increasing distances. Both stations operated simultaneously with the signal from the field station multiplexed over telephone line using several carrier frequencies and recorded beside that from the base station. Simultaneous records were also made of variations in the magnetic field and in the associated earth currents.

University of British Columbia

Analysis of data obtained during the I.G.Y. by stations throughout the world has been carried out during the past year. Results to date (Jacobs and Sinno 1960) indicate that the frequency of occurrence of Pc's increases with latitude as the auroral zones are approached. A definite solar time dependance for the frequency of occurrence was found with the maximum changing from early afternoon to late morning with increasing latitude. Observations at the same geomagnetic latitude showed both a local and a universal time dependance. The time of maximum occurrence of Pc's was about 21 hours G.M.T. in the northern hemisphere. The universal time factor was found to affect the modulation of the diurnal occurrency by about 50 per cent.

CHAPTER III

FIELD WORK, RALSTON ALBERTA, 1 JULY - 15 AUGUST 1959

Equipment

The detectors for the X and Y components of the magnetic field were mumetal cored solenoids 5' in length and 5" in diameter. These solenoids had 35,000 turns of copper wire and a d.c. resistance of 250 ohms. The detector for the Z component was a 20' diameter air cored shielded coil. This coil had 1100 turns of No.21 "Formel" covered copper wire. For higher frequencies of 1/3 - 1/30 cps the detectors for all three components were anhyster cored coils using "Kronhite" filters. All detectors were levelled and lightly buried when in use with the horizontal component detectors aligned geographically north-south and east-west.

The signals from the detectors were fed to a junction box by buried cable and from there by shielded cable to d.c. chopper amplifiers. The amplifier outputs drove Esterline-Angus strip-chart pen recorders at a speed of 3/4" per minute. When desired the output from the amplifiers could also be fed in parallel into a 6 channel Brush strip-chart recorder and into a 7 channel Ampex F.R.1100 F.M. tape recorder. Amplification could be varied although it was always necessary to give the Z component four times the amplification given to the horizontal components.

Detectors, amplifiers, and recorders were duplicated at the mobile station except the 6 channel Brush and 7

