An Investigation of the

Contingent Negative Variation

Using Signal Processing Methods

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Declaration

I hereby declare that whilst registered as a candidate for the degree of Doctor of Philosophy with the Council for National Academic Awards I have not been registered for any other qualification of the CNAA or any other examining body.

Signed   M. J. Nichols

In accordance with regulations 3.8 and 3.9 I have attended and participated in the following:-

Lectures in Communication Engineering (Intended for B.Sc Hons. Students)   October 1977 - May 1978.

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BES/HPA, Nottingham, "International Evoked Potentials Symposium".   4th - 6th September 1978.

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Abstract

The Contingent Negative Variation (CNV) is one of many types of electrical response signals which appear in the electroencephalogram (EEG) of man subsequent to one or more stimuli. Generally these responses are small in comparison to the normal background EEG and had always been thought to consist of a response component which was added to the background EEG. Professor B. McA. Sayers of Imperial College suggested that the auditory response might actually be due to a temporary ordering of the phases of the components of the background EEG. A model, allowing for additive and ordering effects, is proposed here. This model was tested on both auditory and CNV responses using statistical tests not previously used in evoked potential studies. The tests showed that while the additive model satisfactorily described the auditory responses, it did not explain the CNV responses so well. However, both sets of responses showed a certain amount of phase ordering and this was consistent with the model which showed that a repetitive additional component would always incorporate the phase ordering effect. In the absence of detectable additivity pure phase re-ordering might alternatively occur as proposed by Sayers.

The CNV's of a patient group were also studied and certain tests are proposed as a possible method of diagnosis. The reliability of these tests was not conclusively proved as much larger control and patient groups would be required to do this.

An important part of this work involved the introduction of a quantitative method for assessing the effectiveness of methods of removing eye movement artefact from the EEG. This allowed the development of a more extensive correction method which was tested against two other techniques and found to be superior. This correction method will provide the basis for further research and the development of a corrector to be made commercially.

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References, Tables and Diagrams

For each section the references are numbered
[1], [2], ... and are listed at the end of that
section.

Tables and diagrams are numbered 'a-b' where 'a'
denotes the section number and 'b' the numerical sequence
within that section. Diagrams and tables have been
inserted after, and as near as possible to the text which
first refers to them.

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List of Diagrams

1. Introduction

1.1 The Origins of Electroencephalography

Electrical engineers are frequently surprised to find that electrical activity of the brain was observed as long ago as 1875 [1]. Their surprise is however understandable when one considers the infant state of electrical engineering at that time. The discovery was due to a British Physiologist called Richard Caton. Caton used Thomson's (moving magnet) reflecting galvanometer to observe electrical fluctuations from the exposed surfaces of the brains of rabbits and monkeys. The potentials were of the order of millivolts and the necessary amplification was provided optically by the galvanometer. Using this galvanometer Caton was able to study and subsequently comment on the electrical activity he observed. His findings were presented at a Conference and published in the British Medical Journal in August 1875 [1]. Despite being unable to make graphic recordings of the activity, Caton detected background and stimulus related potentials.

However it was not until 1929 that Hans Berger [2] discovered the electroencephalogram (EEG) in man. He used a string galvanometer connected to electrodes attached to the scalp. Berger tried many different types of electrodes made from different metals. Unfortunately however Berger's work remained unnoticed for a number of years until Adrian and Matthews [3] (1934) and Jasper and Carmichael [4] (1935) reviewed and confirmed it.

1.2 Technological Change

Technological advances at this time made it possible for the electrical activity to be amplified and displayed on a cathode ray tube (CRT). Then resulting waveforms could then be photographed for a permanent record. These early valve amplifiers were usually a.c. coupled and often suffered from pick-up of external interference. An elegant solution to this problem was the advent and adoption of the differential amplifier which was able to reject the common-mode noise at its input. During the 1940's pen recorders became more widely available and for the first time electro-encephalographers could have an immediate permanent record of the brain's electrical activity. Interest in the developing field of EEG analysis grew rapidly. Many workers tried to make objective quantitative analyses of the EEG. A physicist by the name of Dietsch [5] was probably the first worker to examine the frequency of the EEG signals. He performed Fourier analysis on short sections of EEG signals using a mechanical desk calculator in the early 1930's. The method was very tedious and it was not until 1943 that Walter [6] overcame this disadvantage with his frequency analyser. This instrument consisted of a bank of twenty tuned reeds covering the range 1.5 to 30Hz. The movement of each reed was used to switch a charging current into a capacitor and thus to integrate the activity over a ten second period. The outputs of the integrators being roughly proportional to the amount of activity in given frequency band.

During the late 1940's and early 50's a considerable

amount of interest was also shown in topographic EEG displays. Typically these devices employed twenty or more CRT's to display simultaneous EEG signals from different points on the scalp. Like the frequency analyser previously described the 'toposcopes' suffered from the instability of the valve technology of the day.

The development of new concepts in statistical communication theory give rise to the EEG signals being considered as a stochastic process. Brazier and Casby [7,8] (1951,1952) were some of the first workers to apply auto and cross-correlation analysis to the EEG. Subsequently this method became quite popular as a shortcut to obtain the power spectrum of the EEG signal.

The major developments of the late 1950's and early 60's were however in the advent and use of the new solid state technology. The equipment was more reliable and required far less maintenance and calibration than the valve equipment that it replaced. Furthermore the advent of the digital computer made the calculation of the power spectrum a much less awesome prospect although it was not until the introduction of the Fast Fourier Transforms (FFT) by Cooley and Tukey [9] in 1965 that this method became practical for multichannel work.

1.3 Evoked Potentials

In parallel with these developments in the analysis of the background EEG signal came developments in the analysis

of potentials evoked by some external stimulus. Dawson [10] (1947) was the first person to record potentials evoked by stimulation of a peripheral nerve. He used photographic superimposition whereby the waveform was displayed on a CRT whilst a camera, set for a time exposure, recorded the waveform on film. The stimulation was applied many times each causing a single scan of the CRT screen. The evoked potential is thus visible on the developed photograph due to the re-inforcing effect of the overlapping individual responses. This elaborate technique was necessary because the magnitude of the individual evoked responses were considerably smaller than the normal background EEG activity.

Development of the analysis of evoked potentials was limited by the lack of equipment capable of improving the signal to background EEG ratio. It was realised at an early stage that if it were possible to average a number of evoked responses an improvement in signal to background EEG would be achieved. Early analogue averagers were built but were cumbersome and difficult to use. The advent of digital memory and logic devices made averaging a much more attractive technique and during the early 1960's many discoveries were made in the field of evoked responses. Furthermore, the advent of the general purpose laboratory minicomputer meant that evoked responses could be studied without further special equipment (except the stimulator). It was during the study of certain evoked potentials that Walter [11] discovered a new evoked potential which later became known as the Contingent Negative Variation (CNV). This evoked potential was found to occur between a pair of conventional auditory or visual

stimuli provided that the patient was required to perform some action on receiving the second stimuli. The response was found to be a gradual negative shift subsequent to the first, or warning stimulus, and increasing in negativity until the second stimulus when the desired action was performed. Unlike normal visual, auditory or somatosensory evoked responses, the CNV depended on active participation by the subject and thus involves the higher mental processes.

1.4 Additivity and Ordering

Since their discovery, it had always been thought that evoked potentials were due to an additional signal component which was added to the background EEG signal. Professor Sayers [12] questioned this basic assumption and performed several tests to try and establish whether the Auditory Evoked Potential (AEP) could be caused by some other mechanism. One of Sayers tests [12] involving taking a section of normal background EEG and re-arranging the phases of the Fourier components. He found that by doing this the section of background EEG could be made to resemble an AEP. Sayers also found that if the energy contained in an AEP was calculated and compared with that for a section of background EEG, there was no significant difference [12]. This led Sayers to the conclusion that AEP's could in fact be due not to an additional signal, but to some form of phase ordering of the on-going background EEG signal. One could, for example, envisage a number of EEG generators becoming entrained for a short while subsequent to the stimulus presentation. This would give the characteristic shape of the AEP

but would not change the energy content of the EEG.

In order to try and verify this, Professor Sayers obtained the Fourier transforms of a set of AEP's. A diagram was then constructed showing the phase angles of the transformed responses for each harmonic [12]. From these diagrams Sayers was able to detect that the phase angles obtained did not form an uniform pattern between $+\pi$ and $-\pi$ but formed groups.

In subsequent studies Sayers used histograms to show these phase ordering effects [13]. For each of a number of the harmonic frequency components histograms were plotted to show the number of times the phase angle fell into any one of twenty-four frequency intervals of width $2\pi/24$ radians (i.e. 15°). From these histograms Sayers observed grouping in harmonics 2 to 5 (the fundamental frequency in these observations was 1.5625 Hz.) The amount of phase aggregation was found to be dependent on the stimulus level but not on the degree of latency. When no stimulus was applied the phases of the transformed EEG formed a roughly uniform distribution [13].

The importance of Sayers' findings were such that it was considered desirable to carry out similar experiments on CNV's to establish whether they were also due to phase re-ordering as had been previously suggested by Walter [14].

1.5 An Application of the CNV to Diagnostic Medicine

Since it was first reported in 1964 the CNV has not
been widely used in routine diagnostic medicine. One possible
area in which the CNV may be useful is in the early diagnosis
of a hereditary neurological disorder known as Huntington's
Chorea (HC). This illness affects several areas of the
brain including the cortex, the caudate nucleus and other parts
of the corpus striatum [15]. These are all areas thought to
be involved in the generation of the CNV [16]. The disease
is currently diagnosed only in its later stages, usually in
middle age, when the chorea (uncontrollable movement) becomes
apparent. The condition becomes progressively worse causing
pre-senile dementia and after a distressing long illness,
ultimately leads to premature death.

A possible diagnostic procedure would therefore be to
compare the CNV's of those people at risk (i.e. those with
a known family history of HC) with those obtained from a
normal population. Significant deviation from the normal
CNV may thus indicate the presence of the disease before the
other symptoms become apparent. Clearly the clinicians would
have to establish the limits of the normal CNV and also
whether other neurological conditions could give similar
CNV's to those of HC victims. However before this can take
place it is necessary to conceive, design, build and test
equipment and processing methods suitable for extracting a
reliable quantitative description of the CNV.

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2.   Theoretical Development

2.1   Models for Additivity and Phase Ordering in Evoked Responses

Although introduced as being mutually exclusive, there is no fundamental reason why an evoked response should not be the result of both additive and phase re-ordered components. Furthermore any added signal giving the characteristic shape of either an AEP or a CNV will have its own well defined phase spectrum. Thus the identification of a phase pattern in an evoked response (CNV or AEP) is not in itself sufficient evidence for phase re-ordering. At this point it is as well to define what is meant by phase ordering and phase re-ordering. Phase ordering is used here to describe the situation where a phase spectrum has a recognizable pattern irrespective of the cause of this pattern, whereas phase re-ordering is used to describe the situation where the phases of an existing signal have been changed so as to cause phase ordering. Since phase patterns are not sufficient evidence for phase re-ordering, it is necessary to consider amplitude characteristics as well.

Consider first a finite realisation of the pre-stimulus background EEG signal which is of the same length as the section of EEG containing the evoked response. Because the signal is random the Fourier harmonic components into which it may be analysed will have random amplitudes and phases. If the nth harmonic is selected it may be very conveniently represented in amplitude and phase by a phasor on a phasor diagram. The same procedure can be carried out for each pre-stimulus realisation recorded in a series of trials, i.e. the

nth harmonic component of each realisation may be plotted
as a phasor on the same phasor diagram. This procedure will
result in a diagram such as is shown in Fig. 2-1a, in which
the amplitudes are random and the phase angles, which are
also random, are distributed approximately uniformly about
a circle. For ease of comprehension a circle of arbitrary
radius has been superimposed on the phasor diagram. The
crosses on the circles indicate the directions of the phasors.

Now consider the effects of a stimulus on this diagram.
Assume that the phasor diagram for the post-stimulus section
of EEG containing the evoked response may be derived directly
from the pre-stimulus phasor diagram. If the evoked response
were due to phase re-ordering effects its nth harmonic phasor
diagram would be obtained by rotating all of the phasors of
Fig. 2-1a towards the preferred phase angle. Thus the phasor
diagram of Fig. 2-1b would be obtained. The characteristic
feature is that although there is phase ordering present the
amplitudes are unaltered. The phase ordering present is
responsible for the characteristic waveform of the evoked
response. This phase re-ordering model may now be compared
with the additive signal model. This will be considered for
the two cases of low and high level stimulus. In the low
level stimulus case it is assumed that a small additive
evoked response is produced which may be analysed into its
harmonic components. The nth harmonic component, assumed to
be the same in each realisation, is represented as a small
phasor which has to be added to each of the phasors of Fig.
2-1a to produce the post-stimulus phasor diagram. This pro-
duces Fig. 2-1c. This figure shows that a certain amount of
phase ordering is produced while the amplitudes of the nth

-25-
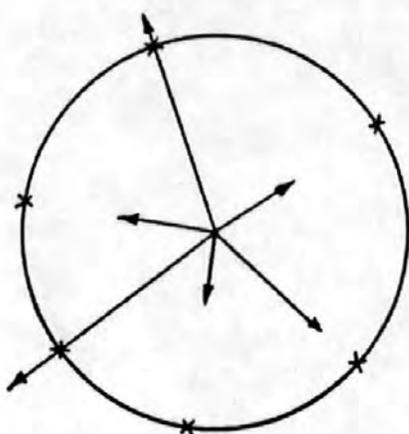
Fig. 2-1a
Background EEG
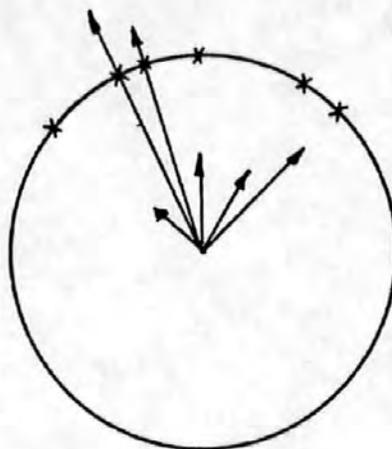
Fig. 2-1b
Phase ordering

Figure 2-1
Phasor diagrams
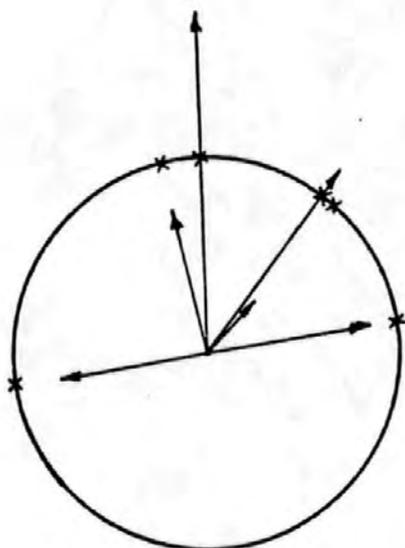
Fig. 2-1c
Small additive component
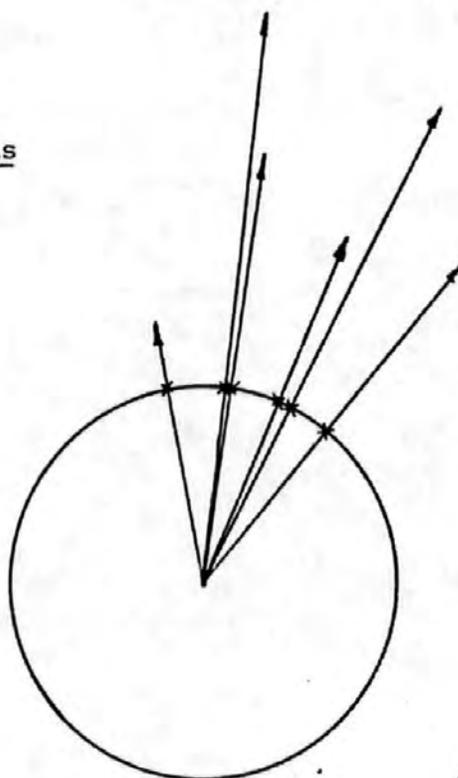
Fig. 2-1d
Large additive
component

harmonic are changed. Those phasors directed towards the preferred angle are increased in length, whilst those opposed are decreased. For a small additive signal the average length of the phasors would be virtually unaltered. The same argument may be applied in the case of a high level stimulus. The phasor to be added to Fig. 2-1a is now large and the post-stimulus phasor diagram is as shown in Fig.2-1d. It is seen that the large additive signal results in pronounced phase ordering and a considerable increase in phasor amplitudes.

The models clearly demonstrate that phase ordering will be produced by either mechanism and will increase with stimulus level. The presence of an additive component may be inferred by changes in amplitude of the nth harmonic. In the next section the statistical tests used to detect phase ordering and amplitude and energy changes will be described.

2.2   Tests of the Models

Various processing methods and tests were devised in an attempt to determine which of the above models was the most appropriate to the CNV. Because of the variable nature of the CNV, both from subject to subject, and also from trial to trial with the same subject, evidence for phase ordering has to be sought on a statistical basis. It is possible to detect phase ordering by Fourier transforming the 'Negative Variation' sections of a sequence of CNV's (i.e. that section of the CNV remaining when the two involuntary stimulus responses were ignored) and testing the phase values. One method of visually detecting phase ordering would be to plot phase histograms, whereas the variability of the responses

could be judged by plotting amplitude histograms.

2.2.1 Histograms of Phase and Amplitude

The phase values for each harmonic frequency component could be grouped into bands of known angular width such that the range $-\pi$ to π was covered in a number of steps. Histograms could then be plotted showing, for a particular frequency, the distribution of the phase values. If phase ordering were present then the phase histograms would be expected to show aggregation about some particular phase value. Indeed if the responses were identical, then in the absence of any noise the histograms would show a given frequency component of every response as having the same phase value. However if no phase ordering were present then the phase histograms would be expected to exhibit an uniform distribution of phase over the range $-\pi$ to π.

By considering the shape of an ideal CNV response [1] it is possible to predict the values, for each harmonic frequency, around which phase grouping should take place. Figure 2-2 shows an idealised CNV of about one second interstimulus interval. Ignoring the evoked responses R_1 and R_2 the responses may be considered as a linear function of time. This may be Fourier transformed as follows:-

$$X(n) = \frac{1}{N} \sum_{i=0}^{N-1} \left[x(i) e^{\frac{-2\pi j i n}{N}} \right] \quad \dots\dots\dots\dots\dots (1)$$

$$= \frac{1}{N} \sum_{i=0}^{N-1} \left[x(i) \left(\cos\left(\frac{2\pi i n}{N}\right) - j \sin\left(\frac{2\pi i n}{N}\right) \right) \right] \quad (2)$$

but $x(i) = -ki$ over the range $0 \leqslant i < N$
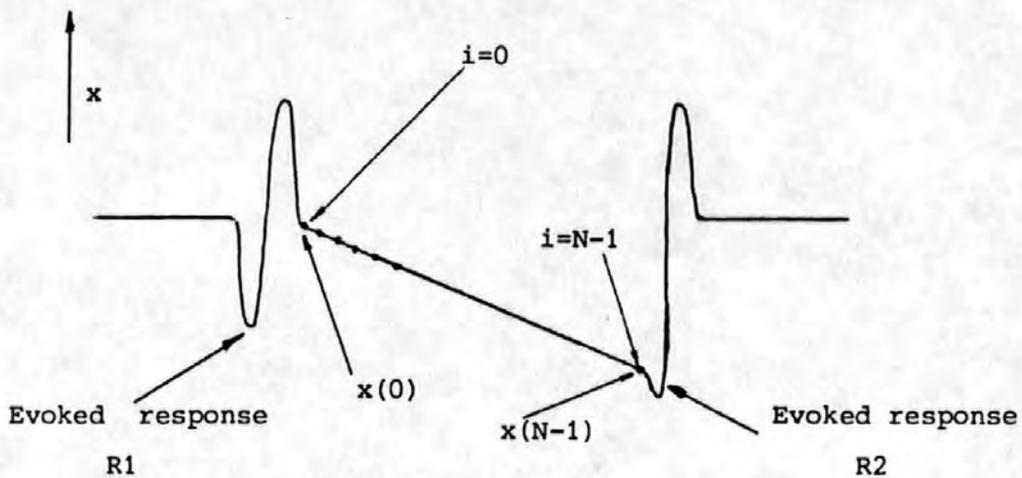
Figure 2-2

An idealized C.N.V response.
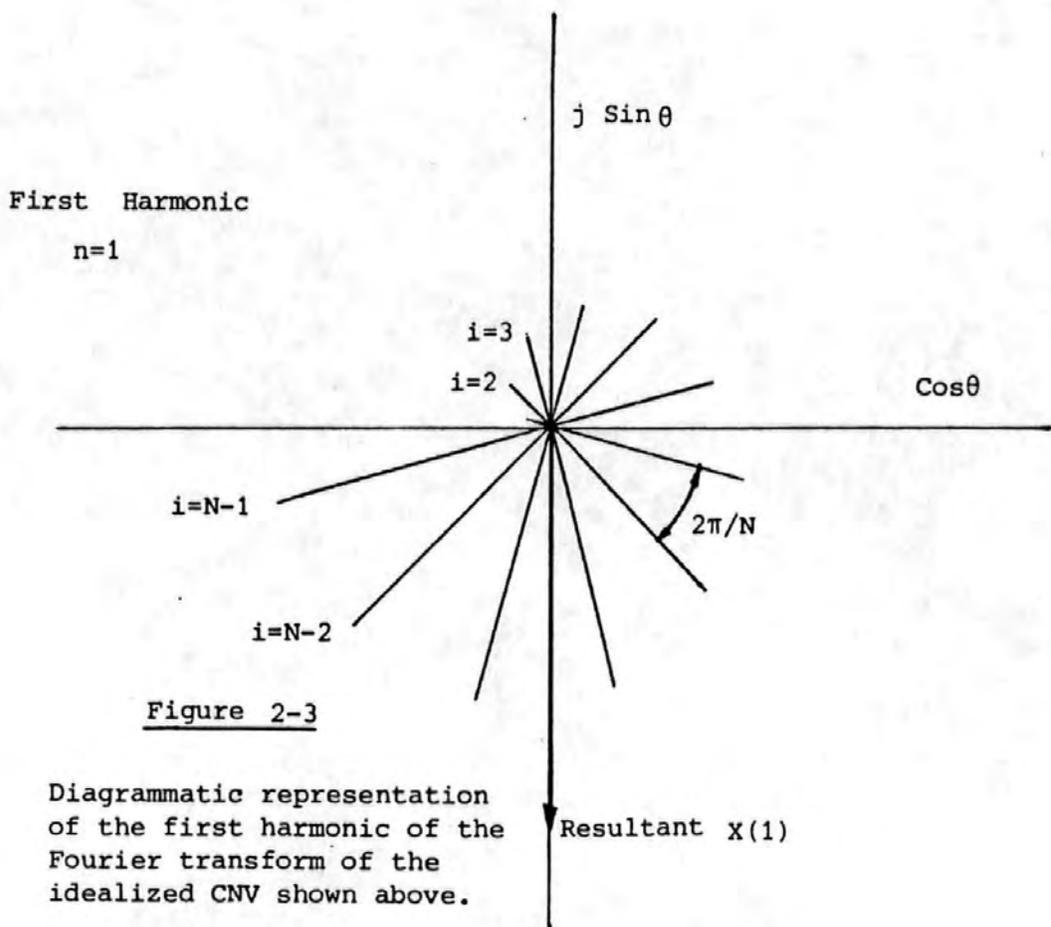
Figure 2-3

Diagrammatic representation
of the first harmonic of the
Fourier transform of the
idealized CNV shown above.

$$X(n) = \frac{1}{N} \sum_{i=0}^{N-1} \left[-ki \cos\left(\frac{2\pi in}{N}\right) \right] + \frac{j}{N} \sum_{i=0}^{N-1} \left[ki \sin\left(\frac{2\pi in}{N}\right) \right] \quad ..(3)$$

The first harmonic component is thus

$$X(1) = \frac{1}{N} \sum_{i=0}^{N-1} \left[-ki \cos\left(\frac{2\pi i}{N}\right) \right] + \frac{j}{N} \sum_{i=0}^{N-1} \left[ki \sin\left(\frac{2\pi i}{N}\right) \right] \quad ....(4)$$

The individual terms of these summations may be re-presented as shown in Figure 2-3. The resultant (i.e. the first harmonic component) is clearly in either the third or fourth quadrant. In fact calculation shows that for large N the angle approaches -90°. Thus the phase histograms would be expected to show aggregation at this phase angle. Additional calculations (see Appendix 8.1) showed that the phase angles of all of the first 6 harmonics would aggregate at -90°. Furthermore, for longer CNV's (i.e. those with a longer ISI) which often change shape after approximately two seconds [2] the phase angles are also in the third and fourth quadrants. This suggests that all normal CNV's should have phase histograms which show aggregation in the third and fourth quadrants.