FIGURE 2 (b) BLOCK DIAGRAM STATION β

RALSTON, ALBERTA 27 JULY 59

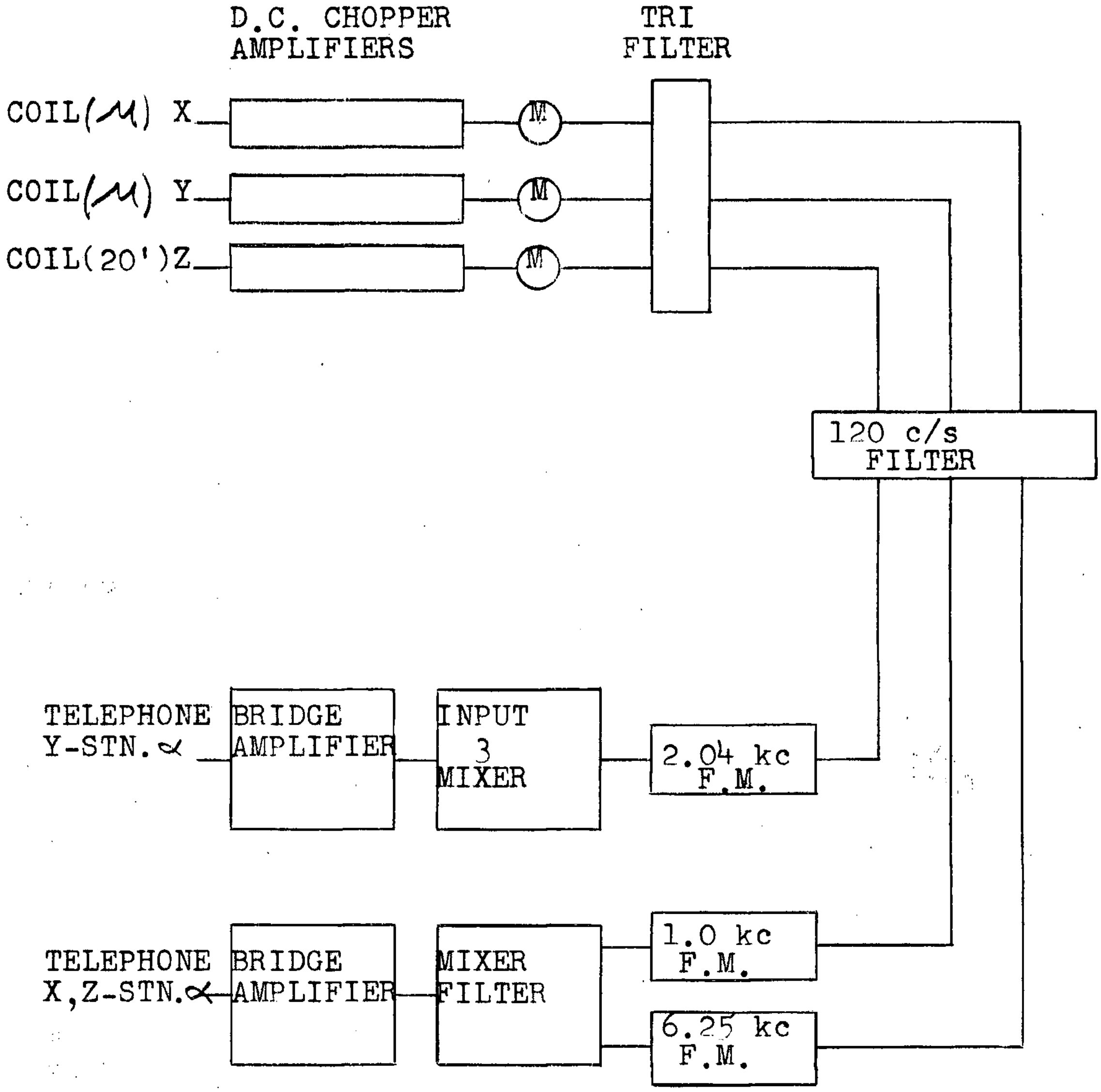
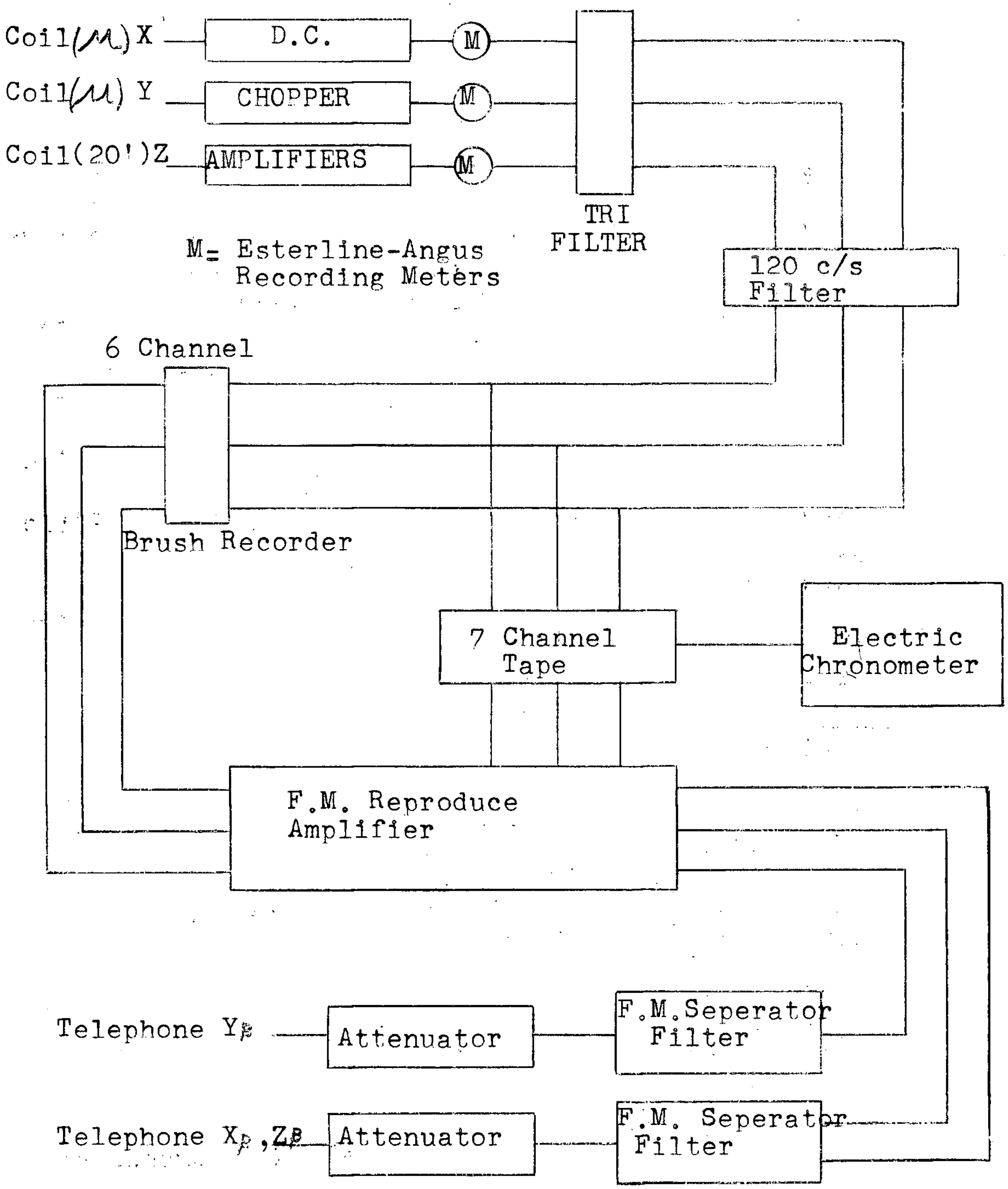


FIGURE 2 (a) BLOCK DIAGRAM STATION α

RALSTON, ALBERTA 27 JULY 59



channel tape recorder. In addition the mobile station had filtering, amplifying, and frequency modulating equipment for multiplexing the signal over two telephone lines to the base station where it was demodulated and fed to the Brush recorder and tape recorder. (See figure 2).

The detectors for earth currents were copper rods driven into moist ground and connected by thin copper leads. One rod was driven in at the station, another 500' to the south, and the third 500' to the east and changes in potential measured. The signals were usually measured on a Texas Instruments recorder and occasionally on the 6 channel Brush.

For daily calibration each mumetal detector (horizontal) components) had a single coil around it and the 20' vertical component detectors had a 200 turn coil placed centrally within. An a.c. current of .81 m.a. at .067 cps could be passed in series through the complete detector system including that at the mobile station. Such a current would induce a signal with a peak to peak amplitude corresponding to a field change of 1 γ at the horizontal component detectors and of 1/4 γ at the vertical component detectors.

Major calibration of the detectors was carried out by placing one of the 20' vertical component detectors around the centre of a circle formed by an outer calibration coil of 120' diameter. An inner one foot diameter calibrated search coil was placed at the centre of the circle. The current through the outer calibration coil which induced a signal corresponding to a known field change at the inner calibration coil was recorded as was the amplitude of the signal on the 20' vertical component detector. Calibration of the horizontal component detectors was done by burying them vertically at the centre of the circle and noting the amplitude of the signal induced by passing the recorded current through the outer calibration coil.

Station Locations

The base station was at site α(50° 16.5'N, 111° 08'W) and the mobile station moved in turn to three sites at β(50° 18.5'N, 111° 08'W), γ(50° 22'N, 111° 08.5'W), and ϵ(50° 30.5'N, 110° 46'W). Station β was 2 miles north, station γ 5½ miles north, and station ϵ 25 miles north-east of the base station at α. The geology of the area was uniform with little topographic relief. Sediments of uniform thickness lie above the gently sloping pre-cambrian basement at a depth of 6000 feet.

The base station at α was 2 miles from Ralston and 1 mile from a travelled road. The site was level with a power line running east-west 400 yards to the north where it was joined by the line supplying the station power. Sites for the mobile station were well clear of any interference except that site β was only 100 yards from a travelled road. Power for the mobile station was supplied by a gas engine driven 60 cycle generator operated 50 yards from the station and in the opposite direction to the detectors. Detectors at both the base and mobile stations were on level ground at a distance of about 100 yards.

Field Work History

During the first two weeks of July, the base station was set up at site α, and major calibration of equipment carried out. Another ten days were required to set up the mobile station at site β, connect it by telephone line to the base at site α, and to adjust the amplifying and recording equipment. By the end of July records were being taken at both stations and were also being multiplexed over telephone wire from station β to station α where the three components from each station were recorded simultaneously on magnetic tape and on the 6 channel Brush.

One of the main problems was correct timing of the records both for absolute time and for comparison of the signals between two stations. For the main station at site α the frequency regulation of the local power system was deemed adequate if occassionally checked by radio signals and a chronometer. The chronometer was wired to place a time signal on the 7 channel magnetic tape. For the mobile station frequent time signals were obtained by radio and the strip-chart records marked. A chronometer was used during periods of radio blackout. When required the speed of the engine driving the field generator could be varied. Despite all efforts there was a possible error of several seconds between individual records of the base and mobile stations. Of course this relative time error did not apply for signals multiplexed over the telephone wire.

Another difficulty was that special pre-amplifiers had to be used for recording signals around 1 - 3 cps. For still higher frequencies of 3 - 30 cps the anhyster rod detectors were required. This meant that when frequencies above 1 cps were recorded the broad band from .001 - 1 cps was not received. Also there were frequent errors caused by the reversal of terminals as the components at one station could be given a 180° phase shift relative either to each other or to the other station. There were even times when the signal from a given detector was fed to the wrong strip-chart record and then incorrectly labelled.

To minimize this type of error a coil and battery could be placed beside each detector in turn and a positive signal induced. Observation of the individual strip-chart records would not only confirm which component was being measured but would indicate whether the signal was in phase or 180° out of phase relative to the other components. Another check was the calibration which was carried out daily during the quiet period in the early evening unless the signal was too large for such calibration to be feasible. The calibration signal with a peak to peak amplitude corresponding to 1 γ for the horizontal components and 1/4 γ for the Z component could then be measured on the individual records giving the scale constant for that component.

Earth current records were made either at the base station or at the mobile station except on a few short occasions when they were recorded at both station. There were a few simultaneous records made of earth currents from the base and mobile station on the 6 channel Brush but usually they were recorded on a Texas Instruments recorder.

During the first week of August the mobile station was moved to site γ and records were again multiplexed over telephone line to the base station. The station at site γ was in operation only a few days and on the 10 August the mobile station was moved to site ϵ. Because of greater line loss and what appeared to be intercapacitance between the telephone lines only one component could be transmitted at a time to the base station. This signal was very weak and showed signs of instrumental interference.

CHAPTER IV

EVALUATION OF DATA

Choice of Records For Analysis

All data were kept at P.N.L. with the records for any given period available on a temporary loan basis. Therefore, it was decided to work only on records from the 6 channel Brush where all three components at the base station at α plus at times the components from the mobile station were recorded simultaneously. There were only comparatively short periods of more or less continuous operation on these records because of the frequent moves of the mobile station. These operating periods were interrupted when higher frequencies or earth currents were recorded because of the different equipment used. Moreover large parts of the record were too disturbed for analysis due either to excessive magnetic activity such as occurred during the frequent thunderstorms or to instrumental difficulties.

With only limited data available the study was of necessity restricted to the normal daytime Pc oscillations of 10 - 30 seconds period. The Z component was not used because of its negligible amplitude. There were several hours of record on 31 July when the signal from site β showed almost complete correlation with that at the base station at α. The envelope of the series of pulsations several times showed distinct "pearls" indicating a possible beat frequency. There were several series of oscillations at site γ on 7 August which could be correlated with those at the base station. The remaining signals studied are from the records on 10 August at the base station only.

In figure 1 the top two records are the X and Y components respectively of a signal at base station α on 10 August with the X component showing modulation from a longer period signal. The third record shows the initiation of a Pc at the base station and the bottom record is of a longer period signal probably a Pt with signs of damping.

Statistical Analysis of Data

The data selected on the strip-chart record from the 6 channel Brush showed fair to good visual correlation between components and between stations. There were either no obvious phase differences or one of 180^{0} which could be explained as a reversal of terminals. A plastic template was centred over each component in turn covering the same time interval and the amplitude read every five seconds for a total of 56 readings. No consideration was given to any phase difference since readings were only being taken approximately every quarter period and no correction was made for any constant value included due to placing of the template. The amplitudes of the nearest calibration signals were also read and the positive sense of the signal noted.