One disadvantage of phase histograms is that the phase data is cyclic yet the histogram axis is not. This disadvantage can be illustrated by assuming that, for example, an evoked response has a phase which tends towards π. Instead of a group of phase 'bins' at π one would observe a cluster at π and a cluster at $-\pi$ (i.e. at opposite ends of

the angular scale). This problem can be overcome by using either Rose diagrams (see Figure 2-4) or by using the phasor diagrams previously described. Whichever method of display is chosen the question to be resolved remains the same. This is simply whether the phase ordering observed occurs by chance or whether there is some mechanism forcing the phasors to some preferred direction.

Histograms could also be plotted for the amplitude information. Provided the background EEG were negligible, these would give information about the variability of the CNV responses. If, for example, each individual CNV response was identical to the next, then the amplitude histograms would show only one value of amplitude for each frequency component. If, on the other hand, the responses were very variable then the amplitude histograms would show many values of amplitude i.e. a spread of amplitude. This may be useful in the classification of certain subject categories. One difficulty which arises with amplitude histograms is that of the choice of the amplitude scale and interval. Unfortunately this choice might be critical in assessing whether one subjects responses are more variable than anothers.

2.2.2 Angular Statistical Tests for Phase Ordering

To determine whether the grouping of a set of phasors could have occurred by chance it is necessary to perform angular statistical tests on the harmonic components of the sample of individual CNV's. These tests are described below. All three tests are non-parametric.
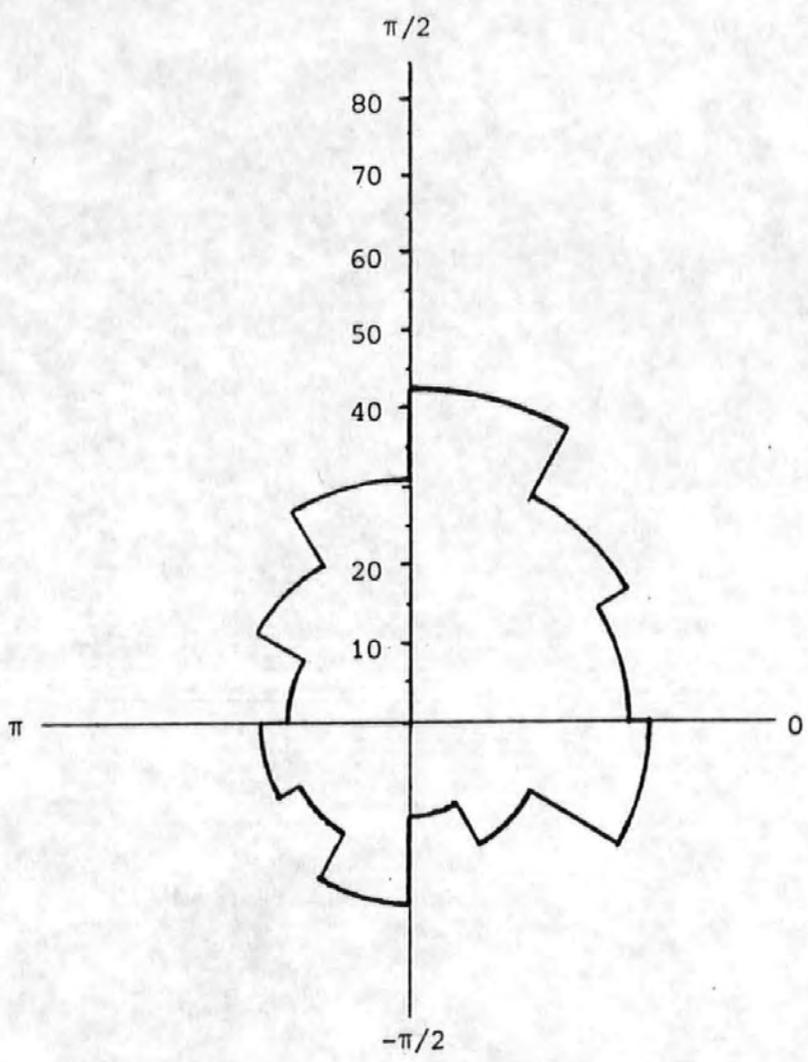
Figure 2-4

The Rose diagram

2.2.2.1 The Rayleigh Test of Circular Variance

This is the first of a number of tests used to determine whether a set of N phase angles $\{\theta_i\}$ are distributed in a non-uniform manner. It could therefore be used to detect phase ordering.

The circular variance can be calculated as follows:- [3]

Circular Variance $So = 1 - \bar{R}$ .... (5)

where $\bar{R} = \sqrt{\bar{C}^2 + \bar{S}^2}$ .... (6)

and $\bar{C} = \dfrac{1}{N} \sum_{i=1}^{N} \cos \theta_i$ .... (7)

$\bar{S} = \dfrac{1}{N} \sum_{i=1}^{N} \sin \theta_i$ .... (8)

Clearly if $\theta_1 = \theta_2 = \ldots\ldots\ldots = \theta_N = \theta$

then $\bar{C} = \cos \theta$ and $\bar{S} = \sin \theta$

This gives $\bar{R} = \sqrt{\cos^2\theta + \sin^2\theta} = 1$ ...... (9)

So $= 0$ ....(10)

This corresponds to the perfect phase ordering situation where all the phase angles are the same.

Alternatively consider the situation where $\theta_i = \dfrac{2\pi i}{N}$

i.e. $\{\theta_i\}$ are distributed uniformly over the range 0 to 2π.

In this case the summations $\overline{C}$ and $\overline{S}$ are both zero.

Hence $\overline{R}$ = 0 .... (11)

So = 1 .... (12)

This corresponds to the situation where all the phase angles are uniformly distributed. Thus to determine whether a set of angles are distributed in a significantly non-uniform manner, tables of the Rayleigh distribution must be consulted. However the commonly tabulated Rayleigh distribution probabilities [3] are in terms of R not $\overline{R}$. These two quantities are related by the expression $R = N\overline{R}$. (In the broadest sense $\overline{R}$ is more meaningful than R since $\overline{R}$ always lies between zero and one whereas R lies between zero and N).

Alternatively, however the tables can be transformed to yield significance levels for So in place of R. Details of this transformation and the resulting tables for So are given in Appendix 8.2

2.2.2.2   The Modified Rayleigh Test of Circular Variance

In an attempt to take both the amplitude and the phase angle into consideration Johnson [4] suggested the use of the modified test statistic To given by

$$
\text{To} = 1 - \sqrt{\left[\frac{\sum\limits_{i=1}^{N} r_i \cos \theta_i}{\sum\limits_{i=1}^{N} r_i}\right]^2 + \left[\frac{\sum\limits_{i=1}^{N} r_i \sin \theta_i}{\sum\limits_{i=1}^{N} r_i}\right]^2} \quad \text{.. (13)}
$$

Where r_i is the length of the ith phasor

θ_i is the phase angle of the ith phasor

If $\{\theta_i\}$ are all aligned (i.e. $\theta_1 = \theta_2 \ldots\ldots = \theta_N$) then the statistic To = 0 whereas if the angles are uniformly distributed over the range 0 - 2π and all the phasors have the same length then To = 1.

Unfortunately however the distribution of To is not easily obtainable and is likely to depend critically on the assumptions made in deriving it. However, Moore [5], uses the rank of the phasor magnitudes rather than their magnitudes and thus avoids this problem. Thus a new statistic Uo may be defined.

$$Uo = 1 - \sqrt{\left[\frac{\sum_{i=1}^{N} R_i \cos\theta_i}{\sum_{i=1}^{N} R_i}\right]^2 + \left[\frac{\sum_{i=1}^{N} R_i \sin\theta_i}{\sum_{i=1}^{N} R_i}\right]^2} \quad \ldots (14)$$

Where R_i is the rank of the ith phasor.

This is closely related to the statistic R* proposed by Moore [5] and significance levels for Uo may be obtained from those for R* by use of the formula

$$R^* = \frac{(1 - U_o)(N + 1)}{2\sqrt{N}} \quad \ldots\ldots (15)$$

Tabulated values of the probabilities for Uo are given in Appendix 8.3. Where calculated values of Uo are significantly different from unity then the phasors are non-uniformly distributed.

2.2.2.3 The Hodges-Ajne Test

This is an alternative test used to determine whether a set of angles are distributed in a non-uniform manner. The test statistic, m is given by the minimum number of observations lying in any semi-circle. If the value of m is small in relation to the number of observations, N then the angles are non-uniformly distributed. For given values of m and N the significance level of the test may be calculated from the formula [6].

$$\text{Significance level} = \frac{(N-2m)\ ^N C_m}{2^{N-1}} \quad \times \quad 100\% \quad \ldots\ldots\ldots\ldots(16)$$

$$\text{Provided } m < \frac{N}{3}$$

This test is similar in principle to that used by Sayers [7]. A table of significance levels is given in Appendix 8.4.

2.2.3 Tests of Additivity

These tests were used in an attempt to detect changes in the energy content of the evoked responses. These tests are described below.

2.2.3.1 Pre - and Post - Stimulus Energy Tests

The energy in the pre- and post-stimulus records was

compared by means of a two tailed t-test. For a section of pre-stimulus EEG the mean square value was calculated using the formula

$$E = \frac{1}{N} \sum_{i=1}^{N} x_i^2 \qquad \dots\dots\dots\dots\dots (17)$$

where E is proportional to the signal energy

N is the number of data points over which E is to be calculated

x_i is the ith value of the signal

This calculation was repeated for the section containing the CNV response and the difference between the two values was noted. For one second ISI CNV's the lengths of the pre- and post- stimulus sections were the same (N = 80 or 640 ms) but for the 4 second ISI CNV's only 200 points (1.6 seconds) of pre- stimulus information was available whereas 400 points (3.2 seconds) were included to encompass the CNV response.

The differences for each of the thirty-two trials were then averaged and the mean of the differences was subjected to a two-tailed t-test (see Appendix 8.5) to determine whether it was significantly different from zero. A non-significant mean value indicated no statistical difference between pre- and post- stimulus energy. A significant positive value indicated that the post-stimulus energy exceeded the pre-stimulus energy, whilst a significant negative value indicated the reverse.

2.2.3.2. Pre - and Post - Stimulus Mean Amplitude
          Differences Test

This test was also a paired two-tailed t-test. For

each of the thirty-two trials the differences between the
corresponding pre- and post-stimulus phasor lengths for a
given harmonic component were formed. The mean of the diff-
erences was calculated and tested to establish whether it
was significantly different from zero. A significant posi-
tive result indicated that the evoked potential was associat-
ed with an additive effect at the nth harmonic, although it
gave no indication as to the mechanism involved. Because of
the limited amount of pre-stimulus information (see section
2.2.3.1) it was not possible to perform this test on the four
second ISI CNV's. (See also Appendix 8.5)

2.2.3.3 Nearest and Furthest Mean Amplitude Test

This test investigated the variation of amplitude with
phase angle in the post-stimulus nth harmonic phasor diagram.
Increased amplitudes in the direction of preferred phase com-
bined with decreased amplitudes in the opposed direction
would be evidence for an additive effect. The mean length
of that half of the vectors whose phase angles lay within the
smallest arc was calculated as was that of the remaining
vectors. A one-tailed t-test was then performed to determine
whether the former mean value was greater than the latter.
In order to allow for the possibility of unequal variances,
a correction was made to the degrees of freedom used in these
statistical tests (See Appendix 8.6). A significant result
would provide evidence for an additive effect. This test is
not infallible, however. The additive signal might combine
with an oppositely directed phasor to produce a small phasor
in the smallest arc, or alignment of all the phasors in the

preferred direction would also render the test unreliable. For these reasons the results of this test should not be examined without reference to the tests for phase ordering previously described.

2.3 Eye Movement Corrections

At an early stage of the investigation it was found to be necessary to remove the effects of eye movements from the measured EEG signal. These effects are due to a steady potential between the cornea and the retina of each eye. When the eyes are moved the proportion of this potential detected at the scalp electrodes varies and hence an artefact related to the ocular position is superimposed on the EEG signal. Because of the relative magnitudes of the EEG and the corneo-retinal potential the artefact introduced is considerably greater than the EEG. Thus the EEG may be completely obscured by the artefact. A number of workers [8,9,10,11,12,13] had published details of methods for removing the artefact but no record of a comparison of the available techniques could be found.

One method of removing the effects of eye movements from the EEG was proposed and used by McCallum and Walter [8]. The method is based on the use of a potentiometer to balance out the effects of vertical eye movements. One end of the potentiometer was connected to a mid-frontal electrode and the other end to an electrode placed on the mastoid processes as shown in Figure 2-5. The centre tap of the potentiometer was used as a reference for a vertex EEG electrode. The operation of the circuit is best explained by the use of

a simplified equivalent circuit as depicted by Figure 2-6. The EOG signal (V_{EOG}) is shunted by the resistors R_1, R_2, R_3 in series. These resistors represent the tissue etc. surrounding the eye. At point P_1 along this resistance chain the EEG generator may be considered to be connected. Another point (P_2) represents the mastoid process. If the EEG signal is measured between points P_3 and P_2 then the observed signal will be the sum of both the EEG and a fraction of the EOG. The fraction of the EOG signal contained in the EEG will be given by $R_3/(R_1 + R_2 + R_3)$.

$$\therefore \quad V = V_{EEG} + \frac{R_3\ V_{EOG}}{R_1 + R_2 + R_3} \quad \dots\dots\dots\dots\dots (18)$$

If, however, the potentiometer is connected as shown in Figure 2-7a then by adjusting the position of the wiper the vertical EOG component can be balanced out. The point of balance can be derived from the re-drawn circuit Figure 2-7b. The current, I, from the EOG generator splits into I_1 and I_2 at the connection of R_5 and R_1

$$I_1 = \frac{R_1 + R_3}{R_1 + R_3 + R_5}\ I \quad \dots\dots\dots\dots\dots (19)$$

$$I_2 = \frac{R_5}{R_1 + R_3 + R_5}\ I \quad \dots\dots\dots\dots\dots (20)$$

The potentiometer, R_5, may be represented as two resistors in series the common point being the wiper. Thus the two resistors have the values kR_5 and $(1-k)\ R_5$ where
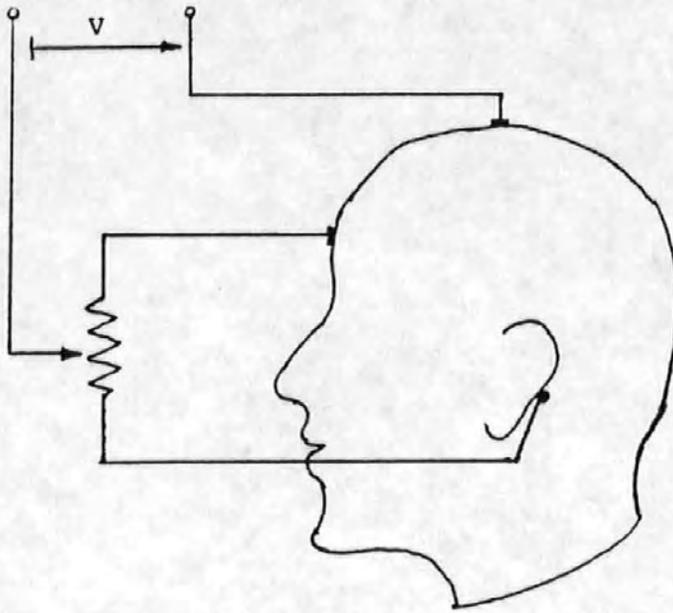
Figure 2-5

Eye movement correction method
due to McCallum and Walter.
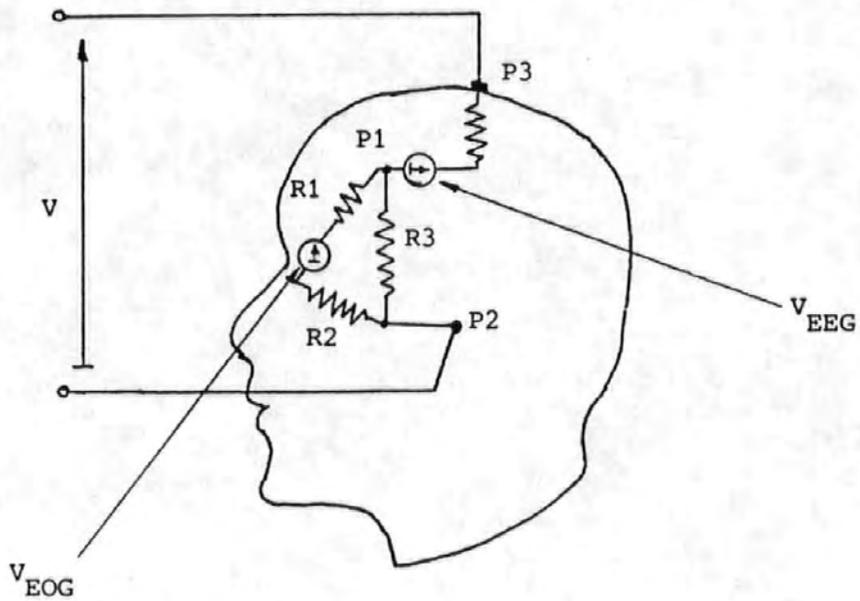
Figure 2-6

The simplified equivalent circuit
without potentiometer
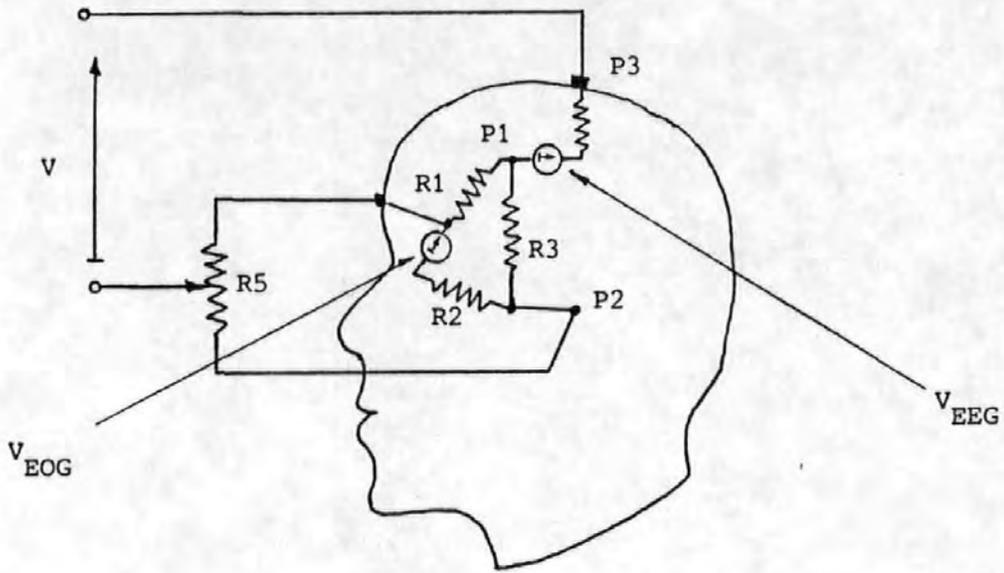
Figure 2-7a

The simplified equivalent circuit
with potentiometer.
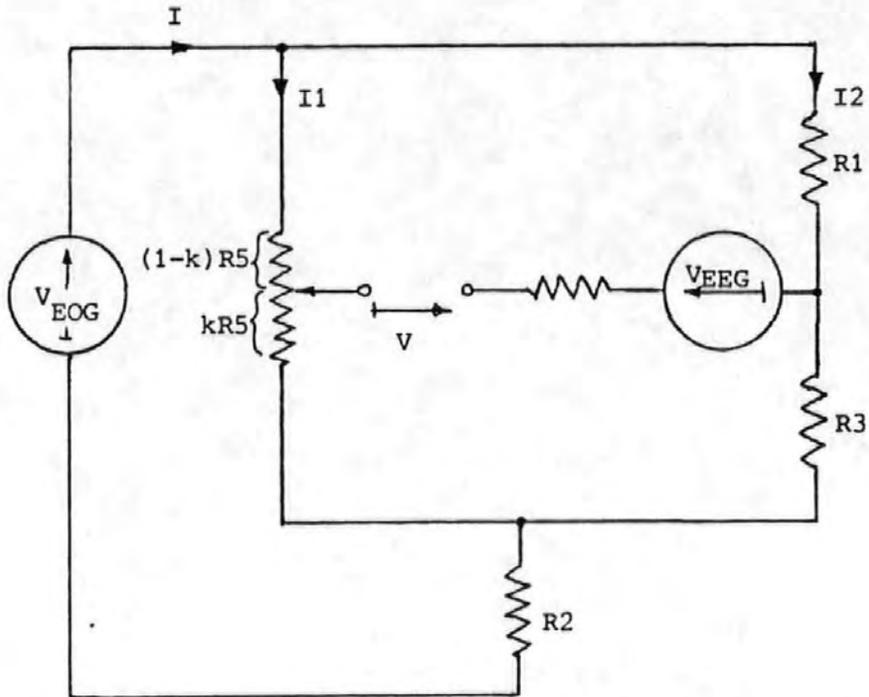
Figure 2-7b The re-drawn equivalent circuit.

k is a fraction between 0 and 1 representing the setting of the potentiometer. When I_1kR_5 equals I_2R_3 then the EOG signal will be eliminated from the EEG.

Thus

$$I_1kR_5 = I_2R_3 \qquad \ldots\ldots\ldots(21)$$

$$\frac{R_1+R_3}{R_1+R_3+R_5} I\ kR_5 = \frac{R_5}{R_1+R_3+R_5} I\ R_3 \ldots(22)$$

$$\therefore \quad (R_1 + R_3)\ k = R_3 \qquad \ldots\ldots\ldots\ldots(23)$$

$$\therefore \quad k = \frac{R_3}{R_1+R_3} \qquad \ldots\ldots\ldots\ldots(24)$$

Since $\frac{R_3}{R_1+R_3}$ is always in the range 0 to 1 for positive values of R_1 and R_3 the balance point can always be attained.