A statistical analysis was made of each component by auto-correlation of its signal amplitudes to obtain the dominant frequency and by calculation of the covariance to obtain the energy in that dominant frequency. The auto-correlation coefficient "r_k" is defined as:

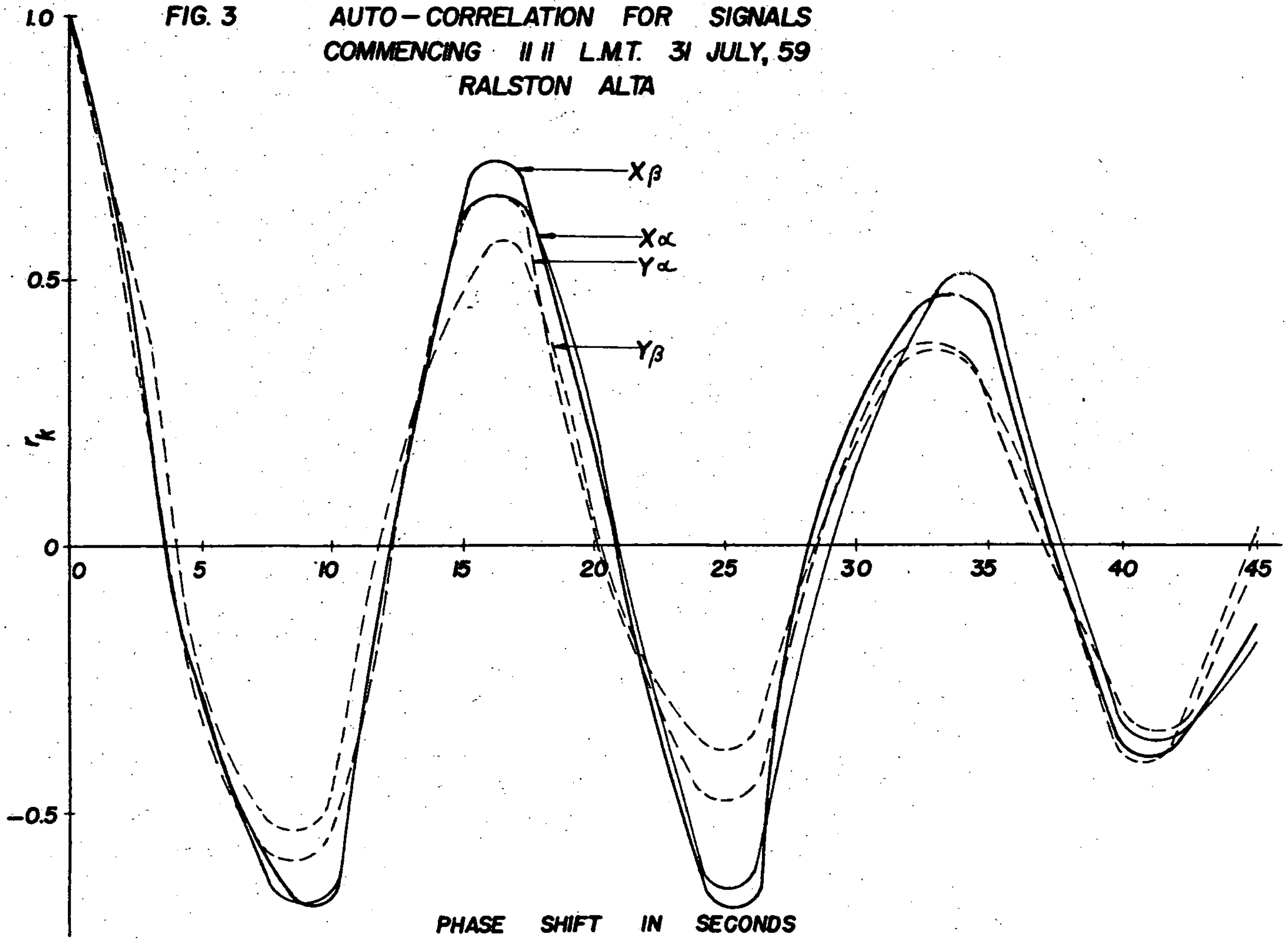
$$r_k = \frac{\sum_{i=1}^{N-K} X_i X_{i+K} - \frac{1}{N-K} \sum_{i=1}^{N-K} X_i \sum_{i=1+K}^{N} X_i}{\sqrt{\left[\sum_{i=1}^{N-K} X_i^2 - \frac{1}{N-K}\left(\sum_{i=1}^{N-K} X_i\right)^2\right]\left[\sum_{i=1+K}^{N} X_i^2 - \frac{1}{N-K}\left(\sum_{i=1+K}^{N} X_i\right)^2\right]}}$$

Where the Xi refer to relative amplitudes in any arbitrary units, N equals 56, and K has integer values from 1 - 9 representing phase displacements of 5 - 45 seconds.

The covariance is defined as the numerator of the above expression divided by N - K and multiplied by the appropiate calibration constant. The covariance corresponding to the maximum value of r_K will be proportional to the energy present for a dominant frequency with a period corresponding to this phase displacement. The amplitude of this dominant frequency will be proportional to the square root of the maximum value of the covariance.

Calculations of the correlation coefficients and of the covariance values were made by an Alwac III E digital computer at the University of British Columbia which required a punched tape data feed. An existing auto-correlation programme had to be modified for the purpose particularily where scaling of the data was concerned. The programme required further modification to obtain the required covariance values.

FIG. 3 AUTO-CORRELATION FOR SIGNALS COMMENCING 11 11 L.M.T. 31 JULY, 59 RALSTON ALTA



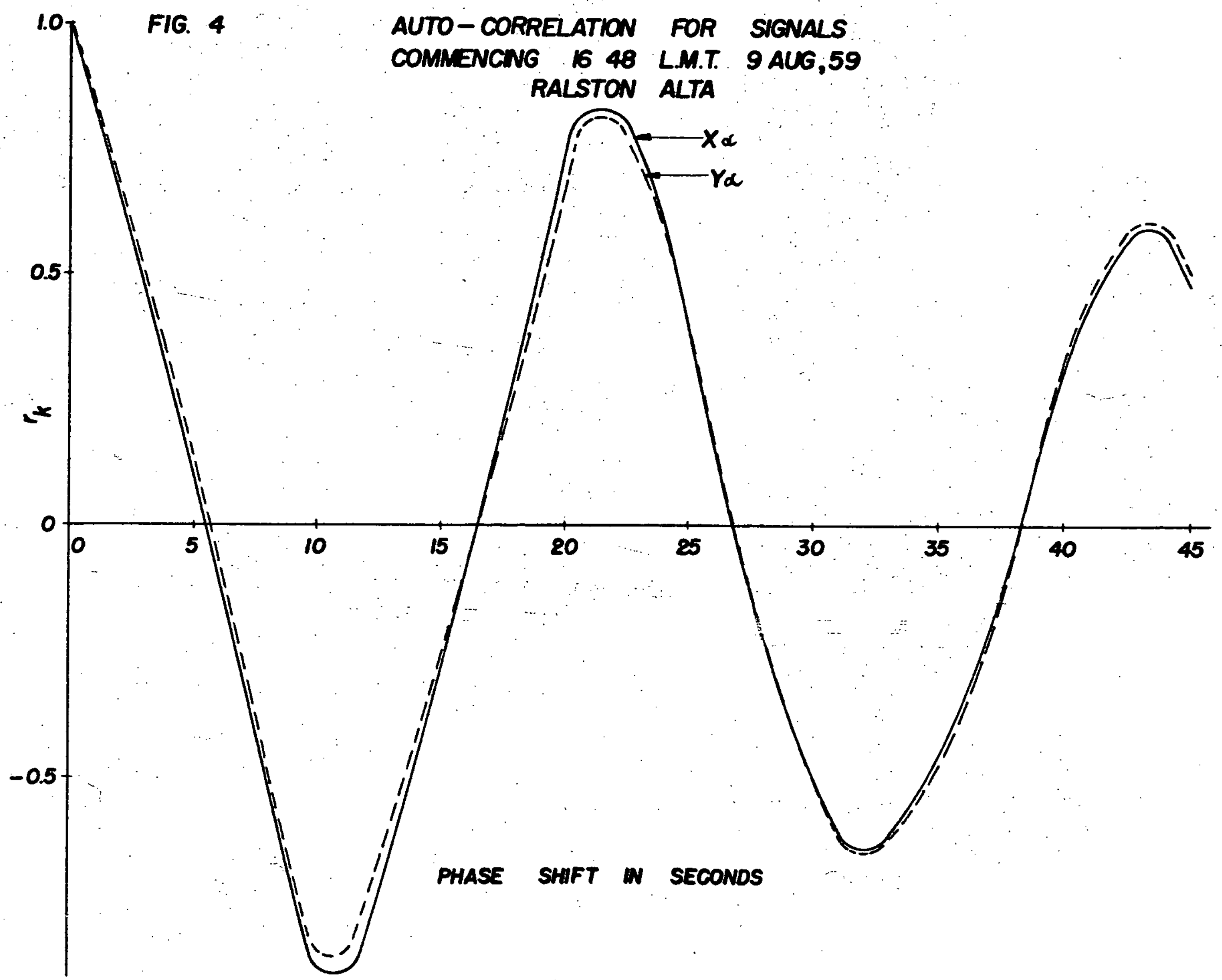


FIG. 4
AUTO-CORRELATION FOR SIGNALS
COMMENCING 16 48 L.M.T. 9 AUG, 59
RALSTON ALTA
Xα
Yα
1.0
0.5
0
-0.5
r_k
0
5
10
15
20
25
30
35
40
45
PHASE SHIFT IN SECONDS