A variation of this technique was proposed by Girton and Kamiya [9] and is shown in Figure 2-8. The observed EEG signal is again assumed to be the sum of the true EEG and a fraction of the EOG signals. Unlike McCallum and Walters method, this technique allows for the independant correction of both horizontal and vertical components of the EOG in the EEG. The horizontal and vertical components of the EOG are obtained from electrodes placed around the eyes and are amplified by the differential amplifiers A_1 and A_2. The EEG signal is amplified by a further differential amplifier A_3 connected to electrodes at the vertex and at the mastoid processes. Fractions of the amplified EOG components are then tapped off by means of the potentiometers R_1 and R_2.
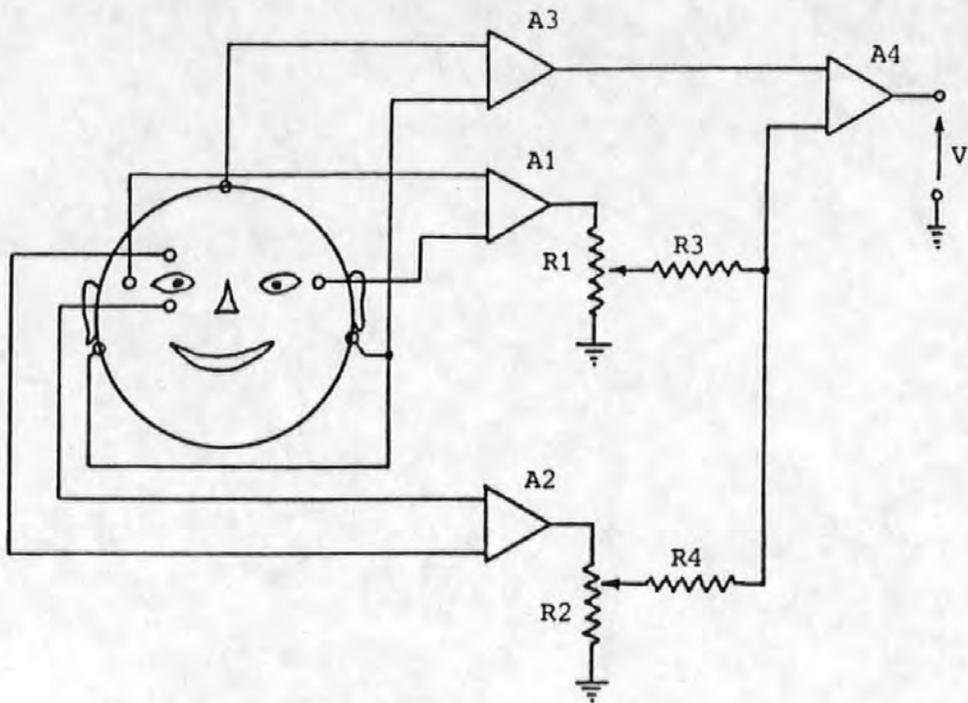
Figure 2-8

The method of Girton and Kamiya
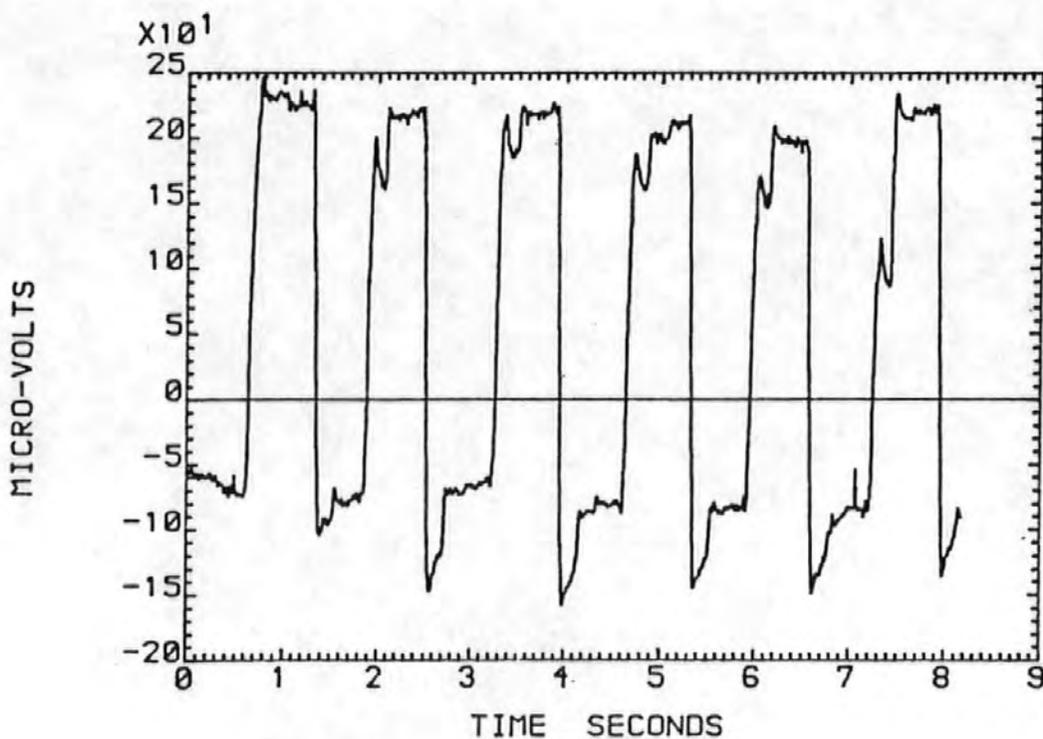
Figure 2-9

A typical vertical left EOG signal during
the eye movement correction experiments

These signals are then summed by the resistors R_3 and R_4.
Finally the summed EOG components are subtracted from the
EEG by means of a further differential amplifier A_4. Thus
the output signal V consists of the corrupted EEG signal
less fractions of the horizontal and vertical components
of the EOG. By adjusting the potentiometers R_1 and R_2 these
fractions can be chosen so as to remove the corrupting EOG
components in the output signal.

Both these techniques (McCallum and Walters and Girton
and Kamiya) rely on the manual adjustment of the potentio-
meter(s) to obtain maximum artefact rejection. These ad-
justments are normally made whilst observing the chart out-
put and are thus subjective. As the balance point (i.e.
the point of maximum artefact rejection) is approached so
the effect of further adjustment becomes more difficult to
assess because of the masking nature of the background EEG.
The process of adjustment is also rather slow. If, for
example, it takes one minute to adjust each potentiometer,
then for a 16 channel recording it would take about a quarter
of an hour to set the potentiometers for McCallum and Walters
method or over half an hour for Girton and Kamiya's method.
This would normally be quite unacceptable.

2.4   Assessment of the Eye Movement Correction Methods

The quantitative assessment of the different correction
procedures was based on the knowledge that the autocorre-
lation function (a.c.f.) of a rectangular waveform is tri-
angular. [14] In the experiments described in Section 3.3
the almost periodic eye movements produced an EOG which was

nearly a rectangular wave (Figure 2-9) and so the measured EEG's were contaminated by a nearly rectangular wave. It is shown below that incomplete correction may be detected by the presence of a triangular component of the same period as the EEG present in the a.c.f. of the corrected EEG. If the a.c.f. showed no triangular components of similar period to the EOG, then the correction procedure was effective. If the a.c.f. fell rapidly to an average value of zero the efficiency of the corresponding correction was high. This method allowed very small residual EOG signals to be detected in the background EEG activity even in cases where they were visually indiscernable in the corrected waveform.

Let $Q(t)$ be the EEG signal after incomplete correction

Then $C_{qq}(\tau) = \varepsilon[Q(t)Q(t+\tau)]$ . . . . (25)

Where $C_{qq}(\tau)$ is the autocovariance of Q at lag τ, ε denotes the expected value and all signals are adjusted to have zero mean value.

$Q(t)$ may be considered to be the sum of the uncorrupted EEG signal $E(t)$ and the remaining artefact $I(t)$, so that

$$Q(t) = E(t) + I(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots (26)$$

Hence

$$C_{qq}(\tau) = \varepsilon\{[E(t) + I(t)] \cdot [E(t+\tau) + I(t+\tau)]\} \ldots (27)$$

$$= \varepsilon[E(t).E(t+\tau)] + \varepsilon[I(t).I(t+\tau)]$$

$$+\varepsilon[E(t).I(t+\tau)] + \varepsilon[I(t).E(t+\tau)] \quad \ldots\ldots (28)$$

or $\quad C_{qq}(\tau) = C_{ee}(\tau) + C_{ii}(\tau) + C_{ei}(\tau) + C_{ie}(\tau)$ (29)

where the suffices indicate the auto and cross covariances.

Because E(t) and I(t) are statistically independant, $C_{ei}(\tau) = C_{ie}(\tau) = 0$, while $C_{ee}(\tau)$ will fall rapidly with increasing τ.[†]

Hence

$$C_{qq}(\tau) \simeq C_{ii}(\tau) \text{ for large } \tau.$$

Since the autocorrelation function and the autocovariance function are related by the variance then

$$R_{qq}(\tau) \simeq R_{ii}(\tau) \text{ for large } \tau. \text{ (where R denotes the auto-correlation function)}$$

Since I(t) is approximately rectangular then $R_{ii}(\tau)$ and hence $R_{qq}(\tau)$ will be triangular.

Thus to assess the effectiveness of the correction method the autocorrelation function of the corrected waveform was calculated and plotted. Those a.c.f.'s which contained any triangularity were examined further and the period, and the peak to peak envelope amplitude of the triangularity were noted at a lag of two seconds. A two second lag was chosen since the initial decrease in the autocorrelation had always been completed within two seconds (by observation of the a.c.f.'s). Figure 2-10 shows graphically how these measurements were made. The peak to peak amplitude of the a.c.f.'s at this lag is referred to as the autocorrelation co-efficient (a.c.c.)

[†]The autocovariance function $C_{ee}(\tau)$ of the EEG signal E(t) will fall rapidly to zero with increasing τ since the EEG contains no regular periodic component.
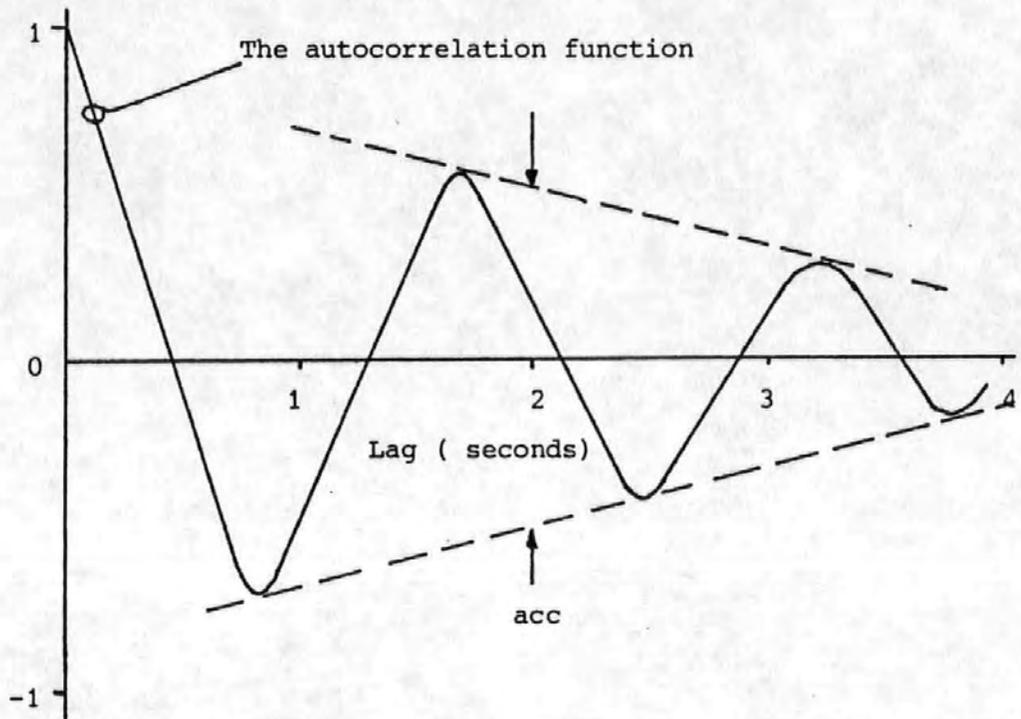
The autocorrelation co-efficient (acc) is the
peak to peak amplitude of the envelope of the
autocorrelation function at a lag of two seconds.

Figure 2-10

Measurement of the Autocorrelation Co-efficient

As a practical test of the sensitivity of the method a square wave of known amplitude was added to a section of 'eyes open' background EEG. The frequency of the square wave was chosen to be 0.8 Hz as this was about the most common frequency observed in the EOG signals during the eye movement correction experiments. The resultant signal was analysed in the same way as the corrected EEG signals. Table 2-1 shows the results of these tests with differing amounts of square wave added to the synthetic background EEG. From the table it may be deduced that the autocorrelation co-efficient gives a good indication of the magnitude of re-sidual artefact and can detect residual components with amplitudes of only one quarter of the background. Figure 2-11 shows the variation of the a.c.c. with differing amounts of residual square wave present in the EEG.

2.5   The Modified Correction Method

The modified form of Quilters correction method [10] is described here. The fundamental assumption upon which the method is based is that the measured EEG signal can be con-sidered to be formed from a linear combination of the true EEG and the interfering artefact signals. Thus if the arte-fact signals could be measured independently of the EEG then by subtracting the appropriate fractions of the artefact signals from the observed (corrupted) EEG the true EEG could be established. Fortunately, the artefact signals due to eye movements can be obtained by placing electrodes in close prox-imity to the eyes, thus if the fractions of these signals present in the observed EEG are known the true EEG can be

Table 2-1

The results of tests performed to determine

the sensitivity of the ACC to residual square wave

SQUARE WAVE BACKGROUND	RATIO dB	ACC OBSERVED	FREQUENCY OBSERVED	COMMENT
100/10	+ 20	1.489	0.8	Triangularity easily visible in ACF Square wave easily visible in EEG.
50/10	+ 14	1.447	0.8	"
40/10	+ 12	1.430	0.8	"
30/10	+ 9.5	1.375	0.8	"
18/10	+ 5.1	1.211	0.8	"
10/10	0	0.885	0.8	Triangularity easily visible in ACF. Square wave visible in EEG but noisy.
7.5/10	- 2.5	0.717	0.8	Triangularity easily visible in ACF. Square wave just visible in EEG.
5/10	- 6.0	0.552	0.82	Triangularity visible in ACF Square wave not visible in EEG.
3.75/10	- 8.5	0.465	0.82	Triangularity visible in ACF
2.5/10	-12.0	0.383	0.78	Triangularity just visible in ACF
0/10	-	0.256	-	No visible periodicity in ACF
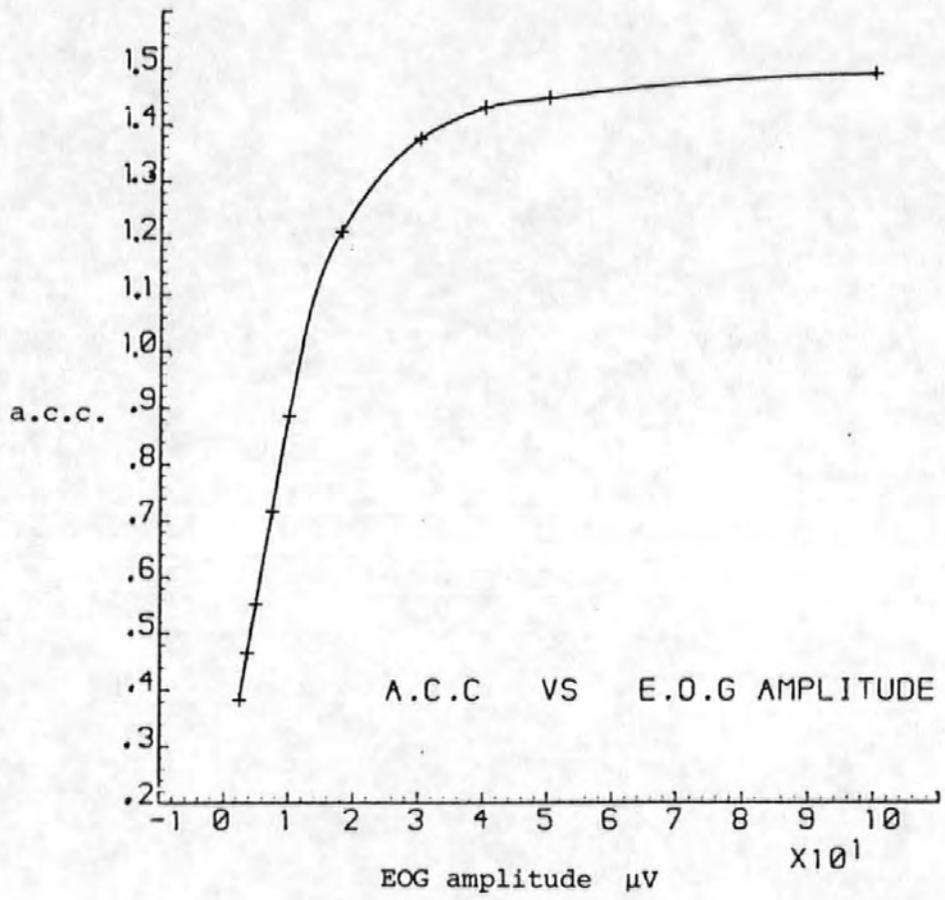
Figure 2-11

A graph showing the variation of the
autocorrelation co-efficient with the
amplitude of a synthesized square
EOG signal.

obtained. Since the eyes are free to swivel about two axes it is necessary to allow for both horizontal and vertical artefact signals. Furthermore since the eyes do not always move in unison or through the same amount of arc, and may have different dipole moments, it may be necessary to allow for horizontal and vertical components from each eye in the EEG.

Assuming that the transmission path between the source and the scalp electrode is linear and $M(t)$ is the measured EEG signal, $E(t)$ is the true EEG signal, K_1, K_2, K_3, K_4 are constants, $V_L(t)$ is the vertical component of the left EOG $H_R(t)$ is the horizontal component of the right EOG etc., then

$$M(t) = E(t) + K_1 V_L(t) + K_2 V_R(t) + K_3 H_L(t) + K_4 H_R(t) \dots\dots (30)$$

or

$$E(t) = M(t) - [K_1 V_L(t) + K_2 V_R(t) + K_3 H_L(t) + K_4 H_R(t)] \dots (31)$$

Thus if the constants $K_1 \dots\dots K_4$ could be found then the uncorrupted EEG signal $E(t)$ could be determined.

Rewriting equation (30) in discrete time form gives

$$M(i) = E(i) + K_1 V_L(i) + K_2 V_R(i) + K_3 H_L(i) + K_4 H_R(i) \quad \dots (32)$$

where i represents the sample number.
Defining

$$M_{VL} = \Sigma [M(i) V_L(i)] \qquad\qquad \dots\dots\dots\dots (33)$$

$$M_{VR} = \Sigma [M(i) V_R(i)] \qquad\qquad \dots\dots\dots\dots (34)$$

$$M_{HL} = \Sigma [M(i) H_L(i)] \qquad\qquad \dots\dots\dots\dots (35)$$

$$M_{HR} = \Sigma [M(i) H_R(i)] \qquad\qquad \dots\dots\dots\dots (36)$$

Where all the summations are carried out over the range $i = 1$ to N, the number of data samples.

Substituting equation (32) into equation (33) gives:-

$$M_{VL} = \Sigma[\{E(i)+K_1V_L(i)+K_2V_R(i)+K_3H_L(i)+K_4H_R(i)\}V_L(i)] \quad \ldots (37)$$

$$= \Sigma[E(i)V_L(i)+K_1V_L^2(i)+K_2V_R(i)V_L(i)+K_3H_L(i)V_L(i) +$$

$$K_4H_R(i)V_L(i)] \qquad \ldots\ldots(38)$$

defining $P_{VL} = \Sigma V_L^2(i)$ $\qquad \ldots\ldots(39)$

$$B = \Sigma[V_R(i)V_L(i)] \qquad \ldots\ldots(40)$$

$$C_{CL} = \Sigma[V_L(i)H_L(i)] \qquad \ldots\ldots(41)$$

$$C = \Sigma[V_L(i)H_R(i)] \qquad \ldots\ldots(42)$$

gives

$$M_{VL} = \Sigma[E(i)V_L(i)] + K_1P_{VL} + K_2B + K_3C_{CL} + K_4C \qquad \ldots\ldots(43)$$

Substituting equation (32) into equation (34) and defining

$$P_{VR} = \Sigma V_R^2(i) \qquad \ldots\ldots(44)$$

$$D = \Sigma[V_R(i)H_L(i)] \qquad \ldots\ldots(45)$$

$$C_{CR} = \Sigma[V_R(i)H_R(i)] \qquad \ldots\ldots(46)$$

gives

$$M_{VR} = \Sigma[E(i)V_R(i)] + K_1B + K_2P_{VR} + K_3D + K_4C_{CR} \qquad \ldots\ldots(47)$$

Substituting equation (32) into equations (35) and (36) in a similar manner and defining

$$P_{HL} = \Sigma H_L^2(i) \qquad \ldots\ldots(48)$$

$$P_{HR} = \Sigma H_R^2(i) \qquad \ldots\ldots(49)$$

$$A = \Sigma[H_L(i)H_R(i)] \qquad \ldots\ldots(50)$$

-53-

gives

$$M_{HL} = \Sigma[E(i)H_L(i)] + K_1C_{CL} + K_2D + K_3P_{HL} + K_4A \quad \ldots\ldots\ldots(51)$$

and

$$M_{HR} = \Sigma[E(i)H_R(i)] + K_1C + K_2C_{CR} + K_3A + K_4P_{HR} \quad \ldots\ldots\ldots(52)$$

Equations (43), (47), (51), (52) may be more conveniently handled if written in matrix form.

$$
\begin{bmatrix} M_{VL} \\ M_{VR} \\ M_{HL} \\ M_{HR} \end{bmatrix} = \begin{bmatrix} \Sigma[E(i)V_L(i)] \\ \Sigma[E(i)V_R(i)] \\ \Sigma[E(i)H_L(i)] \\ \Sigma[E(i)H_R(i)] \end{bmatrix} + \begin{bmatrix} P_{VL} & B & C_{CL} & C \\ B & P_{VR} & D & C_{CR} \\ C_{CL} & D & P_{HL} & A \\ C & C_{CR} & A & P_{HR} \end{bmatrix} \begin{bmatrix} K_1 \\ K_2 \\ K_3 \\ K_4 \end{bmatrix} . (53)
$$

or

$$\underset{\sim}{M} = \underset{\sim}{Z} + \underset{\sim}{X}.\underset{\sim}{K} \quad \ldots\ldots\ldots(54)$$

Where $\underset{\sim}{M}$, $\underset{\sim}{Z}$, $\underset{\sim}{X}$ and $\underset{\sim}{K}$ represent the respective matrices.

The elements of the column matrix $\underset{\sim}{Z}$ may be considered as the cross co-variance between the true EEG signal and the four artefact signals at zero lag.

Provided $E(i)$ does not affect the artefact signals $V_L(i)$ etc. then the correlation between $E(i)$ and the artefact signals will be small. The matrix $\underset{\sim}{Z}$ is thus assumed to be zero.

The values $K_1 - K_4$ may now be obtained by solving the equation

$$\underset{\sim}{M} = \underset{\sim}{X}.\underset{\sim}{K} \quad \ldots\ldots\ldots(55)$$

Since matrices $\underset{\sim}{M}$ and $\underset{\sim}{X}$ only involve quantities which

can be obtained from the signals $M(i)$ and $V_L(i)$, $V_R(i)$, $H_L(i)$ and $H_R(i)$.

Therefore $\underset{\sim}{K} = \underset{\sim}{X}^{-1} \underset{\sim}{M}$ .... (56)

The values of $K_1.....K_4$ may then be substituted into equation (31) and hence the true EEG signal can be calculated.

There are however a number of limitations to this technique. The most important of these are:-

(i)   A considerable amount of computation is involved in the calculation of the 'sums of products' terms in matrices $\underset{\sim}{X}$ and $\underset{\sim}{M}$.

(ii)   The matrix $\underset{\sim}{Z}$ may not be sufficiently small to be neglected.

(iii)   The method (as described) cannot be applied on-line since a prior knowledge of the signals over N data points is required.

Offsetting these disadvantages are:-

(i)   No manual setting up is required. (Unlike the methods due to McCallum and Walter and Girton and Kamiya where manual setting of the potentiometers is required. Manual setting up is both time consuming and is subjective and is therefore also inaccurate).

(ii)   The method is self-optimizing i.e. New and optimum values of $K_1 - K_4$ are found for each N point data epoch.

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3. Experimental Techniques

3.1 Initial CNV Tests

In order to gain first hand information about the problems associated with obtaining CNV responses two subjects were examined using conventional evoked response averaging equipment. These tests were carried out using equipment available at Freedom Fields Hospital during the first few months of this investigation. The two stimuli used were an auditory 'click' followed by a flashing lamp. Averaging over 64 trials was performed by a Medelec DAV6 digital averager. The resulting average CNV's are shown in Figure 3-1.

The observations made from these tests shaped the way in which the present measurement system was developed and the tests were performed. These observations are summarized below.

(1) The dynamic range of the averager[†] was often exceeded causing it to reject some of the trials.

(2) The onset of the visual stimulus caused the subjects to blink in several of the individual trials. These blinks are highly undesirable since they introduce an artefact which is synchronised to the visual stimulus.

[†]The Medelec DAV6 averager uses an 8 bit analogue-to-digital converter and hence has an inherent dynamic range of one part in 2^8 or 48 dB. at the input. However this range is only fully utilized if the gain of the preceeding analogue stage is set such that the largest input signal just fails to overload the converter. Unfortunately the variable nature of most bioelectric signals means that the amplitude of the largest signal cannot be predicted. Thus either a considerable amount of "Headroom" must be allowed (which in turn reduces the effective dynamic range), or a certain degree of overloading of the converter must be tolerated.

−40μV

click   lamp

slight negative shift
i.e. CNV is visible

little or no CNV response

−40μV

click   lamp

← 1 second →
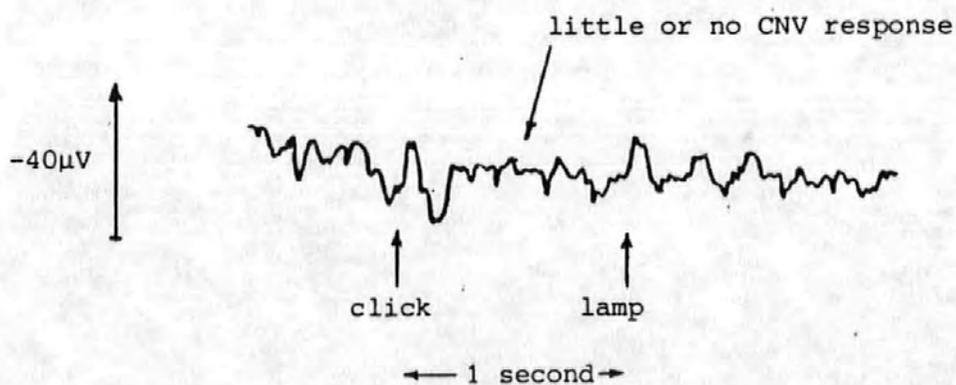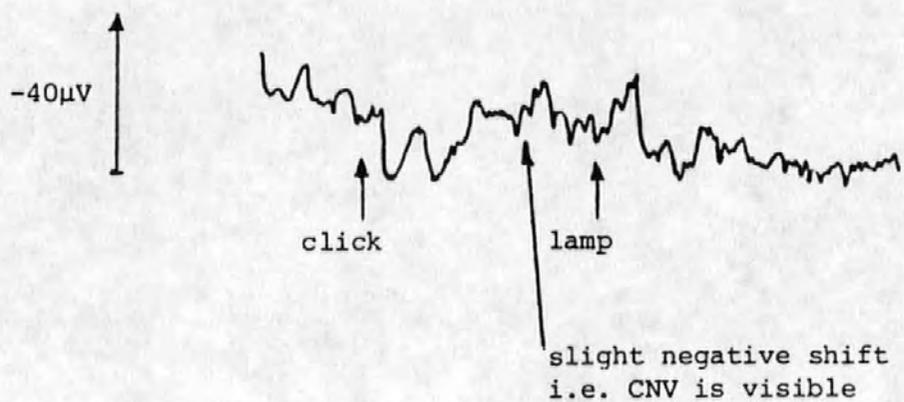
Figure 3-1

The initial attempts at recording CNV responses

(3) The subjects became tired and showed less motivation in the later trials.

(4) The subjects frequently moved their eyes which invariably caused the signal averager to overload. This indicated the presence of quite large artefacts induced by eye movements.

As a result of these observations -

(1) The dynamic range of the proposed data acquisition system was increased to 72 dB.

(2) Two auditory stimuli were used in place of one auditory and one visual.

(3) The possibility of using fewer trials in the averaging process or alternative methods to averaging would clearly have to be considered.

(4) Some method of removing the effects of eye movement artefact would have to be implemented.

3.2 Data Transfer and Preliminary Processing

During transfer from the disk of the minicomputer logging system to a data base on the Polytechnic main computer several tests were performed to verify the authenticity of the data and to ensure that no errors occurred in the transfer. In view of the large amounts of data involved these tests were performed automatically. The eye movement correction experiments involved the transfer of nearly 100,000 twelve bit words for each subject and approximately 400,000 words for each subject for the CNV tests.

For compatibility with conventional hardware each of the twelve bit words was split into two six bit quantities to which parity and marker[1] bits were added. These eight bit quantities (bytes) were initially transferred to the main computer on paper tape although eight inch, single density, single sided, floppy disks were subsequently adopted for speed and ease of handling. To each batch of 1024 words (2048 bytes) were added a batch number, an unique 'start of batch' indicator and a modulo 256 (eight bit) checksum.

When read into the main computer the parity and marker bits were tested for each byte and the checksum re-calculated and compared with that read for each batch. Any errors then found were reported[2] and the faulty batch was rejected. Rejected batches were re-transferred at a later date. The data for each experiment and subject was stored in a sequential access data file along with certain relevant system and other parameters (e.g. the sample rate, the analogue filter cut-off frequencies, the amplitude calibration constants, subjects name etc.) The final test of the transferred data was performed with the aid of a programme written in Fortran IV and using the Gino [1] graphics subroutines. This programme (Appendix 8.7) was used to plot the data on an interactive graphics terminal where a visual comparison[3]

---

[1] The marker bit was used to indicate whether the six bits concerned were the most (marker bit = 1) or the least (marker bit = 0) significant of the original twelve bit word.

[2] Paper tape error rates $\simeq$ 1:1.8 x 10^6 bits
Floppy disk error rates < 1:34.7 x 10^6 bits.

[3] An identical waveform was not expected since the chart output of the EEG machine had different filtering to that employed in the acquisition electronics.

was made with the relevant section of the chart output of the EEG machine.

3.3 Eye Movement Corrections

As previously mentioned the eye movement artefact is caused by a standing potential between the cornea and the retina of the eye[2]. Whilst the eyes remain stationary the potential recorded from scalp electrodes will contain no artefact (except possibly a d.c. component) but any change in position will result in an artefact being superimposed on the background EEG activity. The amount of artefact introduced is related to the angular displacement of the eye and the position of the measuring electrodes [2]. Several methods of removing the artefact have been suggested based on the subtraction of a fraction of the electro-oculogram (EOG) i.e. the potential measured at electrodes placed in close proximity to the eyes, from the measured EEG [3,4,5]

Other methods involving a considerable degree of co-operation from the subjects [6,7] were examined but rejected on the grounds that such co-operation cannot always be obtained, particularly with very young, old or diseased subjects.

In order to test the effectiveness of the methods due to McCallum & Walter [3], Quilter [5] and a modified form of Quilters method derived here, eye movement experiments were performed on six volunteers. The volunteers were asked to make periodic eye movements whilst the EOG and EEG data was stored for subsequent analysis. To obtain consistent

eye movements through a known angle (20°) the wooden screen described in section 4.5.1 was utilised.

During these experiments the subjects were asked to fixate on the illuminated centre LED. One of the peripheral LED's was then switched on and the subjects were told to look repeatedly from the centre LED to the illuminated one at the periphery of the screen and back.

Whilst the subject was performing this task eight second epochs of data were digitized at 125 samples per second and stored. This procedure was repeated twice for each of the eight LED's around the periphery of the screen and for ten subjects. The data thus obtained consisted of digitized versions of the following six analogue signals:-

    (i)   The vertical component of the left EOG
            (electrodes 6 & 7).

    (ii)   The vertical component of the right EOG
            (electrodes 2 and 3).

   (iii)   The horizontal component of the left EOG
            (electrodes 4 and 5).

    (iv)   The horizontal component of the right EOG
            (electrodes 4 & 5).

    (v)   The vertex EEG referred to linked earlobes.

    (vi)   The analogue corrected vertex EEG (McCallum
            and Walters method [3].

The positions of the electrodes for the EOG signals

are shown in Figure 3-2.

Prior to the recordings the subjects were asked to make extreme up and down eye movements in order that the balancing potentiometer utilized in the correction method due to McCallum and Walter [3] could be adjusted for the optimum artefact rejection. It should be noted however that this "optimum setting" was somewhat subjective in that it was based on a visual assessment of the residual eye movement artefact present in the chart output of the EEG machine.

The digitized signals were then transferred from the minicomputer logging system to the Polytechnic main computer for analysis. To assess the effectiveness of the correction techniques the procedure described in section 2.4 was utilized.

3.4 Processing of Eye Movement Data

The computer programme in Appendix 8.8 was used to perform the eye movement corrections described in section 2.5 This programme also calculates the auto-correlation function of the corrected signal for analysis of the effectivness of the correction method. It was realized at an early stage that although Quilter's original correction method only used single horizontal and vertical EOG components it should be tried to discover if the modified method was significantly better. Furthermore, since visual examination of the early data showed a high degree of correlation between the left and right vertical EOG components it was thought worthwhile to try a correction based on two horizontal EOG components but only one vertical component. (The horizontal components
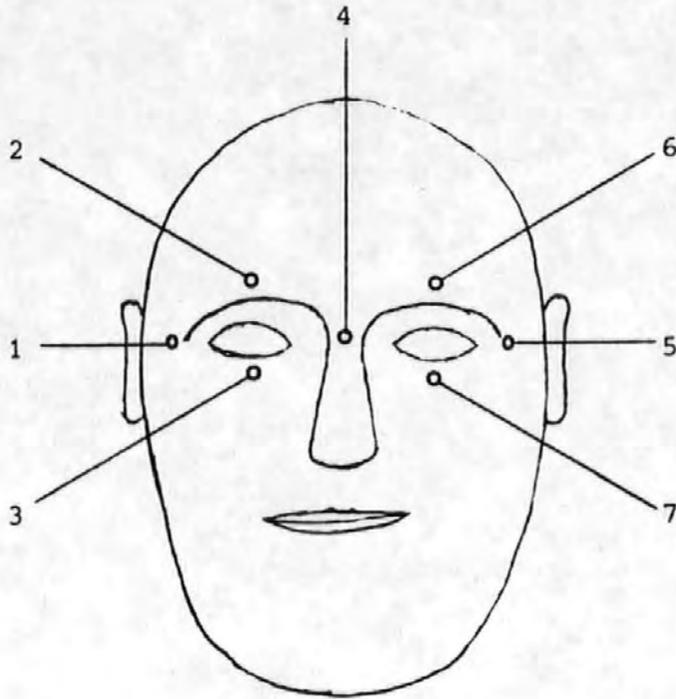
Figure 3-2

Electrode positions for
eye movement corrections

Plastic body

13 mm

Chlorided
silver wire
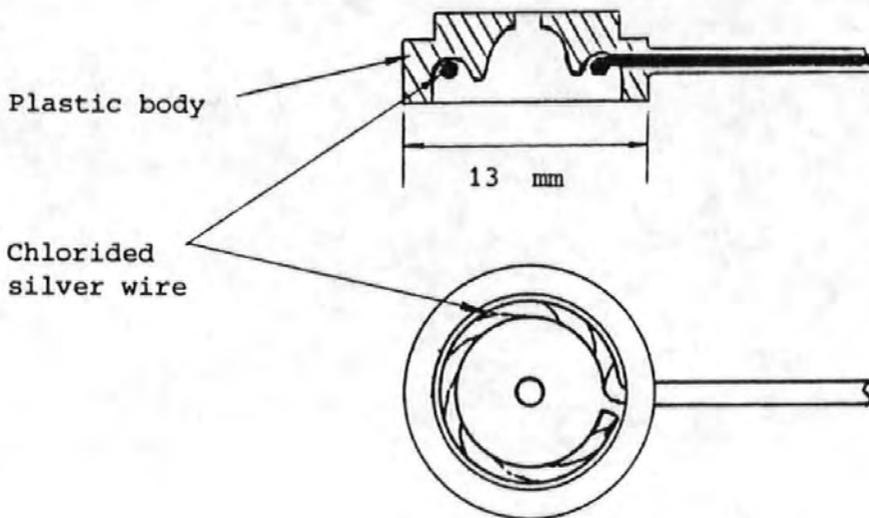
Figure 3-3

Chlorided silver wire
low frequency electrode

of the EOG's were not so highly correlated as the vertical ones). This correction method (the three channel method) may be derived in a similar way to that described in section 2.5 except that the initial equation is

$$M(t) = E(t) + k_1 V(t) + k_2 H_L(t) + k_3 H_R(t) \ldots\ldots\ldots (1)$$

where $V(t)$ is the vertical EOG signal from either the left or the right eye and all other quantities are as described in 2.5

The following processing was thus performed.

(i)   Correction by Quilter's method and calculation of autocorrelation function (acf).

(ii) Correction by the three channel method and calculation of the acf.

(iii) Correction by the method described in 2.5 i.e. the four channel method and calculation of the acf.

(iv) Calculation of the acf for the signal corrected by the method of McCallum and Walter.

In the four channel method electrodes 6-7 (vertical left EOG), 4-5 (horizontal left EOG), 2-3 (vertical right EOG) and 4-1 (horizontal right EOG) were used, (see Figure 3.2). In the three channel method all the above electrodes were used with the exception of those giving the vertical right EOG signal. For Quilters method electrodes 6-7 and 4-5 were used. (This is very slightly different to the electrode placements used by Quilter who would have used 6-7 and 5-7 instead of 6-7 and 4-5).

3.5 CNV Acquisition

In an attempt to obtain consistent CNV's from the subjects the recording procedure was standardized. The subjects were seated at one end of the recording room facing, and at about 2 metres distant from the end wall. The silver-silver chloride electrodes were attached to the subject with glue (scalp electrodes) or adhesive tape (facial electrodes). Facial electrodes (see Figure 3-2) were used to record the four components of the EOG for subsequent eye movement artefact correction by the four channel method described in Section 2.5 Two channels of CNV information were obtained from electrodes located at the vertex and at a point on the midline approximately 30mm anterior to the vertex. Both electrodes used a common reference which was obtained from a pair of connected electrodes on the left and right earlobes.

After being attached to the subject the electrodes were filled with 'Neptic' electrode gel by means of a syringe with a blunted needle inserted into the hole in the plastic body of the electrode holder (see Figure 3-3) The blunted needle of the syringe was also used to abraid the skin under the electrode whilst the gel was inserted. This procedure ensured a low impedance between the electrode and the scalp (typically $5k\Omega$ or less). When all the electrodes had been similarly treated the impedance between an arbitrary electrode and each of the others was measured using a Specialised Laboratory Equipment model EIT impedance meter.

This instrument measures (approximately) the modulus of the complex impedance at 13Hz. It is important to note that

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although the electrode scalp interface impedance is largely resistive at low frequencies, the use of a resistance measuring device with a d.c. internal source must be avoided at all cost when using chlorided silver electrodes [8]. Failure to observe this principle results in a serious degradation of the electrode stability.

If the impedance between any electrode pair was found to be greater than $5k\Omega$ the skin below the offending electrode was further abraided until this value was achieved. When the impedance of all the electrodes was satisfactory they were connected to the EEG machine and the electrode selector switches[†] set for the required electrode pairs. The filters in the data acquisition system (see Section 4.2) were set for a -3dB passband of 0.016 to 30Hz. The sample rate was 125Hz.

In order to familiarize the subject with the stimuli eight presentations were made during which the subject was not required to respond to the second stimulus. The subject was then told to "press the button as quickly as you can when you hear the tone" and a further thirty-two trials were made constituting the CNV run.

Since one particular area of interest was the effect of the inter-stimulus interval (ISI) i.e. the time delay between the click and the tone, two sets of thirty-two CNV trials were made. The first with a one second ISI and the second with a four second ISI. In each case eight presentations

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[†]These switches allow each of the machines differential amplifiers to be connected to any two electrodes on the scalp.

were made (with the appropriate ISI) before the run.

As with the previous section the digitized signals were transferred from the logging system to the Polytechnic main computer for processing and analysis.

3.6 Processing of CNV's

Because the CNV is of such a small magnitude in comparison to the normal background EEG activity they are difficult to quantify on an individual basis. Typically the CNV may be of 5-20μV in magnitude whereas normal background activity can be 50μV or more. However in favourable circumstances the individual CNV's can be observed in chart output of the EEG machine (see Figure 3-4). The normal method employed to improve CNV to background EEG (which may be regarded as signal to noise) ratio is to take a number of individual CNV's and average them. This process produces an average CNV but since the background EEG is not correlated from trial to trial the background EEG in the average is reduced by a factor proportional to the square root of the number of individual CNV's included in the average. In their original report Walter and colleagues [9] used averages of six or twelve trials.

After verification of the stored CNV data a programme was used to calculate the average CNV and plot this waveform on a graph plotter. The averaging was normally carried out over thirty-two individual CNV's. A typical average CNV is shown in Figure 3-5. Prior to averaging, each individual CNV was processed to remove the effects of eye movements as

Time marker (1 second per division).

Vertical left EOG.

Vertical right EOG.

Horizontal left EOG.

Horizontal right EOG.

30 µV/mm

Increasing
negativity

Vertex to linked earlobes EEG.

S1 evoked
response.

CNV

S2 evoked
response.

15 µV/mm

30 mm anterior of vertex to linked earlobes.
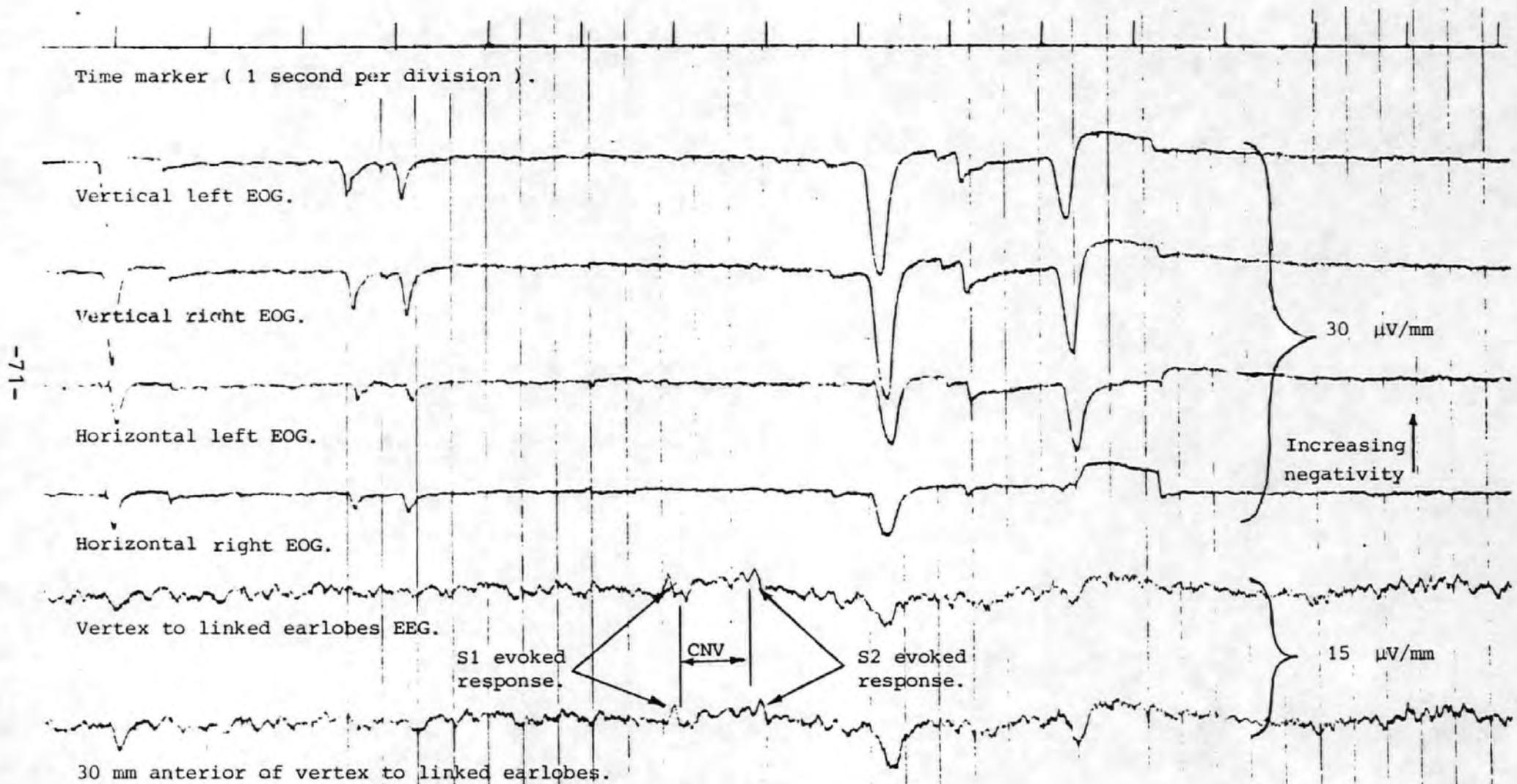
Figure 3-4   The raw CNV waveform
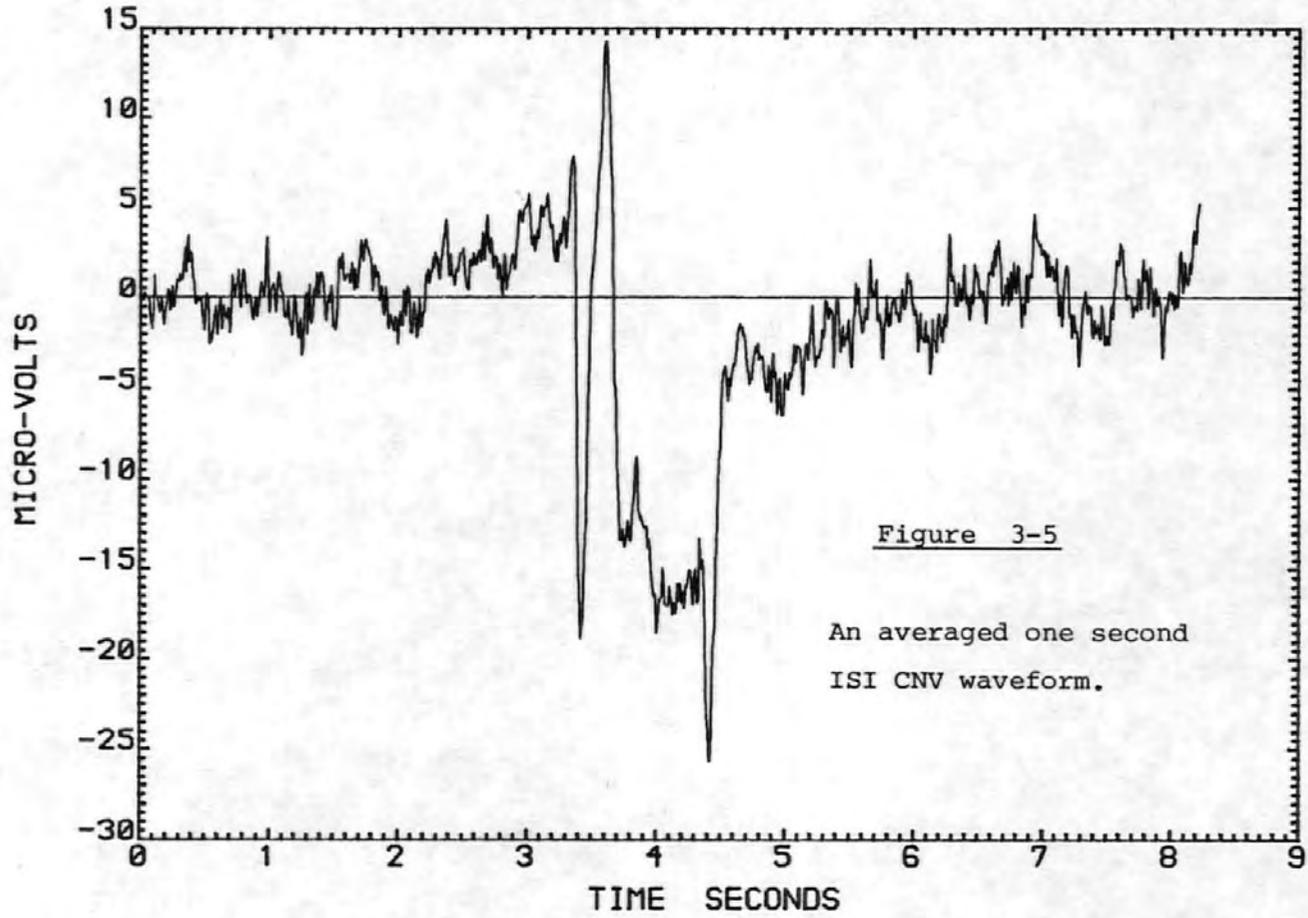
Figure 3-5

An averaged one second
ISI CNV waveform.

previously described. In an attempt to further improve the averaged CNV a linear phase digital lowpass filter was used to remove some of the remaining higher frequency background components. A linear phase filter was chosen in order to preserve the shape of the CNV as much as possible. The response and weighting co-efficients of the filter used most often are given in Figure 3-6. This and other filters have been designed with the aid of the computer programme given in the book by Rabiner and Gold [10].

In view of the work of Professor Sayers and colleagues [11, 12, 13, 14, 15, 16] concerning the nature of the aud-itory evoked response it was decided to perform similar ex-periments on the CNV. Sayers showed that the auditory evoked response may be due not to an additional response, but to a re-ordering of the phase spectra of the background, i.e. the phases of certain frequencies of the background EEG generators become entrained by the stimulus and hence re-shape the background EEG into the characteristic auditory evoked response. One of Sayers' most important tests was to calculate the energy in the EEG before and during the response to the auditory stimulus. According to Sayers if, as had previously been assumed, the response was an additional sig-nal then the energy during the response would be greater than that before or after, whereas if the response was due to a phase re-ordering then the energy would not change. Sayers offered evidence to suggest that this response may indeed be due to a phase re-ordering. A programme was therefore written to calculate the energies of individual background and CNV sections of the EEG. In addition to this test Fast

Frequency Hz.