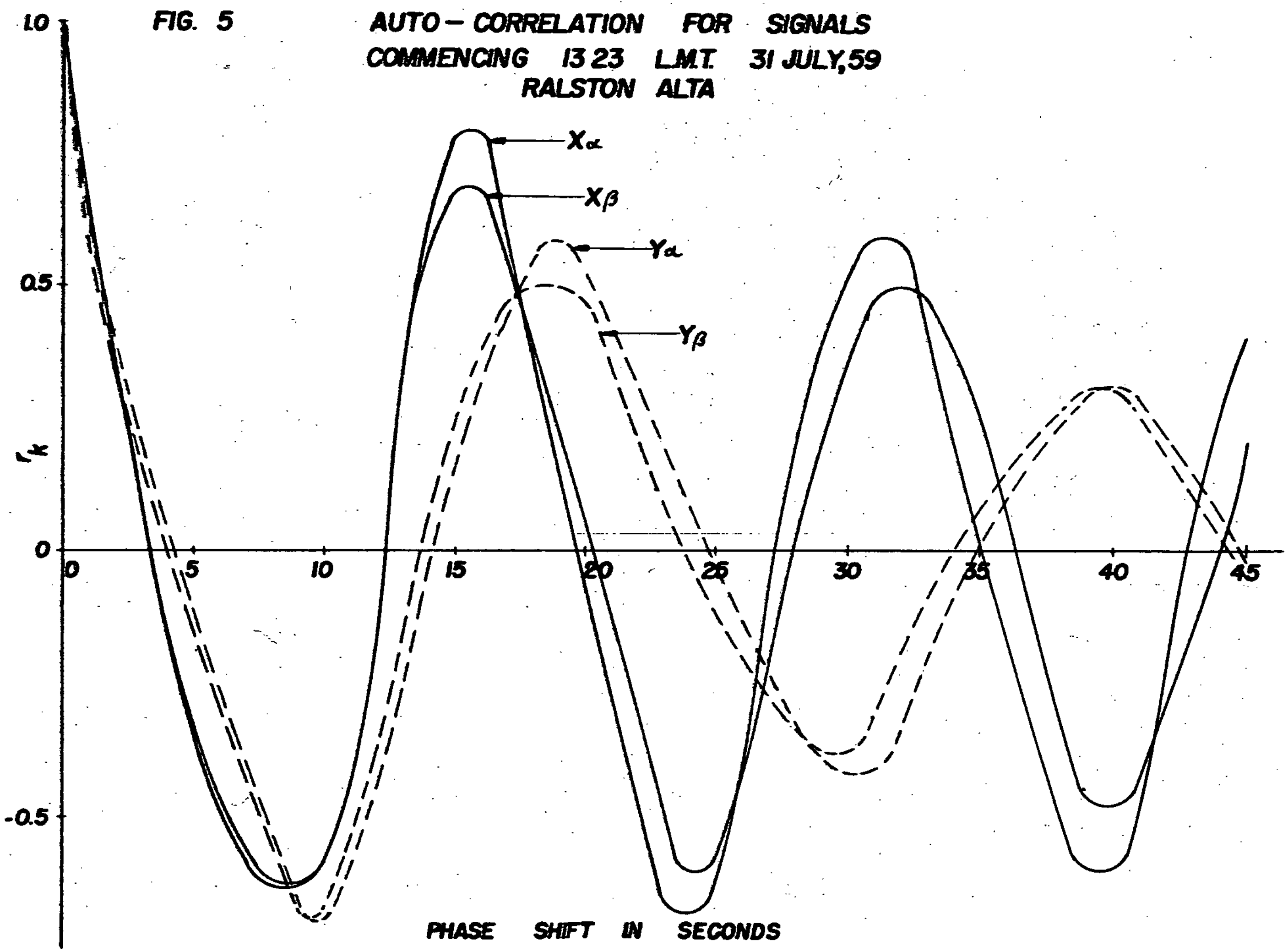


FIG. 5
AUTO-CORRELATION FOR SIGNALS
COMMENCING 13 23 L.M.T. 31 JULY, 59
RALSTON ALTA
1.0
0.5
0
-0.5
r_k
$X\alpha$
$X\beta$
$Y\alpha$
$Y\beta$
0
5
10
15
20
25
30
35
40
45
PHASE SHIFT IN SECONDS

CHAPTER V

RESULTS

Dominant Frequencies

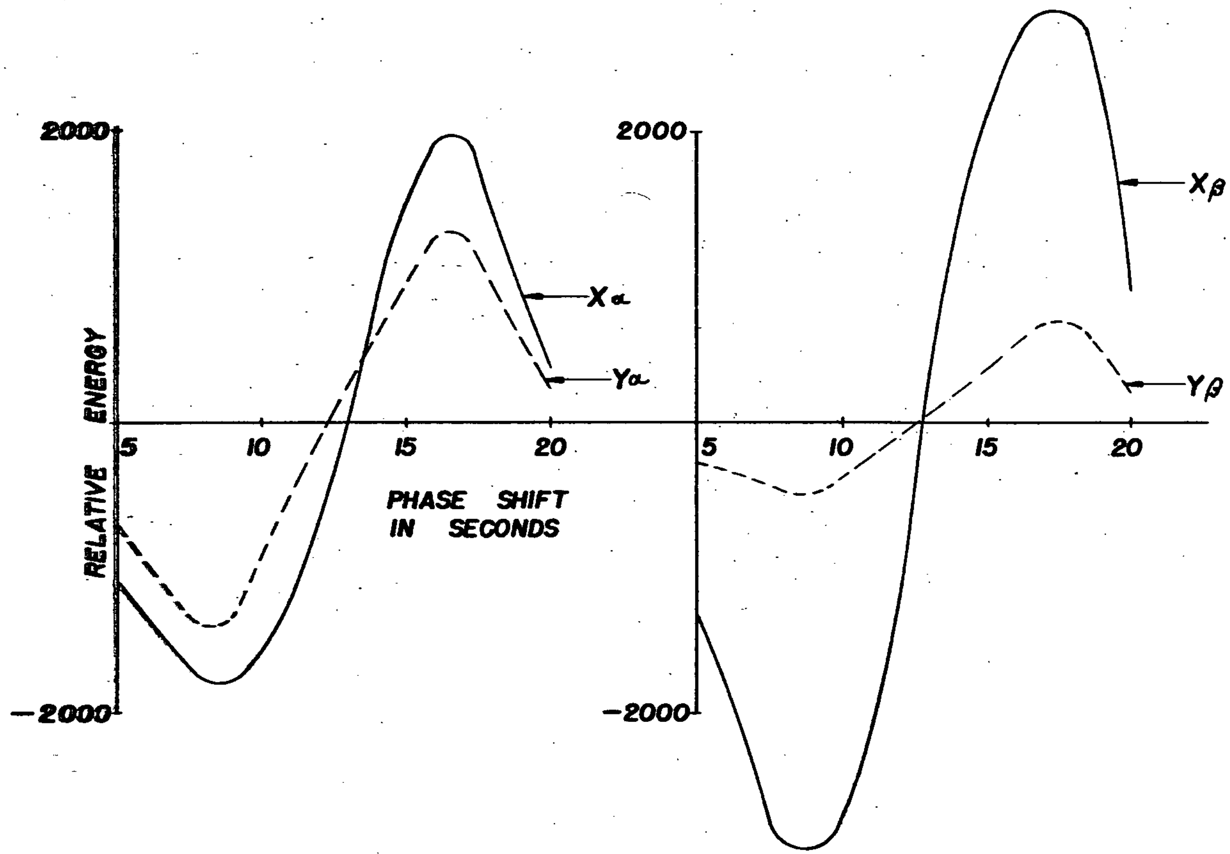
The auto-correlation coefficient r_k was plotted as a function of phase displacement in order to compare components and to obtain the dominant frequencies. (See figure 3). Whenever the signals for two stations were compared a small band of Pc's seemed to centre around the same dominant frequency for both base and mobile stations. Except where different frequency signals occurred on the X and Y components the plots of the correlation coefficient r_k for the two components were very similar. (See figure 4).

Out of 17 sets of data there were four occasions when the signal appearing on the Y component differed in periodicity by at least two seconds and in one case by as much as ten seconds from that on the X component. Where records had been obtained from both the base and mobile stations this same difference in periodicity occurred at both stations, (See figure 5).

The periods of the Pc's on 31 July were 16 - 18 seconds except when a longer period of 19 - 20 seconds twice appeared on the Y component only. On 7 August the periods ranged from 16 - 21 seconds and on 10 August from 19 - 29 seconds except on one occasion when a shorter period of 17 seconds appeared on the Y component only.

Maximum values of r_k were between .4 and .9 with no apparent relation to frequency or amplitude of

FIG. 6 RELATIVE ENERGY FOR SIGNALS COMMENCING 13 03 L.M.T. 31 JULY, 59



the signal. There seemed only a very general trend that the larger the amplitude of a signal the larger the maximum value of r_k because of a smaller proportion of noise or signal with frequency outside the small band under consideration. Usually the Y component had a smaller amplitude and hence usually a smaller value of r_k.

Direction and Amplitude of The Horizontal Vector

The relative values of the covariance as scaled by the computer programme were plotted as a function of phase displacement, the curves reaching a maximum at the displacement corresponding to the dominant frequency. (See figure 6).

The amplitude of the vector is then given by:

$$H = \sqrt{\mu_{x,\,x+k} + \mu_{y,\,y+k}}$$

Where $\mu_{x,\,x+k}$ and $\mu_{y,\,y+k}$ are the values of the covariance at the dominant frequency for the respective horizontal components and:

$$\mu_{x,\,x+k} = \frac{S_x\,[\text{Maximum Relative Amplitude of Covariance}]}{N-K}$$

Sx is the combined scaling factor from calibration and scaling for the computer, N equals the number of readings (56), and K is the closest integer value to the period divided by five. For the data with a different frequency signal appearing on the Y component, readings were taken at the average period. The amplitude and direction of