Figure 3-6

Frequency response of low pass digital filter.
(sample rate = 125 Hz.)
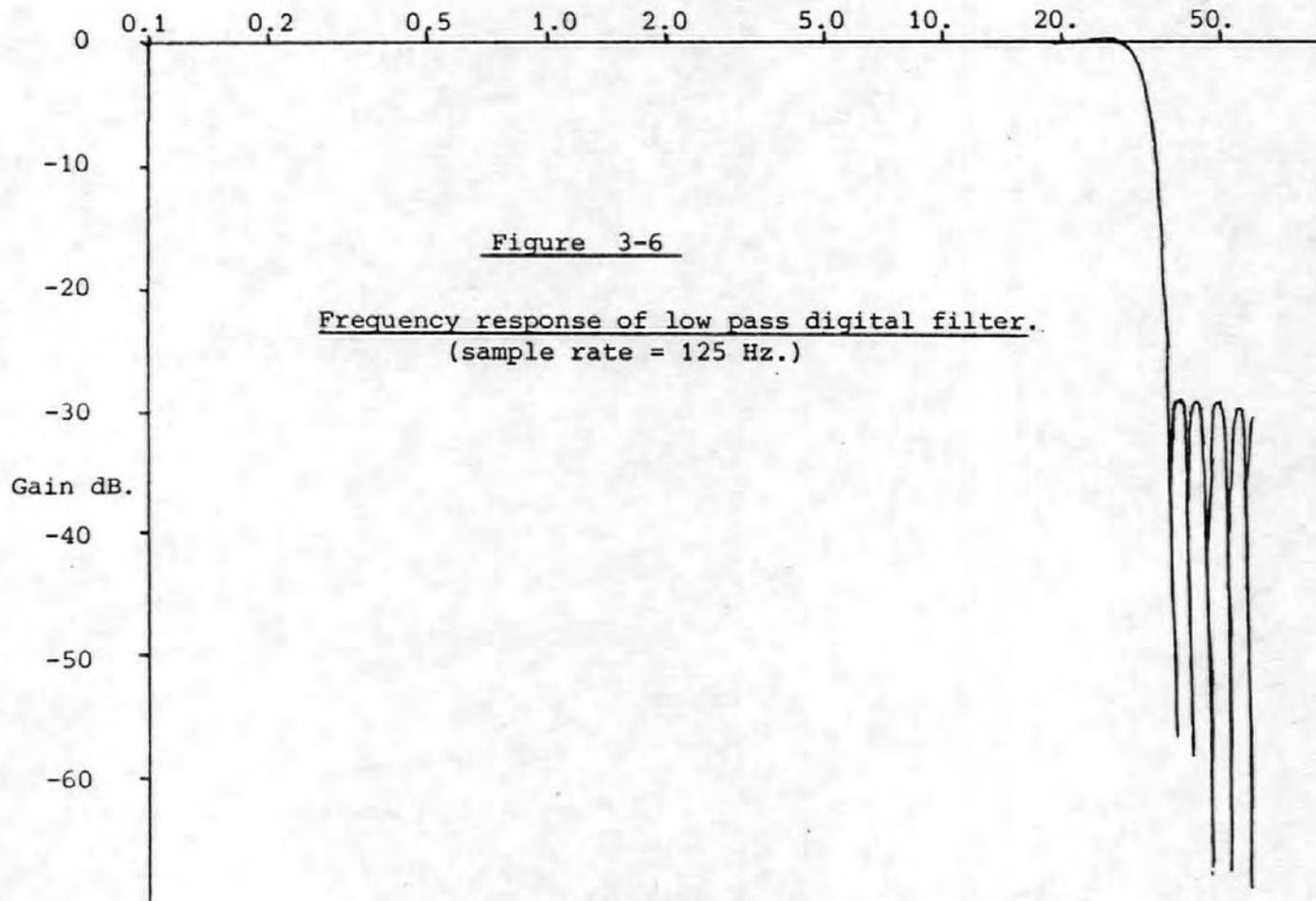
Filter co-efficients

H(1)=H(21)= -0.02232808
H(2)=H(20)=   0.01758909
H(3)=H(19)=   0.02921061
H(4)=H(18)= -0.01742668
H(5)=H(17)= -0.02649306
H(6)=H(16)=   0.04697604
H(7)=H(15)=   0.03685932
H(8)=H(14)= -0.09247865
H(9)=H(13)= -0.03773736
H(10)=H(12)= 0.31495064
H(11)   = 0.54097712

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Fourier transforms of the CNV's were performed and the phases of the first few frequency components were noted. This procedure was repeated for each of the thirty-two CNV measurements for each subject. The phase information for each frequency components was then sorted into twenty four bands of fifteen degrees each. Histograms (Figure 3-7) were then plotted for each frequency component showing the number of times a phase angle occurred within each band.

3.7 AEP Acquisition

In view of the important nature of Professor Sayers work [11, 12, 13] on the Auditory Evoked Potential (AEP), and the possible relevance of his findings to other evoked potentials (e.g. the CNV), it was decided to perform a short series of experiments in an attempt to confirm his results. AEP's were recorded from three subjects whilst relaxed and seated in the measurement room. The recording electrodes were placed at the vertex and on the right mastoid processes for the EEG signal, and in the usual facial positions for the four channel eye movement corrections. The auditory stimulus was obtained from an Amplaid stimulus generator set to deliver 1kHz. tone bursts with 100 ms. duration including approximately 10 ms of rise and fall according to a "cosine squared" law. This signal was applied to the right transducer of a pair of Koss K6 stereo headphones. The subjects auditory threshold was then determined by applying the above stimulus with gradually decreasing intensity. When the subject could no longer hear the stimulus tone then the threshold had been found. The experiment then commenced with an

HARMONIC 1

HARMONIC 2

HARMONIC 3

Figure 3-7

A typical CNV phase histogram

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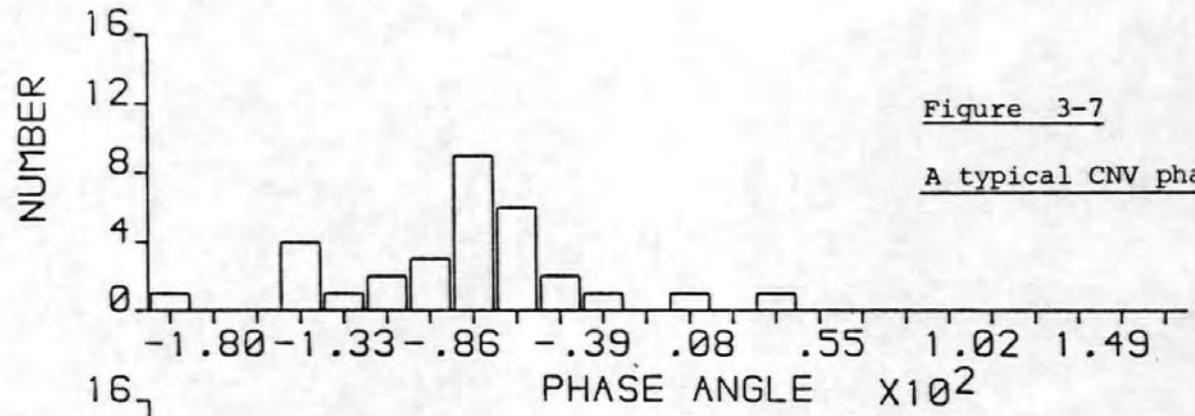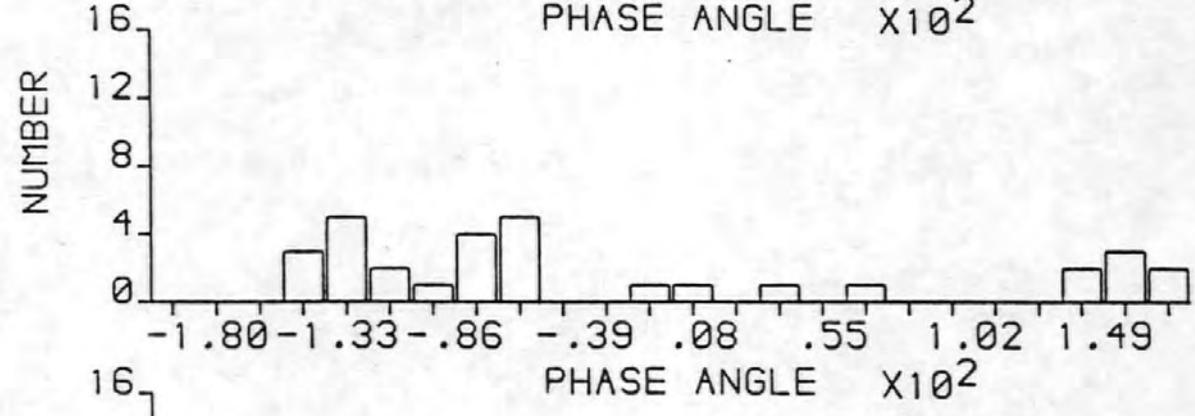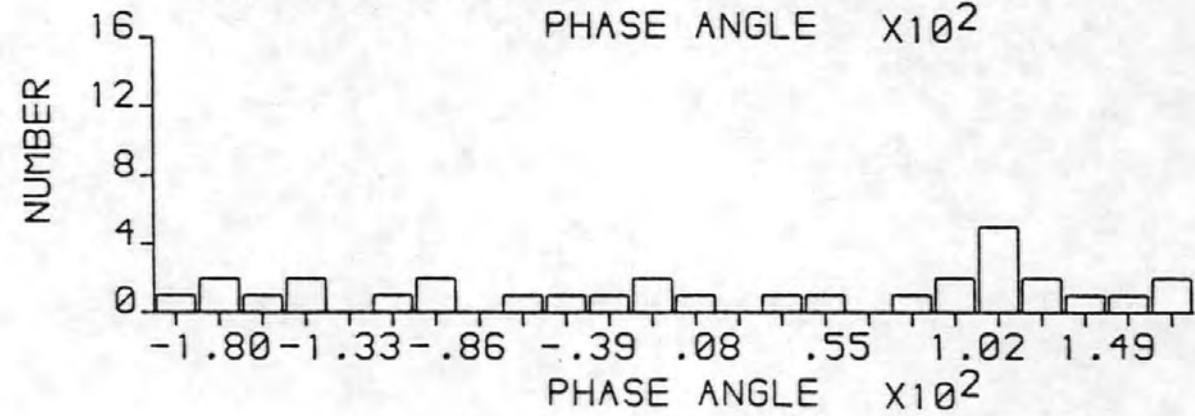
auditory stimulus 70dB (65 for one subject) above the threshold. Thirty-two sections of the EEG/EOG signals were then recorded each with two stimulus presentations at known places within each section. This gave a total of 64 evoked responses at this stimulus level. A further thirty-two trials were then made with the stimulus level set to 40dB above the subjects threshold.

3.8   Processing of AEP's

The stored AEP's were first processed to remove any eye movement artefact by the four channel correction method. The average AEP was then calculated and plotted. A typical pair of high and low stimulus averaged AEP's are shown in Figures 3-8a and 3-8b. A test was then performed to determine whether the energy present in the EEG signal after stimulus was any different to that in the signal prior to the stimulus. The "energy" values were calculated by summing the squares of values of the 64 data points preceeding and succeeding the stimulus as described in Section 2.2.3.1 Since the sampling rate was 125Hz this represented 0.512 seconds of data prior and subsequent to the stimulus. The differences betwen the pre- and post-stimulus energey values were calculated for each of the 64 individual responses, and the mean of these differences was subjected to a two-tailed t-test. The result of this test indicated whether the mean of the differences was significantly different from zero.

In an attempt to establish whether phase-ordering was present the eye movement corrected sections of EEG containing the AEP's were subjected to Fourier transformation by a
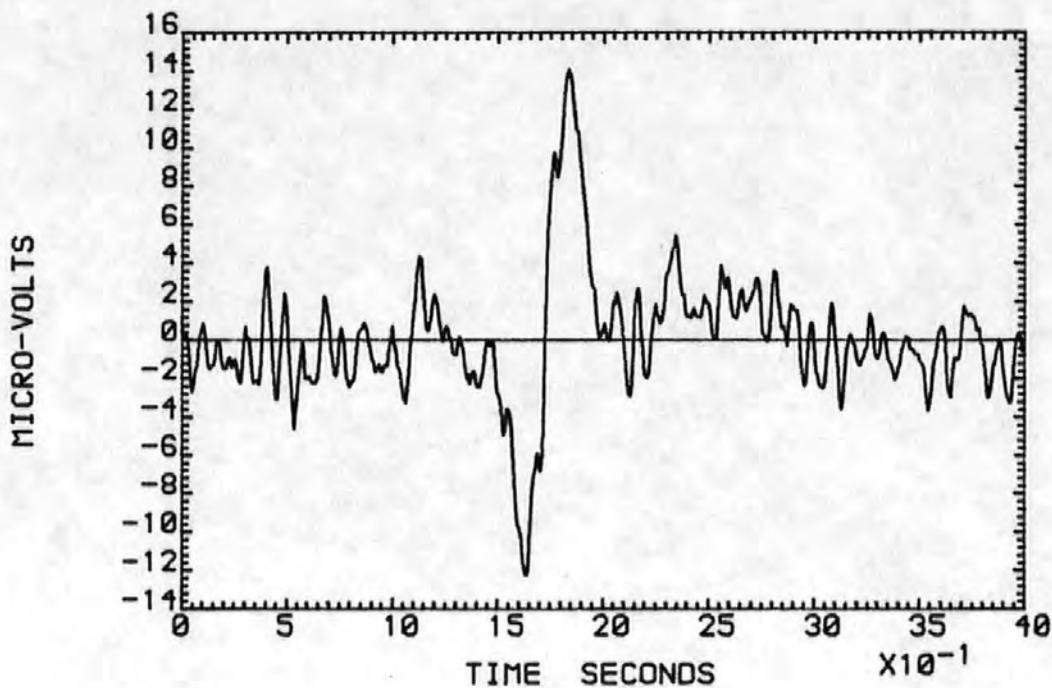
Figure 3-8a An averaged auditory response
to a high level stimulus.
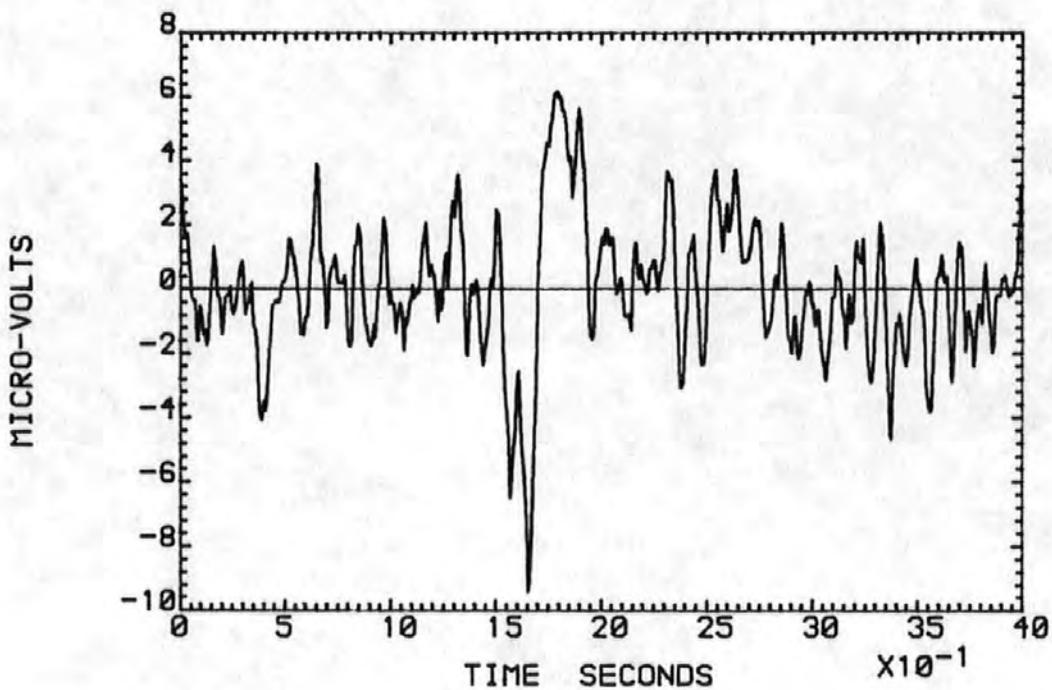
Figure 3-8b. An averaged auditory response
to a low level stimulus.

radix two FFT. The phases of the six lowest frequency components (excluding the d.c. term) were stored for each of the 64 AEP's. Histograms were then plotted showing the number of times the phase angle of the transformed AEP's fell within a particular range for each of these six frequency components (sometimes referred to as harmonics).

As an alternative to the phase histogram, phasor diagrams were plotted showing, for a particular harmonic frequency, the amplitudes and phases of the transformed responses. These diagrams were also plotted for the sections of EEG data preceeding the application of the stimulus (i.e. background EEG data). A typical pair of background/AEP phasor diagrams are shown in Figure 3-9. For clarity the phasors were represented by a cross at (what would have been) the tip of the phasor. Also for ease of interpretation a circle of arbitrary radius has been drawn and onto this small triangles have been added to show the phases of the components independently of their amplitudes. Like the phase histograms the phasor diagrams were plotted for each of the first six harmonics. The statistical tests described in Section 2.2.2 were then applied to the phasor diagram information.

3.9   Fourier Transform Considerations

Several of the methods adopted for studying the CNV's and the auditory evoked potentials (AEP's) made use of a time to frequency transformation. A Fast Fourier Transform (FFT) was used to split the responses up into different frequency components which could then be studied in greater detail. A number of important factors were considered in

PRE STIM.   POST STIM.

HARMONIC 1
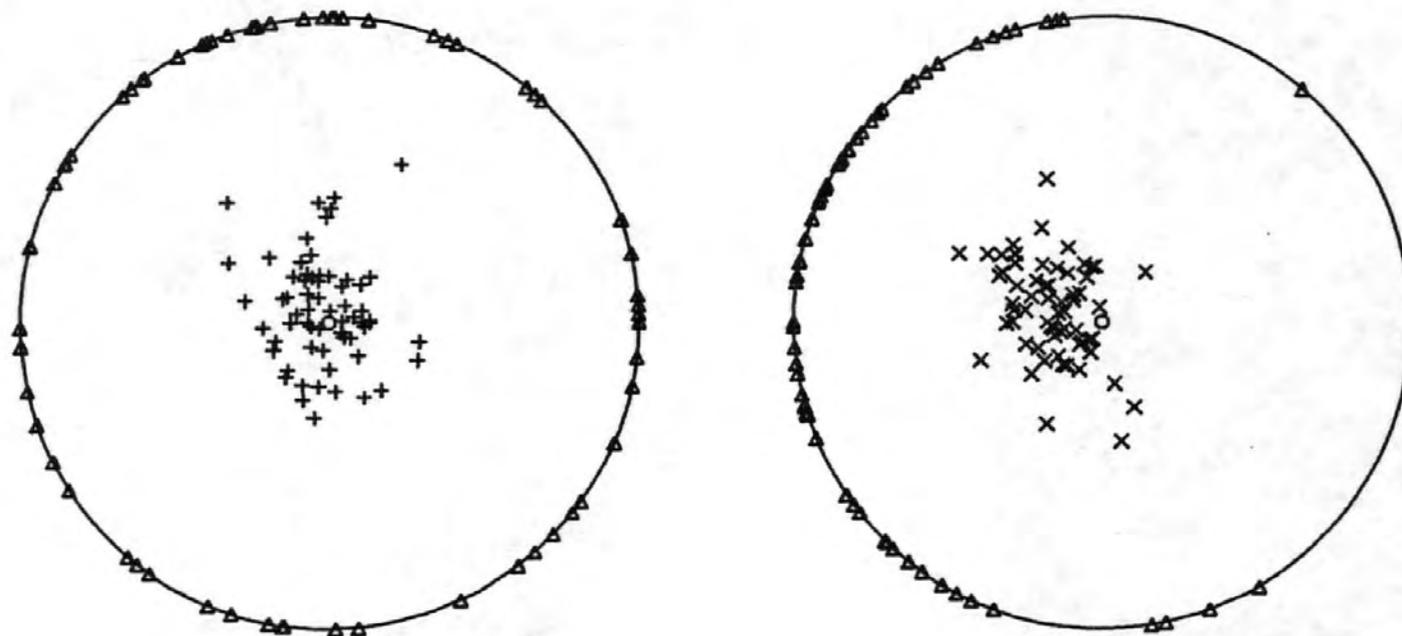
Figure 3-9   A typical AEP phasor diagram

choosing the parameters of the transform. These included the length of the section of data to be transformed, the required spectral resolution, and the time (and cost) of the transformation. However since the lengths of both the CNV's and AEP's were well defined these proved to be the ultimate limitation. In practice the response data was augmented with a number of zero valued "data" points to bring the total number of points up to a value suitable for transformation with the radix 2 FFT.

Because of the finite length (T_m) of the data the spectrum obtained was that of the data convolved with that of the window or truncation function. If, for example, the truncation function was rectangular i.e.

data to be transformed = data multiplied by one
$$(0<t<T_m)$$
= data multiplied by zero
elsewhere,

then the spectrum of the data would be convolved with the well known SINC function with zero crossings at frequencies of n/T_m, where n = ...-3, -2, -1, 1, 2, 3............ This would result in distortion of the true spectrum to an extent that would often be unacceptable. For this reason many other truncation functions have been devised which cause much less spectral distortion. The truncation function chosen was the cosine taper (sometimes referred to as the raised cosine) which was applied for 10% of the data length at each end of the data. This function can be described mathematically by the following expressions:-

$$W(t) = \begin{cases} \frac{1}{2}[1 - \cos\{\frac{t\pi}{0.1\ T_m}\}] & 0 < t < 0.1\ T_m \\ 1 & 0.1\ T_m < t < 0.9\ T_m \\ \frac{1}{2}[1 - \cos\{\frac{(1-t)\pi}{0.1 T_m}\}] & 0.9\ T_m < t < T_m \end{cases}$$

This window function has smaller and more rapidly decreasing side lobes than the rectangular window which resulted in much less spectral leakage [17].

Where it was necessary to augment the response data with zeros to fulfil the transform requirements, the windowing was applied prior to the addition of the zeros. Since windowing the zeros does not remove any discontinuity at the end of the true data. Furthermore since the d.c. component was of no interest it was removed by subtracting the mean value of the data from the data.

The FFT algorithm adopted was that described by Robinson [18]. The FORTRAN implementation of this algorithm was capable of forward and inverse Fourier transforms. The data to be transformed was submitted to the subroutine as an array of complex numbers. Since all the input data was real, the imaginary components of the array were set to zero before transformation took place. The N output data points were returned to the calling program in the same array and were generally complex. For some of the analysis methods these were then converted by a further subroutine to modulus and phase information arrays. Although N complex points were returned by the FFT only the first $N/2+1$ were meaningful since

the remaining $N/2-1$ points represent the negative frequency values. (i.e. a mirror image of the first $N/2$ points. The zero frequency or d.c. component was not mirrored).

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4. Experimental Apparatus

In order to investigate the processing of EEG signals a data acquisition and storage system was required. Several constraints were placed on the choice of this system. The most serious constraint was the lack of finance to fund such a system. However a considerable amount of equipment was available both at the Polytechnic and at Freedom Fields Hospital. Thus whilst the apparatus described here may not be the most elegant solution possible, it is a solution which, for the main parts, utilised freely available equipment.

4.1 Choice of Apparatus

Two commonly used methods for the storage of the EEG data were initially considered. The first of these being an analogue magnetic tape system. This method has the advantage that large amounts of data may be recorded and stored for subsequent retrieval and analysis. Typical modern instrumentation tape recorders are capable of storing seven channels of data with a bandwidth extending from d.c. (by the use of frequency modulation) to 20kHz or more depending on the tape speed. Since EEG signals are normally of interest between d.c. and 40 Hz. very low tape speeds may be used. With such low speeds many hours of data may be stored on a 366m (1200 feet) spool of tape.

The second technique considered was on-line digital storage. The signals are first amplified and filtered in the normal way but are than digitised instead of being sent to the usual EEG chart recorder. The digitised signal may be

stored on any convenient medium but magnetic tape or disk is most common due to the high rates at which the data may be transferred. This method has the advantage that once digitised, the signals are subject to no further noise or distortion. Since two minicomputers were available one of which had a high speed analogue-to-digital converter, multiplexer and numerous other interface components, and the other a flying head disk of approximately 2.5 M bytes capacity, the digital method was chosen. Furthermore, since evoked responses lasting but a few seconds were to be studied the disadvantage of being unable to store more than a few minutes of data was not considered important. An added bonus was that the minicomputer could be programmed to provide pulses at the chosen instant to trigger the external stimulus generators necessary for evoked response studies.

4.2 Analogue Electronics

Figure 4-1 is a block diagram of the complete data acquisition system. The EEG signals were obtained from silver-silver chloride electrodes attached to the subject by glue or adhesive tape. These signals were fed into the electrode selector switches and differential amplifiers of an eight channel Elma-Schönander electroencephalograph. In addition to producing the normal paper chart record, the electroencephalograph was coupled to external amplifiers and filters to allow the information from six of the eight channels to be digitised and stored for subsequent analysis.

The point at which the signals were extracted from the EEG machine was chosen such that the electrode selector

8 Channel
EEG Machine

Paper Chart

Amplifiers & Filters
Sample Hold
Multiplexer
A-D Converter

Loudspeaker
or Earphones

Stimulus
Generator

Minicomputer

X-Y Display

Isoltr.

To all 250V
equipt.

High speed serial
data link.

Mains
leakage
trip

Minicomputer

Disk

Mains in

Disk
cntrlr.

Tape
punch

Figure 4-1

Floppy disk

Paper   tape
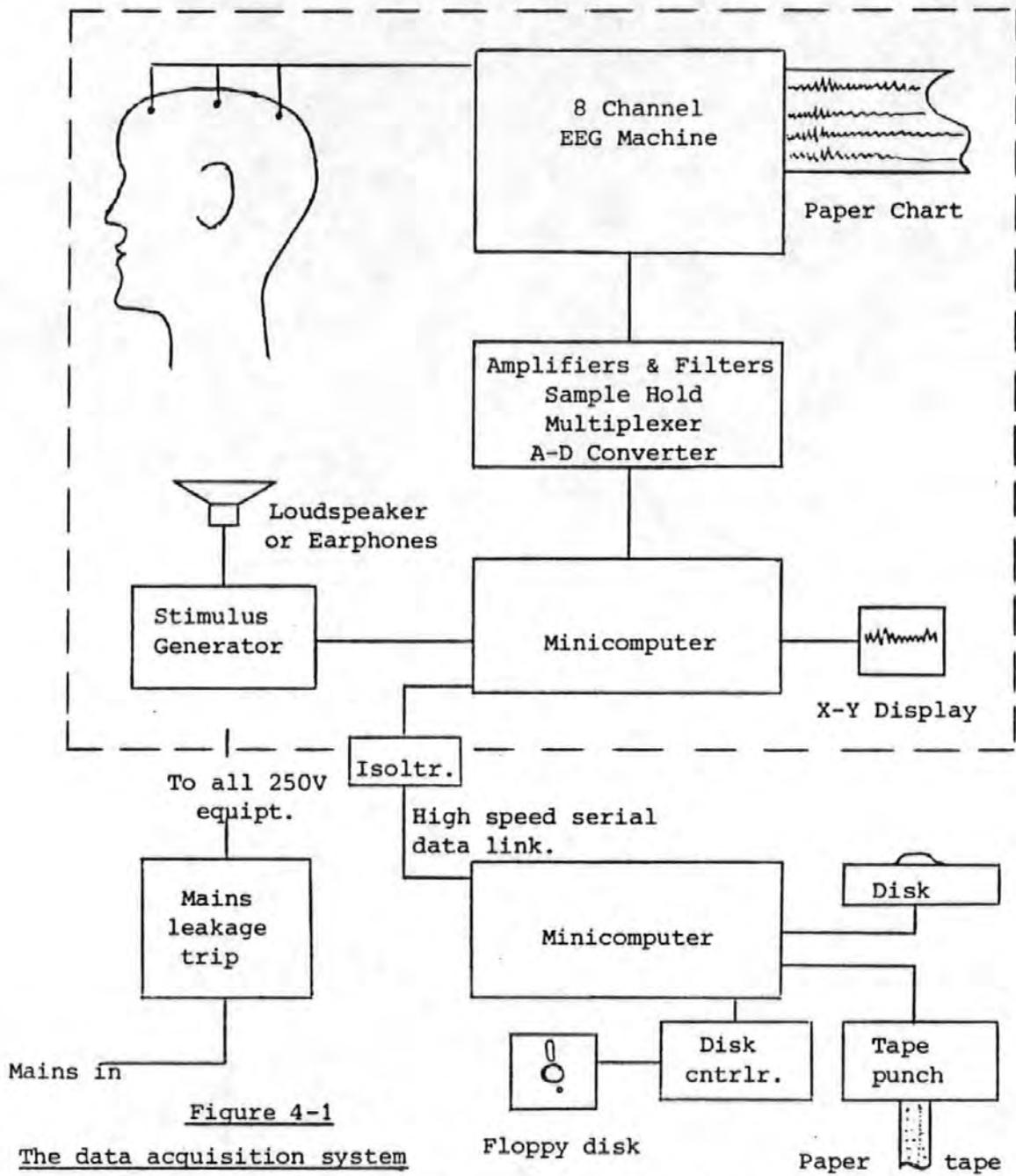
The data acquisition system

Graphics terminal

Floppy
disk

Tape
punch

Tape
reader

Polytechnic
main computer.

Main computer
system A.

Main computer
system B.

1.2 GByte
disks

-89-
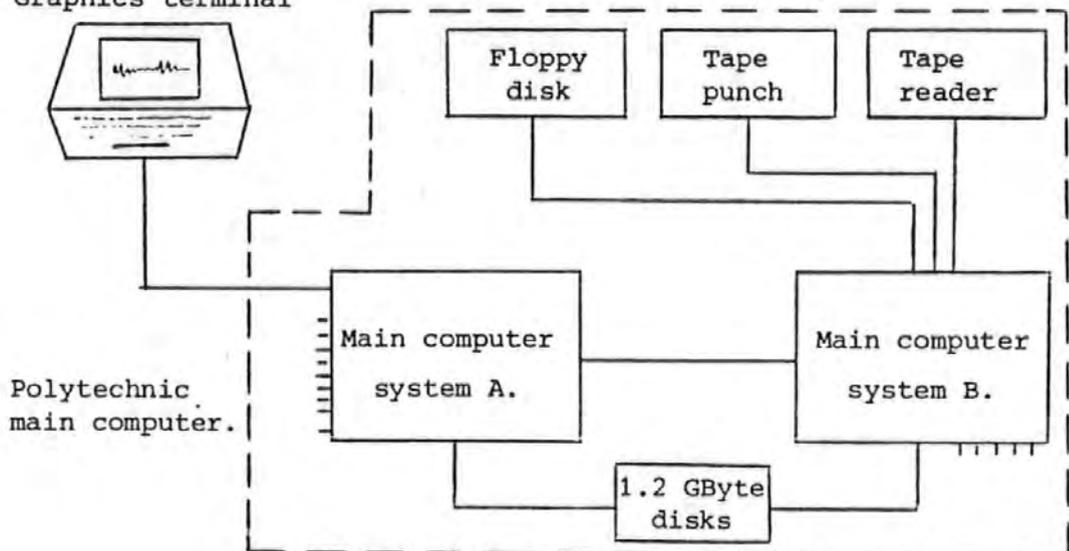
switches and the first stage (d.c. coupled x 50) of amplification were utilised (see Figure 4-2). The next stage of amplification in the EEG machine could not be used because the interconnection between the first and second stages formed a high pass C-R network with a cut-off frequency of 0·069 Hz. This frequency was not low enough for CNV recordings where 0·016 Hz. is usually considered to be a more appropriate lower limit (this value corresponds to a time constant of 10 seconds). For this reason the differential outputs of the first stage were wired to a 25 pin 'D type' socket on the rear of the EEG machine. In this way the machine was still able to perform its normal duties and could simply be un-plugged from the additional equipment used to digitise the signals. When used for data logging a fairly short screened multicore cable with a 25 pin 'D type' plug at either end was used to connect the EEG machine to a screened box containing modules for amplifying, filtering and sampling six of the eight EEG machine channels (further modules could be added at a later date should it become necessary to digitise all eight channels).

The input circuit of each module (see Figure 4-3) comprised of a differential high pass C-R network with switchable capacitors to give cut-off frequencies of 0·016, 0·034 and 0·16 Hz. The differential signals were then converted to unbalanced form by an amplifier comprising of two BIFET[†] operational amplifier integrated circuits (RCA type 3140) and a single bipolar operational amplifier (type μA 741). The gain of this stage was adjusted to 100. The variable resistor VR1 was incorporated to allow optimisation of the

[†]An integrated circuit employing both bipolar and field effect transistors.

25 pin 'D'
type socket

(to Figure 4-3)

Multi-core
cable

Electrode
selector
switches

8 channels
differential

(only two channels shown for clarity)

Headbox with
sockets for scalp electrodes

X50

C-R coupling
network

Filters

X30
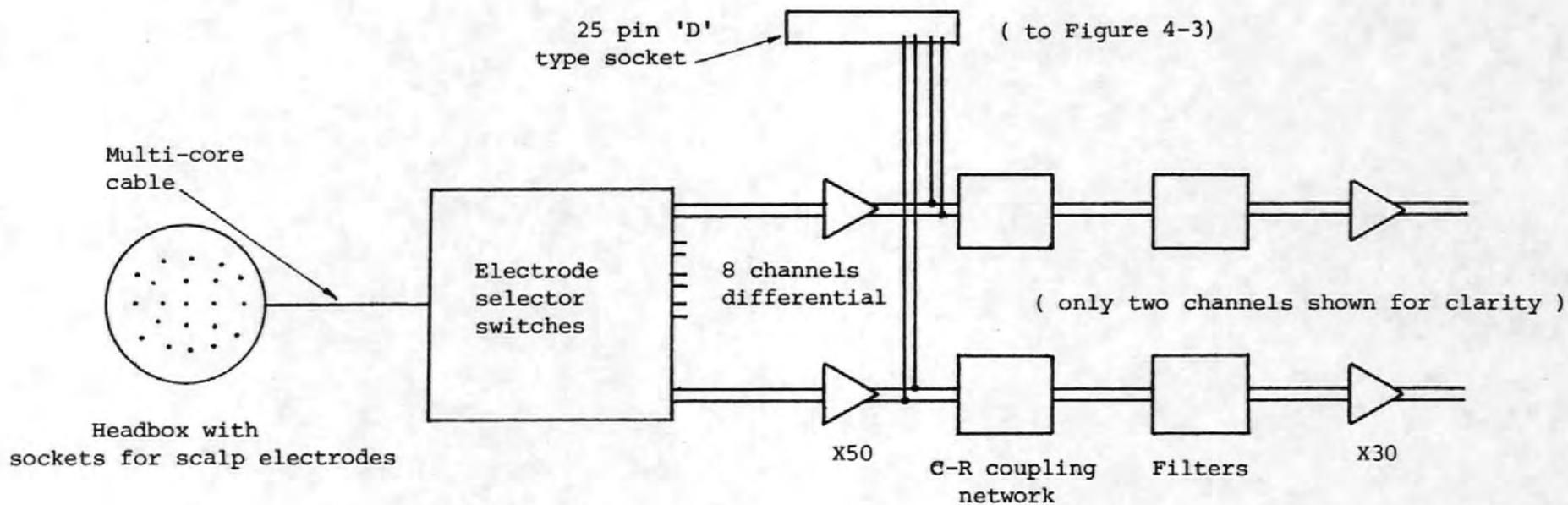
16 switches allowing any of the 8
channels to be connected to any
pair of scalp electrodes.

Figure 4-2

A block diagram of the input section of the EEG machine.
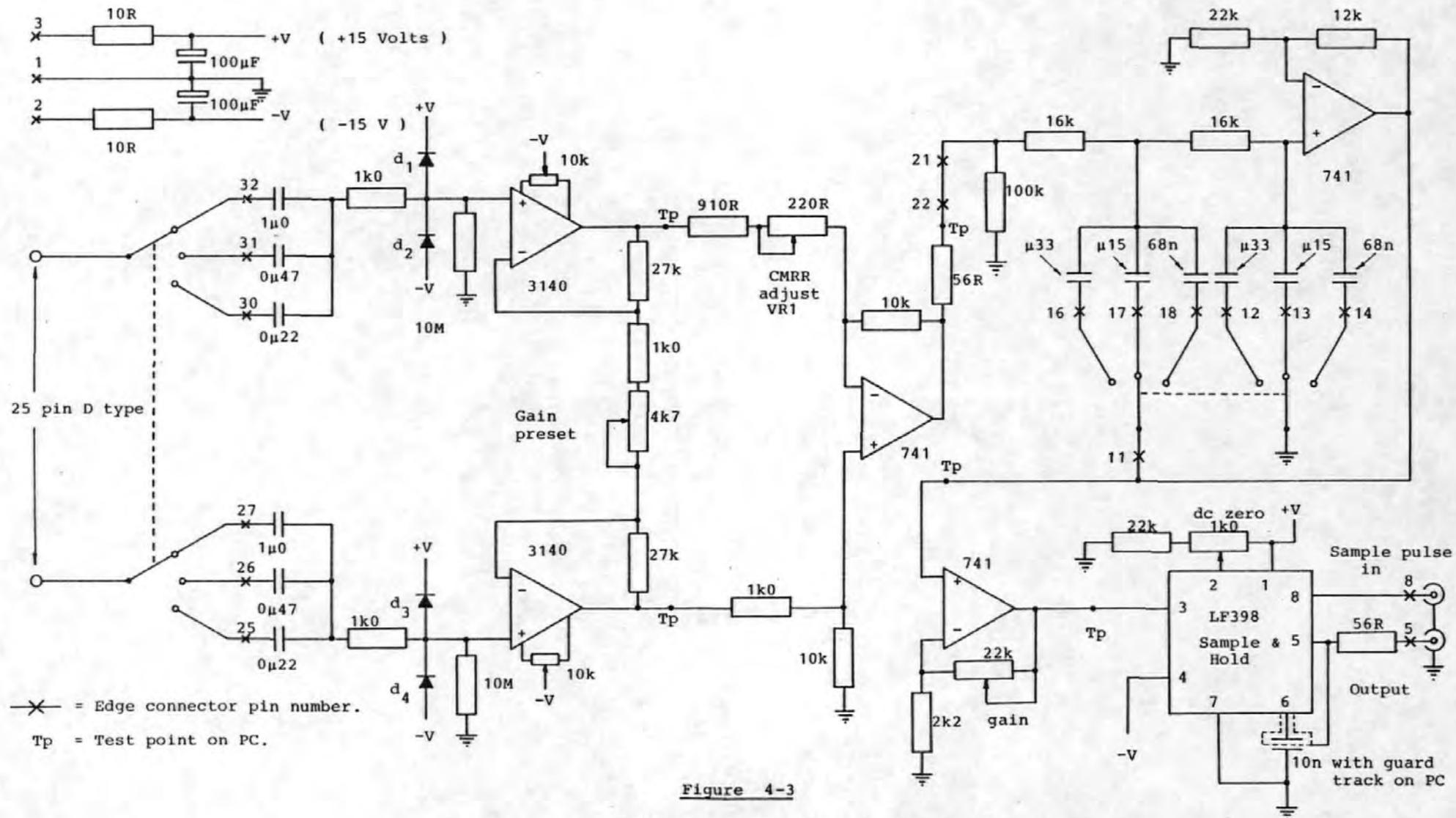
Figure 4-3

The circuit of an amplifier and sample hold module

common mode rejection ratio (CMRR). The diodes d_1 - d_4 were incorporated to protect the input circuits of the 3140 operational amplifiers.

The output of this stage was then fed into a second order active filter based on the Sallen and Key design [1]. The calculation of the circuit elements for the desired cut-off frequencies (30, 70 and 130 Hz. switch selectable) was simplified by the use of the tables given in Millman and Halkias [2]. After careful consideration of the various frequency response characteristics the Butterworth filter was chosen because it had a suitably flat amplitude response in the passband without undue phase distortion. The cut-off frequencies of 30, 70 and 130 Hz. were chosen because they are commonly used in EEG work and would therefore make any results obtained from our data logging system comparable with results obtained by other workers. Low pass filtering is necessary to prevent aliasing in the subsequent digitisation stage and to attenuate some of the unwanted higher frequency components (e.g. muscle artefact, power frequency interference etc.) High pass filtering (the CR input network) was included to minimise the drift which can occur because of electrode instability. After low pass filtering the signals were further amplified by an operational amplifier (type μA 741) connected in the non-inverting mode with a variable gain. The gain of these amplifiers was set to utilise the complete range of the 12 bit analogue to digital converter with scalp signals of ± 700μV (channels 1-4) and ± 350μV (channels 5 & 6). The final function of the modules was to sample and hold the output of the final amplifier at the required instant in time.

This function was performed by a Signetics type LF 398 integrated circuit.

In order to sample the analogue signals at the required rate a pulse signal was generated by an oscillator and divider network which was then fed into each of the six sample and hold IC's. This pulse signal was also fed into the PDP 8/f Hybrid Computer Interface [3] so as to cause an interrupt at every sample instant. Since the sampling was to be performed at precisely regular intervals a quartz crystal oscillator and a frequency divider were built specially. The oscillator (Figure 4-4) used a circuit recommended by the crystal manufacturers [4] and provided a signal of approximately 1 volt RMS at a frequency of 100kHz. This signal was squared by T_r2 and divided in frequency by two Transistor-Transistor Logic (TTL) 7490 decade dividers and a TTL 7493 4 bit binary divider as shown in Figure 4-4. The outputs of the 7493 give possible sampling frequencies of 500, 250, 125 or 62·5 Hz. Since only two of these frequencies were likely to be needed (125 or 250 Hz.) a two position toggle switch was employed to select the required frequency and feed it to the input of a TTL 74121 monostable multivibrator. This device was employed to convert the square wave output of the divider chain into a pulse waveform, with a 100 μs active period, necessary for the sample hold circuit. The sampling frequencies are accurate to within approximately one part in 10^5.

The six sampled analogue waveforms were then passed to an Analogue Devices MPX8A multiplexer and a Hybrid Systems Corp. ADC-591-12A-G 12 bit analogue to digital converter. These two devices were part of the PDP 8/f Hybrid Computer Interface
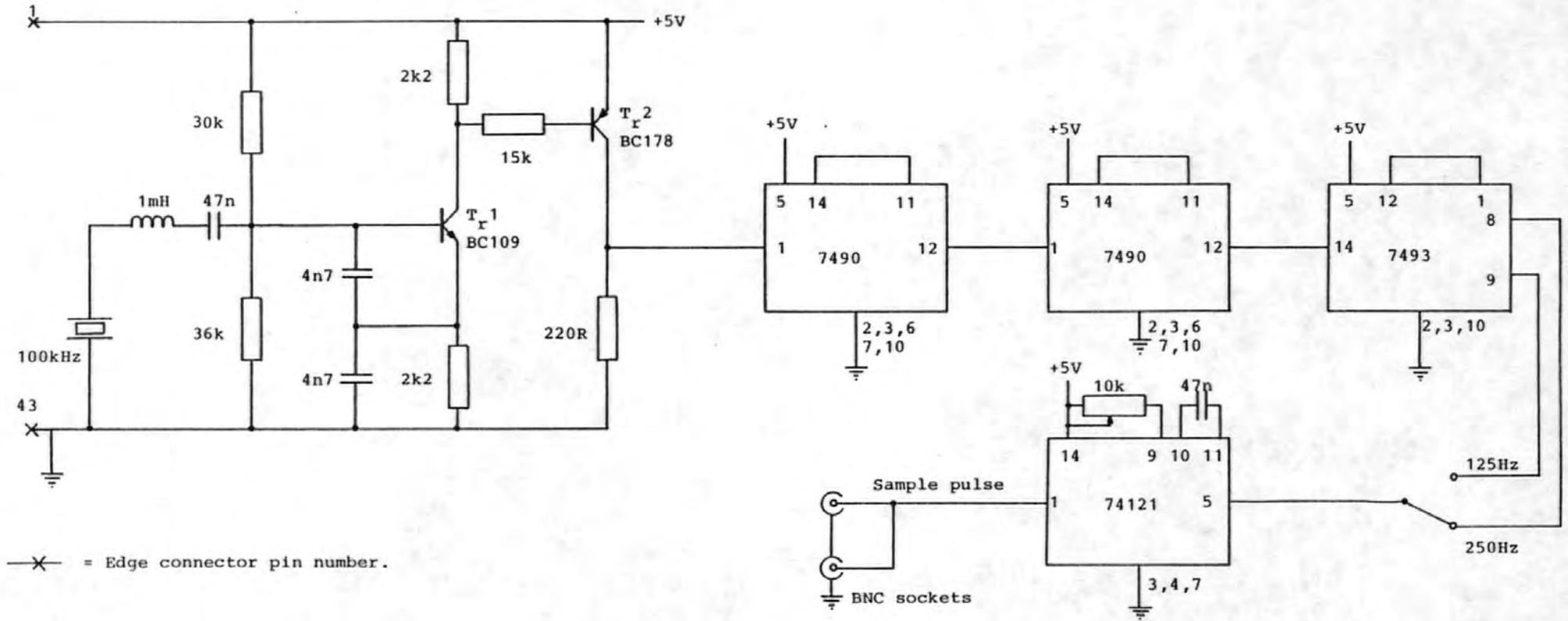
Figure 4-4

The crystal oscillator and divider network

designed and built by Yeats [3].

4.2.1 Testing of the Analogue Electronics

The amplitude and phase responses of one channel of the measurement system are shown in Figures 4-5a and 4-5b. In addition to measuring the amplitude and phase responses other tests were performed to determine the common mode rejection ratio (CMRR) and the effect of the filtering on a ramp waveform (similar to an ideal CNV). The CMRR was measured by connecting the inputs of the channel under test together at the headbox and injecting a 15 Hz. sine wave signal between the connected inputs and earth. The common mode input voltage (V_{ic}) and the output voltage (V_{oc}) were measured and the common mode gain (A_c) found by dividing V_{oc} by V_{ic}. The CMRR was then obtained by dividing the differential gain (A_D) by the common mode gain (A_c). The values of the CMRR for channels 1 and 5 are given in table 4-1.

Table 4-1

The Common Mode Rejection Ratio for Channels 1 and 5

CHANNEL	A_D	A_C	CMRR	CMRR dB
1 [†]	14290	0·182	78520	97·9
5 [†]	28570	0·212	134800	102.6

†

   The time constant was set to 10 seconds and the low pass filter was set to a cut-off frequency of 30 Hz.