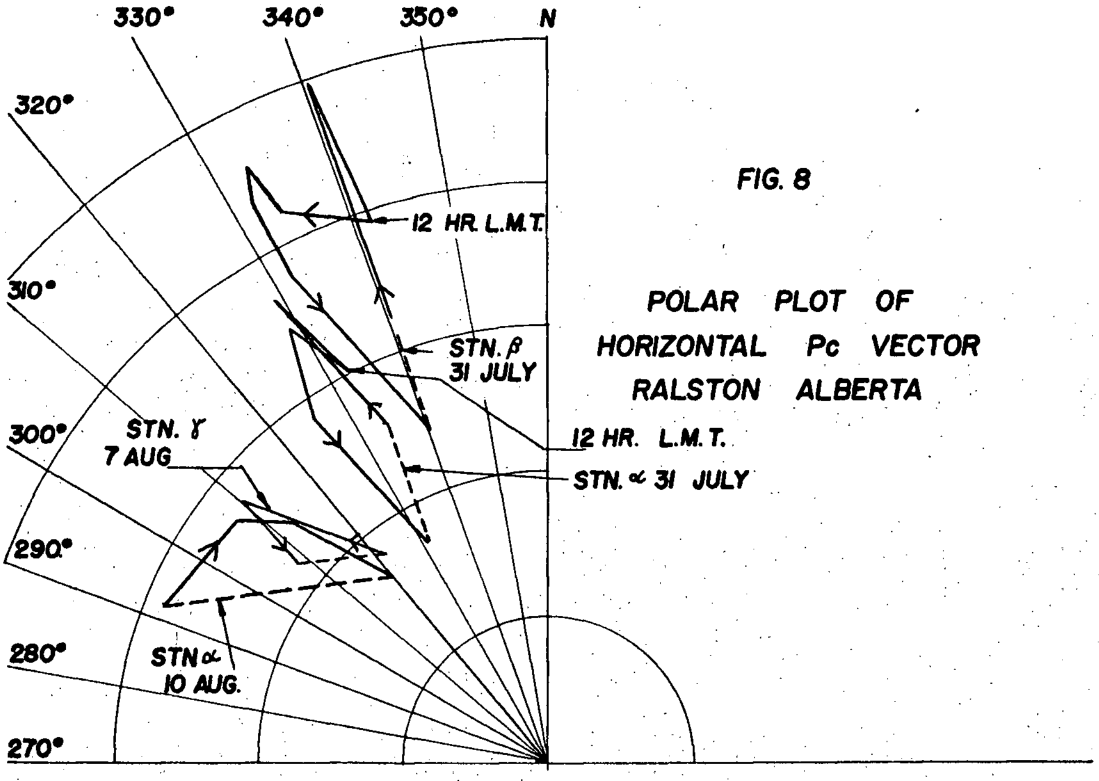


FIG. 8

POLAR PLOT OF HORIZONTAL Pc VECTOR RALSTON ALBERTA

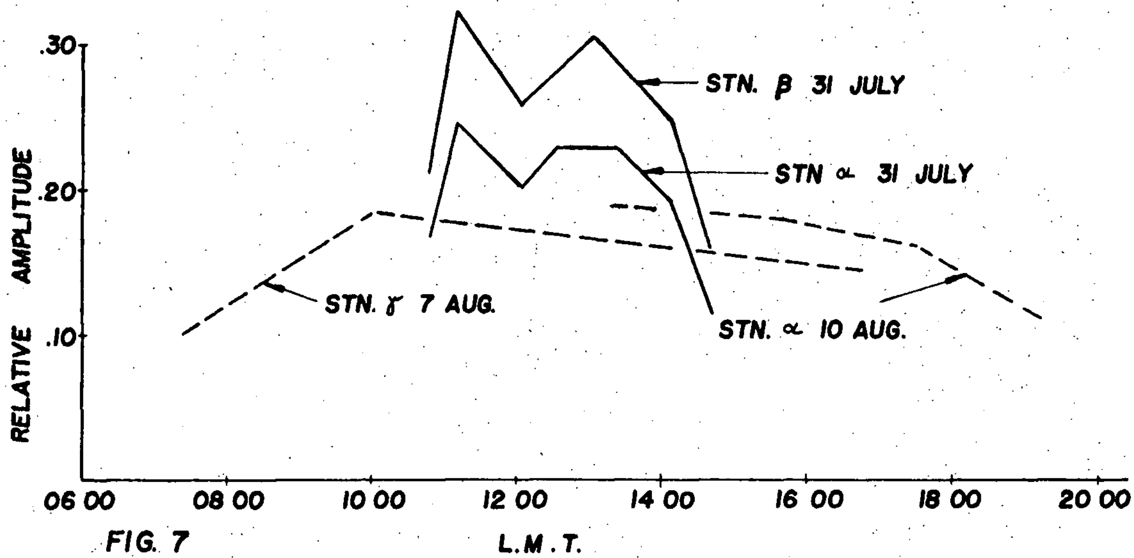


FIG. 7

the resultant vector was then biased in favour of the stronger component.

The azimuth of the vector was calculated from the expression:

$$\Theta = \text{ARCTAN}\left[\sqrt{\frac{\mu_{X,X+K}}{\mu_{Y,Y+K}}}\right] + 270^{\circ}$$

Where Θ is the true bearing of the vector and the addition of 270^{0} is required since the calibration and observed signals indicate the azimuth is northwest.

Amplitudes obtained were of the order of magnitude o.2 γ and seemed to follow a diurnal pattern reaching their peak shortly before local noon. (See figure 7). The amplitude of the vector at site β averaged 30 per cent greater than that at the base station at α. With only two cases for comparison the amplitude at site γ was only 20 per cent greater than that at the base station although site γ was twice the distance of site β.

The polar plot of the horizontal vector indicates that the diurnal pattern is a closed figure with the maximum excursion taking place during daylight hours caused mostly by changes in amplitudes (See figure 8). The azimuths are northwesterly, those at site β being more northerly than those at the base station at α. This arises because the greater amplitude at the mobile station is due to a larger X component. The direction of motion of the diurnal pattern is anti-clockwise except on 10 August when the direction is reversed.

CHAPTER VI

CONCLUSIONS

The normal daytime Pc oscillations with period from 10 - 30 seconds seem to occur in a small frequency band centred around one dominant frequency. The observed signal may be made up of two or more small bands of Pc's with some instrumental noise and possibly low amplitude Pc of a different dominant frequency. At times two such small bands of Pc's with different dominant frequencies and equivalent amplitudes may occur with widely separated azimuths. On such occasions the X component has one dominant frequency and the Y component another.

Beats should occur when two Pc's of different frequency but equivalent amplitude are present in the signal. Pearls indicating such beats occurred on several occassions on the record for the 31 July including two sets of data when there were different dominant frequencies on the X and Y components. These pearls could have been caused by two signals beating with a difference in period of a few seconds.

The horizontal vector seems to follow a closed diurnal pattern with the greatest excursions occurring during daylight hours. The maximum amplitude seems to be reached shortly before local noon.

Initiation of a signal at two stations separated by a few miles is simultaneous and the signals show a high correlation except for differences in amplitude and azimuth of the horizontal vector. The amplitude averaged 30 per cent greater for a station 2 miles north of the base station although it seemed to be only 20 per cent greater for a station 5 ½ miles north of the base. There is no obvious explanation for this difference in amplitude since any latitude effect should increase with distance and the uniform geology precludes any difference due to changes in the earth currents. The small effect on the total vector of the associated earth currents is also evident in the negligible Z component.

The statistical analysis of the data gave satisfactory results. If amplitudes could be read electronically possibly by including the data on magnetic tape then greater accuracy would be obtained. This would permit more exact determination of the dominant frequency, and of the amplitude and azimuth of the vector. When Pc's of different frequency occur it should then be possible to resolve the signals into two vectors with different periods and possibly different azimuths.

There is a need for simultaneous records from two stations over a long time interval. Only after sufficient data is obtained should the distance between the two stations be increased.

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