Figure 4-5a

Frequency response of system.
(electrodes to A-D converter)

Time constant   = 10 seconds
Input voltage   = 10 μV
Channel 1-4 absolute gain 83.1 dB
Channel 5-6 absolute gain 89.1 dB
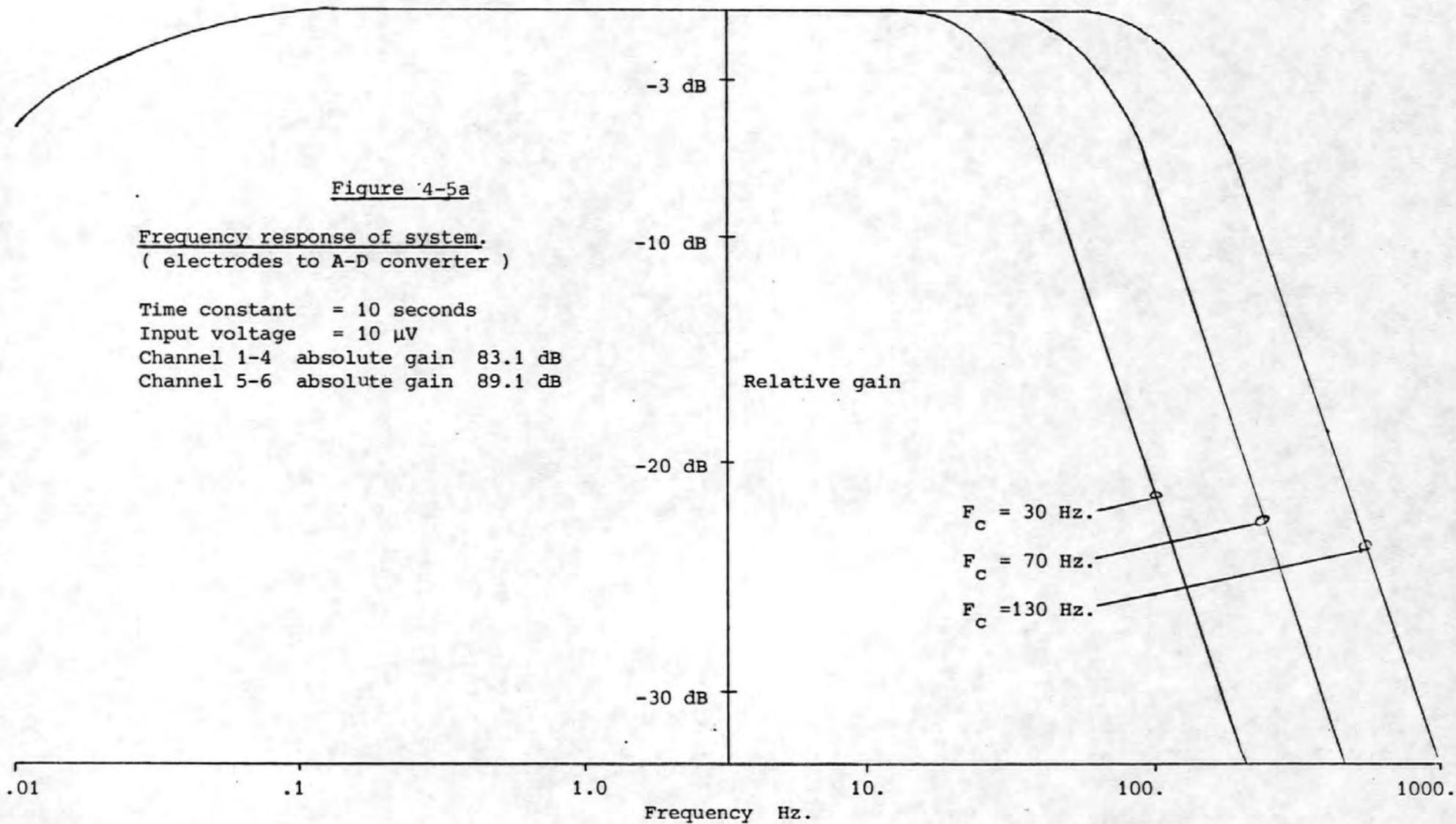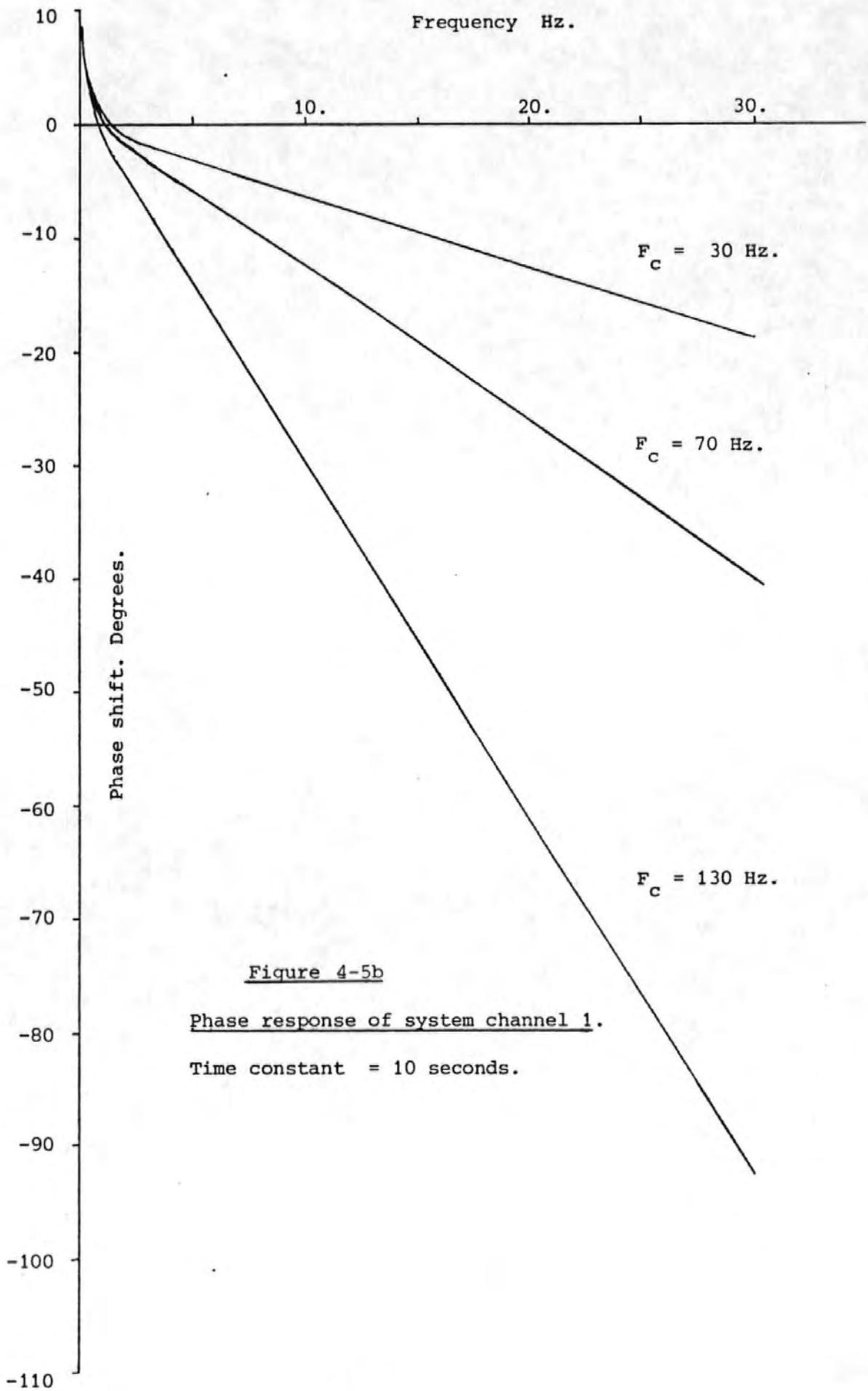
Figure 4-5b

Phase response of system channel 1.

Time constant = 10 seconds.

-98-

The circuit of Figure 4-6 was used to show the likely effect of the low and high pass filters on an ideal CNV response. The function generator was set to deliver a ramp waveform which was fed into an attenuator and also to the Channel 2 multiplexer input. The output of the attenuator was fed into the headbox and amplified and filtered in the usual way before being passed on to the multiplexer. Figures 4-7a and 4-7b show the two waveforms, one having been subjected to low and high pass filtering, and the other having undergone no filtering[†] It may be observed from these diagrams that the distortion introduced is quite small. The settings of the low and high pass filters were 30 Hz. and 0·016 Hz. (time constant = 10 seconds). The amplitude of the ramp signal at the headbox input connections was as indicated in Figure 4-7b. Because of the unusual connection the voltages indicated in Figure 4-7a must be multiplied by the system gain (14290) to give the true voltage levels.

[†] except that inherent in the sampling process.

Function
generator

Attenuator
80 dB

Headbox

* EEG
machine

* Amplifiers
&
Sample
Hold ccts.

gain X14290

Multi-
plexer
A-D
etc.

Channel 2

Channels 1,3-6
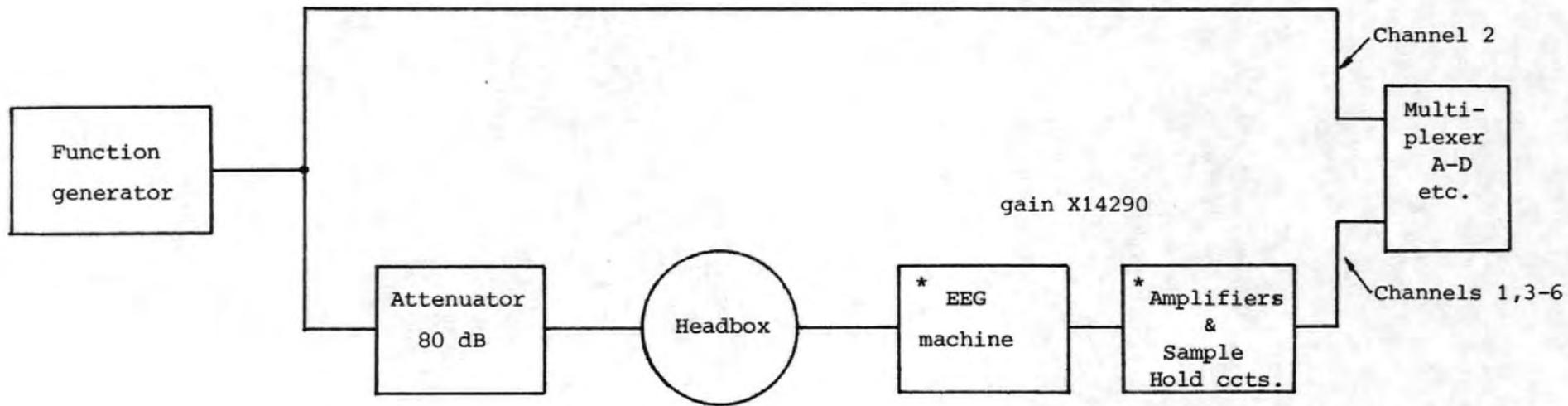
* See Figures 4-2 & 4-3.

Figure 4-6

The connection of the measurement system for the ramp response tests
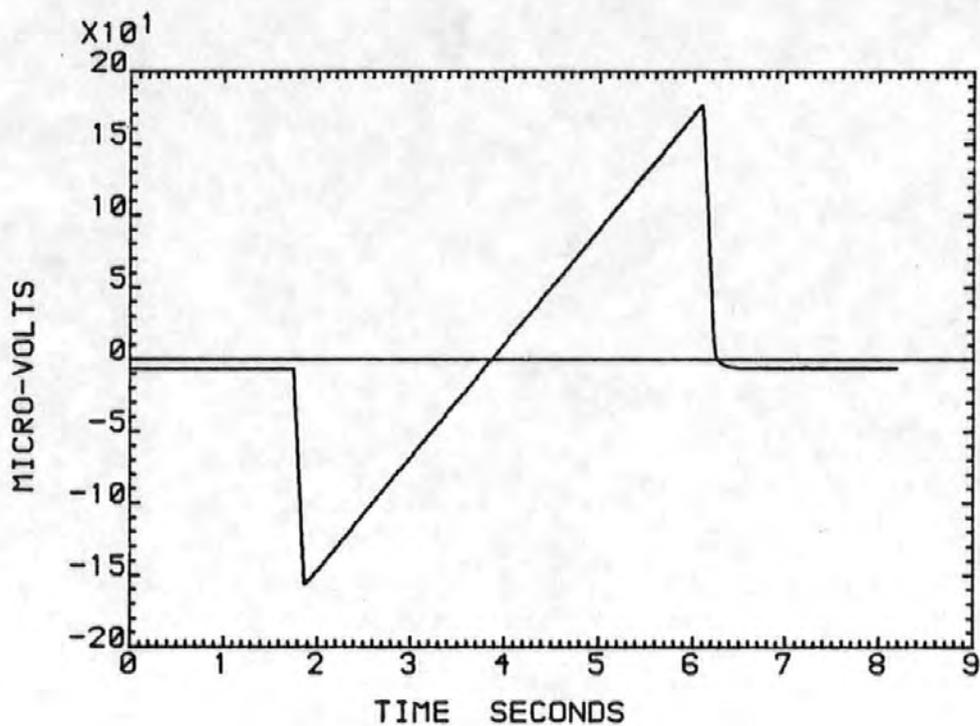
Figure   4-7a

The ramp input waveform (X 14290)
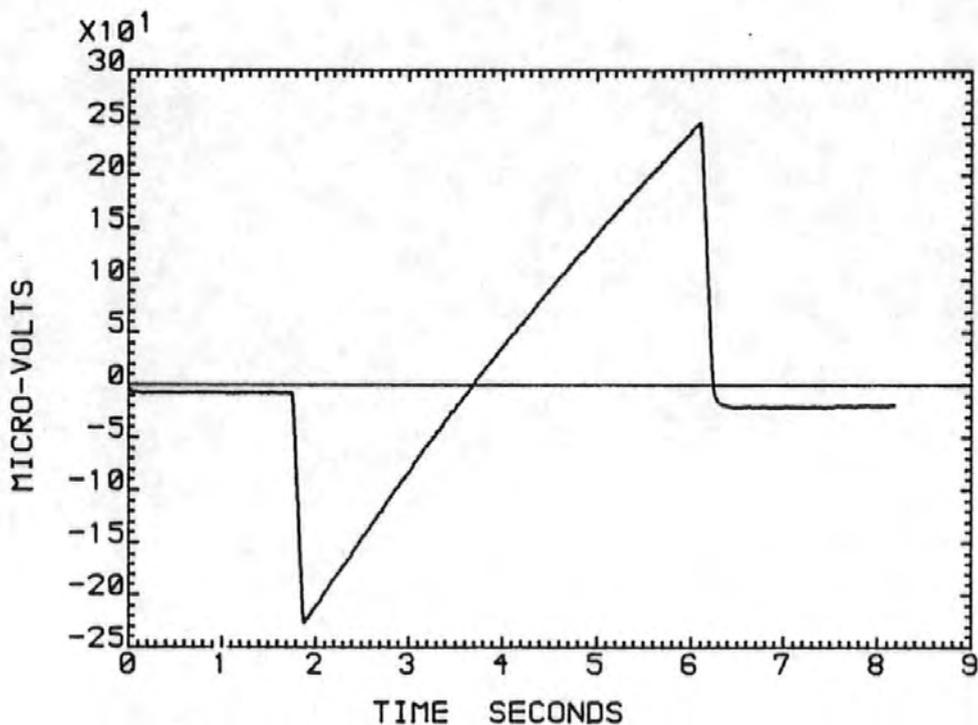
Figure   4-7b

The ramp output waveform.

4.3   High Speed Serial Data Link

In order to transfer the digital data from the mini-computer in the measurement room to the remote minicomputer with the magnetic disk, a pair of high speed serial data transceivers were designed and built.   Two identical units were made to allow bi-directional communications to take place over a four-wire link using the 20mA current loop convention.   The units were constructed on Vero-cards with 43-way edge connectors suitable for insertion into the extended input/output (I/O) bus racking system with which both the PDP 8's were fitted.   This bus comprised of all the input/output timing pulses, the accumulator input and output lines six of the twelve memory buffer lines (from which the I/O devices were addressed), the instruction skip line, the interrupt request line and power supplies of +15, +5, and -15 volts.   A block diagram of one of the serial transceivers is given in Figure 4-8.   The design of the transceivers was based on two large scale integration integrated circuits.   These were the Intersil 6402 Universal Asynchronous Receiver Transmitter (UART) and the Motorola MC 14411 Baud rate generator. The UART is a device capable of translating 8 bit parallel binary data into a serial data stream at a rate determined by an externally supplied clock signal.   Simultaneously the device can receive a serial data stream and convert it to an 8 bit parallel binary data word.   By means of an internal register, which may be loaded by the user, the device can be instructed to perform many variations on this basic theme.   (e.g. the device can be instructed to generate a parity bit and append this to the data being transmitted whilst any received data is
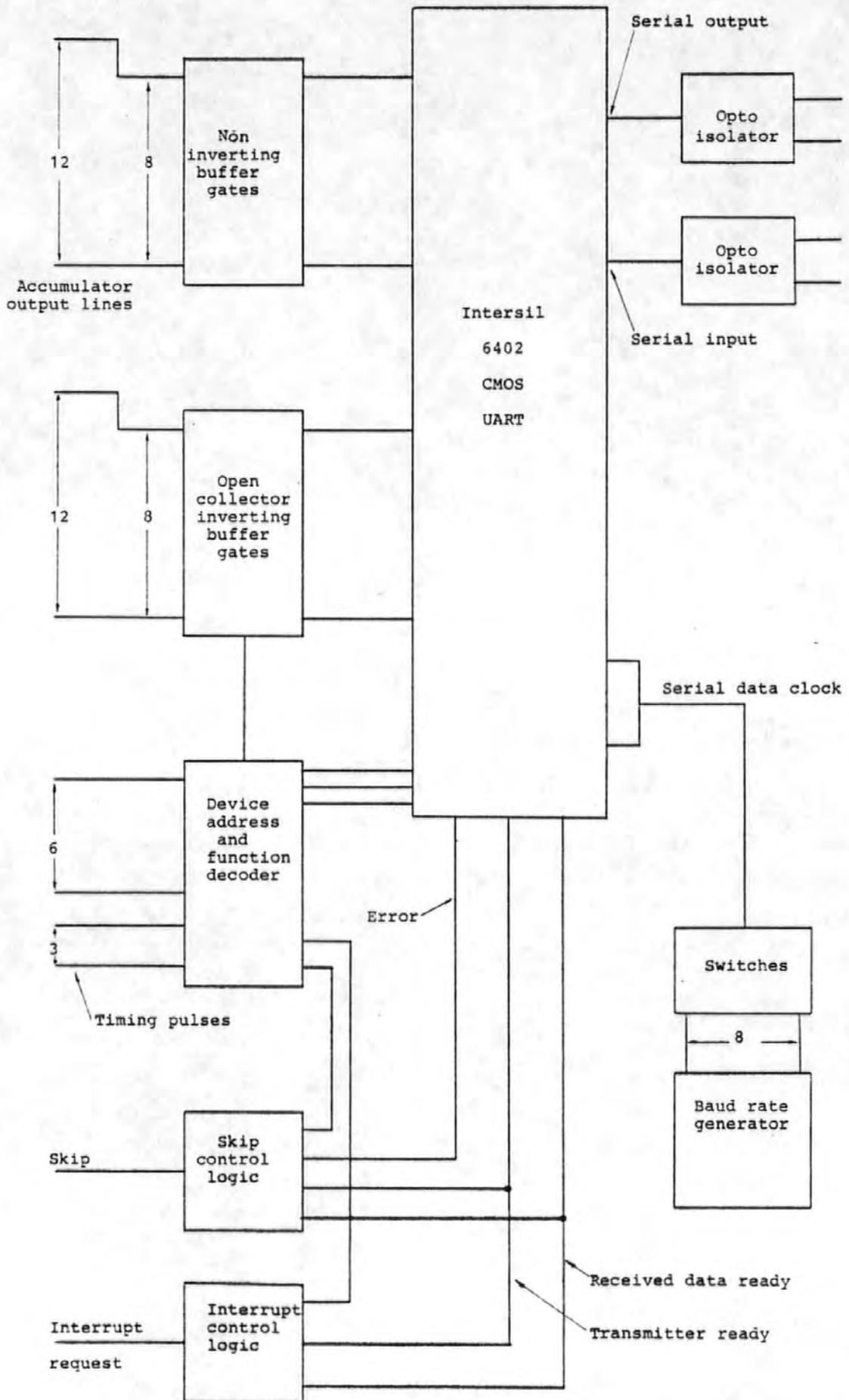
Figure 4-8   A block diagram of the serial transceiver

checked for parity errors). The Baud rate generator was used to generate one of a number of standard frequencies used for serial data transmission. Selection of the particular frequency required was controlled by a group of five dual-in-line switches giving serial data rates from 75 Baud up to 38·4 k Baud. The full circuit diagram of one of the transceivers is given in Figure 4-9. In order to achieve electrical isolation between the equipment in the measuring room and the remote minicomputer, all the data (both transmitted and received) was passed through a pair of opto-isolators.

Numerous Transistor-Transistor Logic (TTL) gates perform the necessary interfacing and decoding between the signals on the 43-way I/O bus and the UART. Additional circuitry, in the form of I/C's 10 and 13, perform the functions associated with the control and generation of programme interrupts. These interrupts may be generated when the UART is ready to transmit another 8 bit word (a transmitter interrupt) or when the UART has just received an 8 bit word (a receiver interrupt). I/C 14 performs an 'inclusive OR' of the three possible receiver error conditions which may then be detected (by the software) upon execution of a 'Skip on error' instruction. Table 4-2 gives a list of the instructions decoded and acted upon by the serial transceivers.
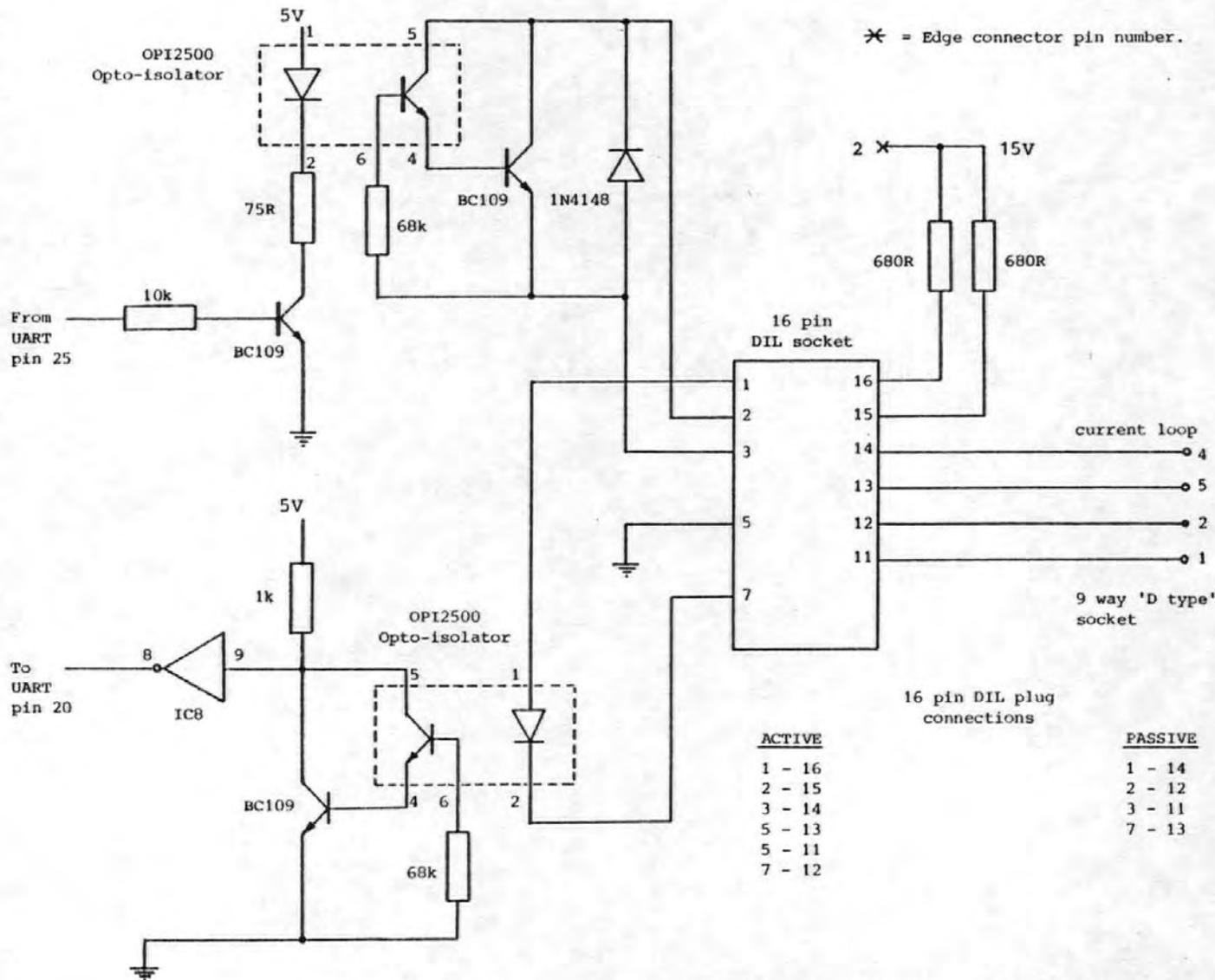
Figure 4-9a   The circuit of one of the serial data transceivers

Figure 4-9b The current loop interface of the serial data transceivers

Table 4-2

Instructions Obeyed By The Serial Data Transceivers

OCTAL INSTRUCTION CODE	MNEMONIC	ACTION
6621	SDR	Skip if the receiver has a data word ready
6631	RUD	Read the data word
6641	SKERR	Skip if an error has been detected
6622	DUI	Disable all interrupts
6632	ERI	Enable receiver interrupts
6642	ETI	Enable transmitter interrupts
6624	STR	Skip if the transmitter is ready for more data
6634	LSTAT	Load the control status register
6644	OUT	Load the data and transmit

A more detailed account of the operation of these instructions and their effect on the serial data transceivers is given in Appendix 8.9.

4.4 Minicomputers and Software

The analogue to digital (A-D) converter and the multi-plexer were controlled by a Digital Equipment Co. PDP 8/f minicomputer with 8k words of ferrite core memory. Since evoked potentials were to be studied the computer was also used to present trigger pulses to the external stimulus generators at the appropriate instants. As the digital data was acquired it was stored in the memory of the minicomputer. Simultaneously the data was transmitted over a high speed serial data link to the second PDP 8 minicomputer some distance away from the measurement room for storage on a magnetic disk.

The operation of the complete measuring system can best be described by outlining the sequence of events involved in obtaining a single evoked response.

(i)   The minicomputer waits until the operator pushes a button to start the acquisition process.

(ii) Under interrupt control the six analogue data channels are digitised and stored in the memory of the minicomputer. The interrupts are generated by a crystal oscillator and divider giving either 125 or 250 samples per second.

(iii) Under interrupt control the data stored in the memory of the minicomputer is transferred via the serial data link to the second (remote) mini-computer. The interrupts are generated every time the serial data link becomes inactive.

(iv)   When not busy (i.e. when not interrupted) the mini-computer displays via two ten bit digital-to-analogue converters and an X-Y CRT display any one of the six incoming data channels.

(v)   When each sample is taken the minicomputer checks the sample number and if a preset number have been taken it sends a pulse to trigger the first stim-ulus generator.

(vi)   When each sample is taken the minicomputer checks the sample number and if another preset number have been taken it sends a pulse to trigger the second stimulus generator.

(vii)   After each sample has been taken a test is per-formed to determine whether the required total number of samples have been taken and if so whether they have all been sent to the remote minicomputer for permanent storage.

(viii)   If both conditions in (vii) are met then the mini-computer waits for the remote minicomputer to ack-nowledge that the data has been successfully stored before returning to state (i) above.

The sequence of events for the remote minicomputer is as follows;

(i)   Send the 'Ready' signal to the minicomputer in the measurement room.

(ii)   Wait for the data and store it in core memory as it arrives. Perform tests to detect transmission errors.

(iii)   When all the data for the evoked response has been
        received store it on the magnetic disk.

(iv)   Return to state (i)

The two programmes to perform the above tasks were
written in the PAL 8 assembly language and listings are given
in Appendices 8.10 and 8.11.

It should be noted that the speed of the serial data
link may be greater or less than the rate at which the data
is acquired since the computer memory is used as a temporary
storage buffer.

For analysis and processing of the evoked responses the
data stored on the magnetic disk of the PDP 8 minicomputer
was transferred on either paper tape or floppy disks to a
large database on the Polytechnic main computer.

4.5   Other Equipment

4.5.1   Eye Movement Correction Screen

Our experiments comparing the effectiveness of various
methods of removing eye movement artefact from the EEG were
undertaken with the aid of a simple wooden screen shown in
Figure 4-10. The screen was approximately 1.3m square into
which a set of nine 5 mm red light emitting diodes (L.E.D.'s)
were inserted on a 0.55m grid. A remote control box allowed
any of the LED's to be switched on or off as required. The
procedure adopted for using the screen is described in Sect-
ion 3.3.

5 mm Dia. LED's

0.55 m

0.55 m

0.55 m

0.55 m
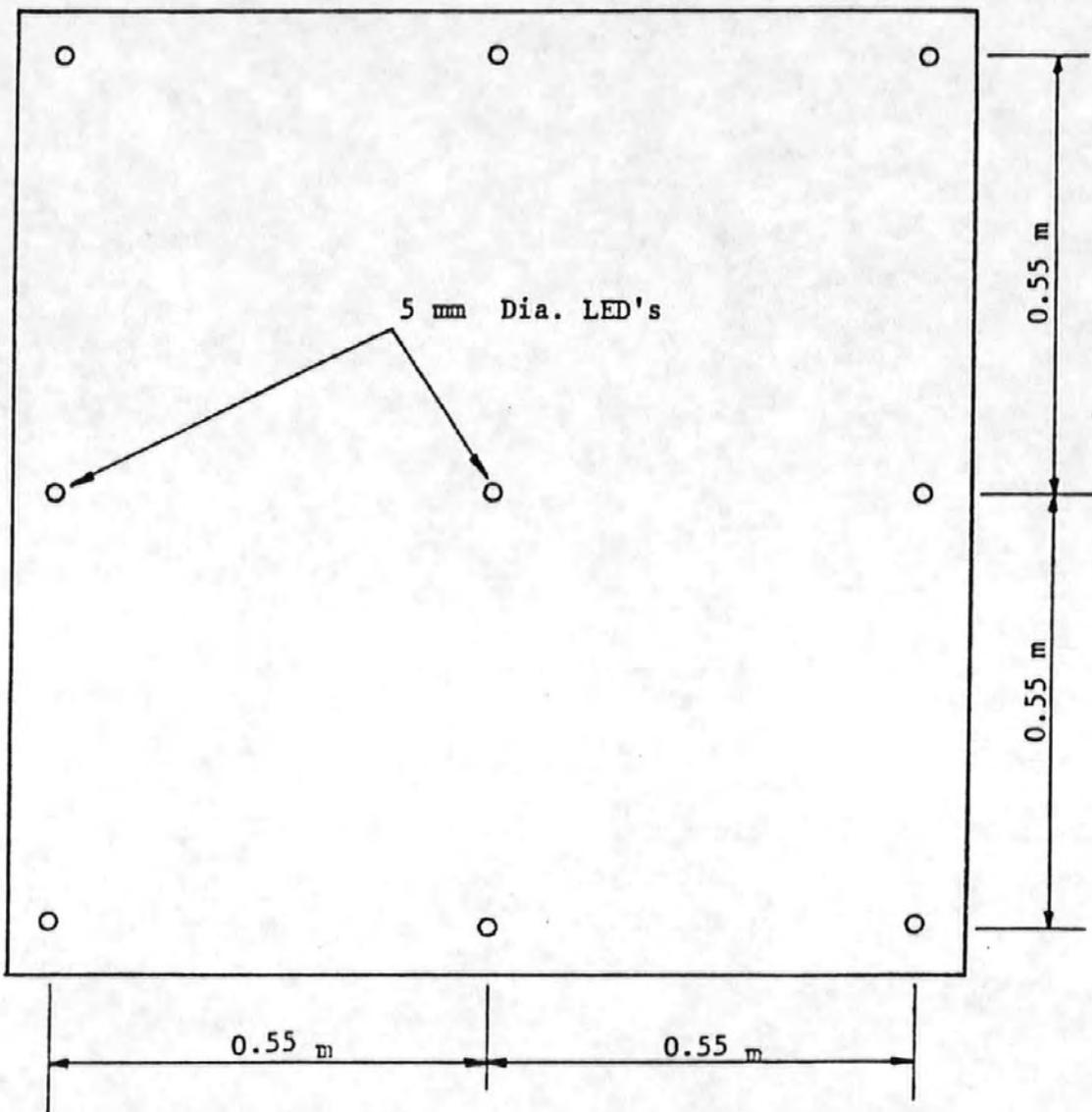
Figure 4-10

The eye movement correction screen.

4.5.2 The CNV Stimulus Generator

In order to record CNV's it is necessary to present the subject with some form of stimulus. The type of stimulus is not important to the final result and the two most commonly used stimuli are auditory and visual. Some workers use two auditory stimuli (e.g. a click followed by a tone [5] whereas others use combinations of auditory and visual stimuli (e.g. a click followed by a flashing light [6]. Our initial experiments at Freedom Fields Hospital had indicated that the use of a visual stimulus was to be avoided if possible since this often resulted in the subject blinking and hence introducing an artefact in synchronism with this stimulus.

The stimulus paradigm subsequently chosen was that of a click followed by a 1kHz. tone of 90dB. intensity (A weighting). The circuit used for generating this is given in Figure 4-11.

In order to obtain correct CNV responses the subject must perform some action upon receipt of the second stimulus. It is normal practice to use a hand held push button which the subject is required to press.

It is also normal for the push buttom to be connected to the stimulus generator in order to terminate the second stimulus. This feature gives the subject some motivation for responding to the second stimuli and was incorporated in our stimulus generator.

Note : S1 and S2 are the trigger inputs and are driven by short (approx 2μs) TTL pulses from the mini-computer.

Integrated circuits
CD4016 Quad analogue switch.
MC14528 Dual monostable.
NE555   Timer.
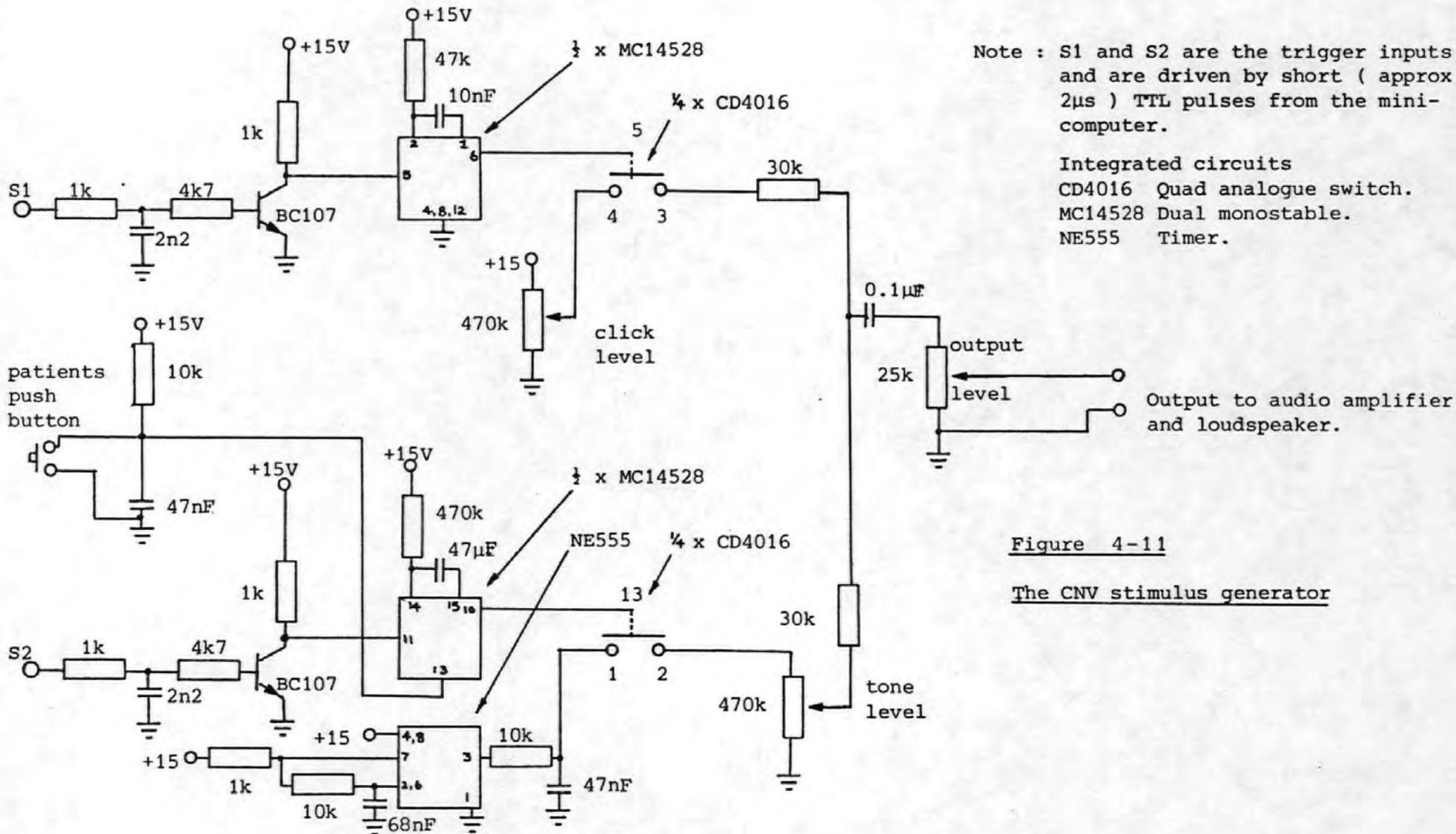
Figure 4-11

The CNV stimulus generator

4.5.3 The AEP Stimulus Generator

The equipment used in the recording of the AEP's was virtually identical to that used for the CNV's. The only difference was in the generation of the stimulus. The auditory stimuli were delivered from an Amplaid stimulus generator to the right transducer of a pair of Koss K6 stereo headphones. Triggering of the stimulus generator was performed at the required instants by the PDP 8 minicomputer. Two different levels of stimulus were applied. A 1kHz. tone of 100ms duration including 10ms of rise and fall according to a cosine squared law was used. The low level stimulus was applied at a level of 40dB. above the subject's auditory threshold, while the high level stimulus was applied 70dB. above it. These stimuli were presented as the subject sat relaxed in a chair.

References for Section 4

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     Nature, Volume 203, pp 380-384, July 1964.

5. Results and Discussion

5.1 Eye Movement Corrections

A set of typical waveforms depicting the raw EEG, the raw (vertical left) EOG and the corrected EEG are given in Figure 5-1 (a-c). Also shown are the autocorrelation functions (a.c.f.'s) of the EEG, the EOG and the corrected EEG signals Figure 5-1 (d-f). Table 5-1 gives the results as evaluated from the plots derived from four experiments. This table gives both the frequencies and the autocorrelation co-efficients (a.c.c.'s, see Section 2.4 for details) of each of the corrected EEG's along with the frequency of the EOG deduced from its own a.c.f. Some of the frequencies present appear to be harmonics of the EOG which suggests that the path between the eye and the scalp electrode may be frequency selective or non-linear. If this is so then the proportions of the harmonics making up the rectangular EOG will not be maintained at the scalp electrode. This will result in some harmonics being over or under corrected and thus remaining in the output waveform.

When the artefact contains components due to both eye movements and blinks (which do not have the same effect on the EEG [1]), then the computerised correction will attempt to achieve an optimum correction so that as much as possible of both components is removed. This is still a compromise however, since neither artefact signal can be completely removed by this method whilst the other is present in the same section of signal record. The methods of McCallum and

(a)

The raw EEG

(b)

The raw EOG (V_L)

(c)

The corrected EEG

(d)

The ACF of (a)

(e)

The ACF of (b)

(f)
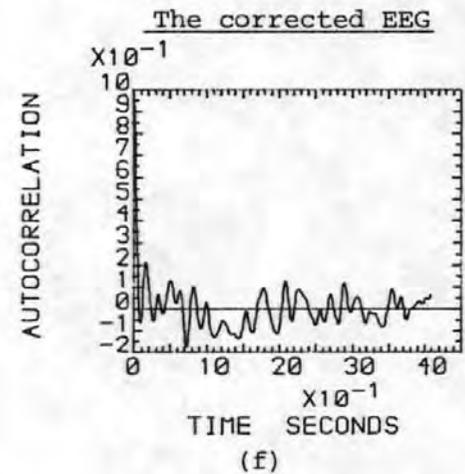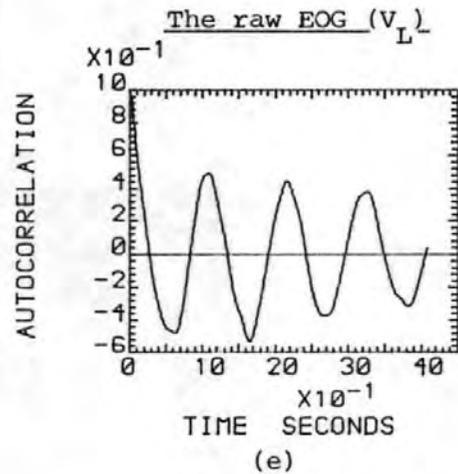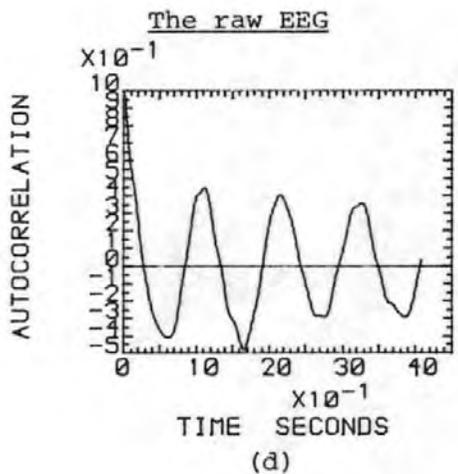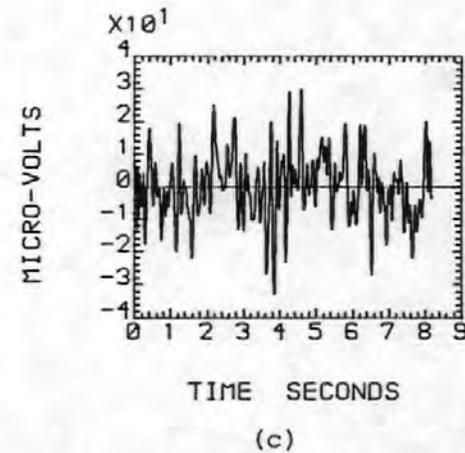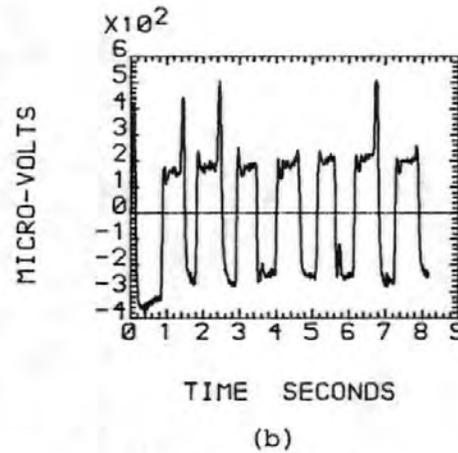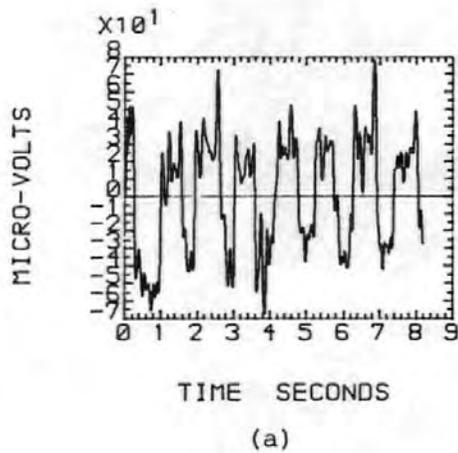
The ACF of (c)

Figure 5-1

Table 5-1

QUANTITATIVE RESULTS OF EYE MOVEMENT

EXPERIMENTS

EYE MOVEMENT	PARAMETER	2 CHANNEL CORRECTION (± 0.02)	3 CHANNEL CORRECTION (± 0.02)	4 CHANNEL CORRECTION (± 0.02)	ANALOGUE CORRECTION (± 0.02)	EOG FREQ. (± 0.02)	INTERPRETATION
DOWN	FREQ.	0.70*	N.P.	N.P.	0.38*	0.38	A B
	r	0.09	N.P.	N.P.	0.38		
LEFT	FREQ.	N.P.	N.P.	N.P.	0.27 +	0.36	A
	r	N.P.	N.P.	N.P.	0.16		
UP	FREQ.	N.P.	N.P.	N.P.	0.33 +	0.38	A
	r	N.P.	N.P.	N.P.	0.22		
RIGHT	FREQ.	0.55*	0.50*	0.50*	0.55*	0.52	A
	r	0.22	0.15	0.15	0.28		

FREQ. = frequency of autocorrelation function (Hz)
r = autocorrelation coefficient at T=2 sec.
N.P. denotes a non-periodic autocorrelation function indicating complete correction.
A means correlation technique better than analogue technique.
B means 4 and 3 channel correction are better than 2 channel.
* denotes a frequency related to the EOG frequency.
+ denotes a frequency unrelated to the EOG frequency.

Walter, and Girton [2] and Kamiya [3] make no allowances at all for the differential contributions of blinks and eye movement artefacts.

The deductions made from forty-eight experiments are summarized in Table 5-2. Due to the amount of computer time involved only the vertical and horizontal eye movements were analysed (i.e. The Forty-eight other experiments involving the subjects looking to the corners of the eye movement screen were, with a few exceptions, not analysed).

Table 5-2

Summary of Results of Quantitative

Eye Movement Experiments

INTERPRETATION	VERTICAL EYE MOVEMENT	HORIZONTAL EYE MOVEMENT
A	20	17
D	3	7
E	3	3
F	2	0
G	1	0
H	1	1

A   means the correlation correction method was better than the analogue method.

D   means both the correlation correction and the analogue correction were equally effective.

E   means the 3-channel correction was better than the 2 channel correction.

F · means the 2 channel correction was better than the 3 channel correction.

G   means the 4 channel correction was not the best.

H   means the correlation correction was incomplete.

From Table 5-2 it was deduced that:

(i)   The correlation correction technique was complete in
      96% of the cases.

(ii) In the majority of cases (77%) the correlation
      correction technique was superior to the analogue
      correction technique.

(iii) In 21% of the cases it was not possible to distinguish
      between the effectiveness of the analogue and correlation
      techniques.

(iv) The evidence from interpretations E and F suggests that
      to correct for horizontal eye movements it may be nec-
      essary always to use the 3-channel correction rather
      than only a 2-channel correction. This is to be expect-
      ed since the ocular dipoles tend to oppose each other
      during horizontal eye movements whereas they re-inforce
      each other during vertical eye movements.

(v)   Interpretation G indicates that in 98% of cases the 4-
      channel correction is as good as or better than the
      other methods. However if computing time is at a pre-
      mium (e.g. in an on-line situation) it would probably
      be adequate to rely on the 3-channel correction method.

(vi) Interpretation D shows that the analogue technique was
      as good as the correlation technique more often for hor-
      izontal eye movements than for vertical eye movements.
      (7 times against 3 times out of 48 experiments). Since
      the analogue technique is not intended to correct for
      horizontal eye movements, this suggests that it may

actually be an unsuitable one to use to
correct for vertical eye movements.

In addition to the points previously mentioned, two
other disadvantages of the analogue techniques were noted.
Firstly it was difficult to optimise the potentiometer
setting required to minimise the artefact and analogue
correction would therefore be very time consuming in multi-
channel recording. Second, in all the subjects tested there
was a degree of coupling between the EOG and EEG when the
EOG changed rapidly. This was probably due to the R.C. net-
work formed by the potentiometer resistance (25kΩ) and the
electro-chemical capacitance of the electrode-skin interface.
This effect was reduced when a larger value potentiometer
(1MΩ) was used. Unfortunately however this solution adver-
sely affects the common mode rejection ratio of the EEG
machine's differential amplifier (because of the increased
source impedance of the input with the 1MΩ potentiometer in
circuit). The presence of this R.C. time constant will re-
sult in distortion of the EOG and hence false correction of
the artefact. This may be the reason behind the evidence in
(Vi) above that the analogue technique may even be erroneous.
This is illustrated in Figure 5-2.

In conclusion it was found that the 4-channel comput-
erised correlation method of correcting the EEG for eye
movement artefact gave complete correction in 96% of the
cases studied. However, in practice the 3-channel method
would normally be adequate. The analogue technique was
never the best. Furthermore it was very time consuming and
quite possibly erroneous.
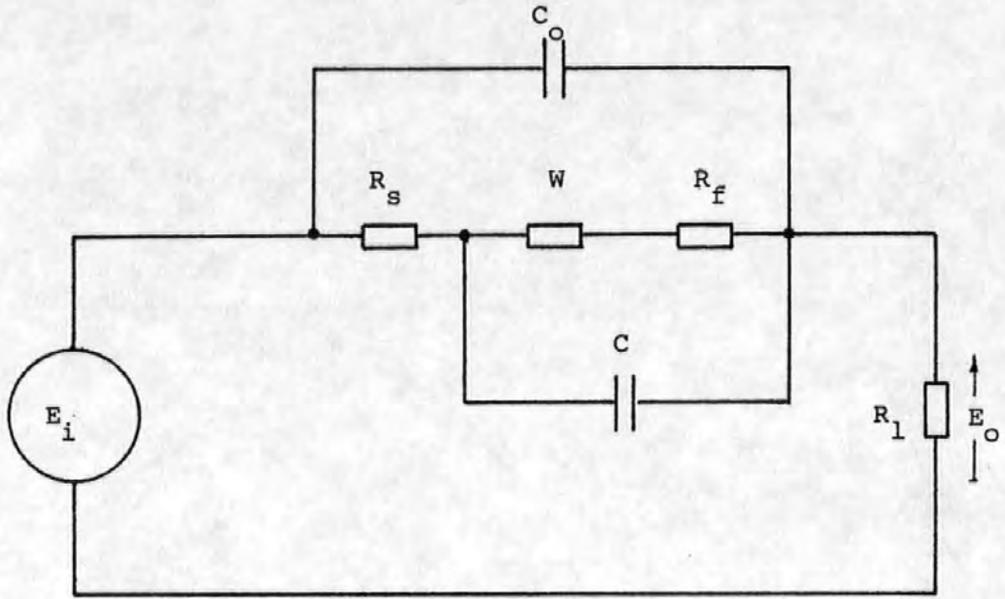
E_i	scalp EEG signal.
C_o	stray capacitance (usually negligible).
R_s	resistance of the electrode jelly.
R_f	Faradic resistance.[†]
W	Warburg impedance.[†]
C	electro-chemical capacitance.

see [11] for further details.

[†] These quantities are usually resistive and small for Ag-AgCl electrodes.
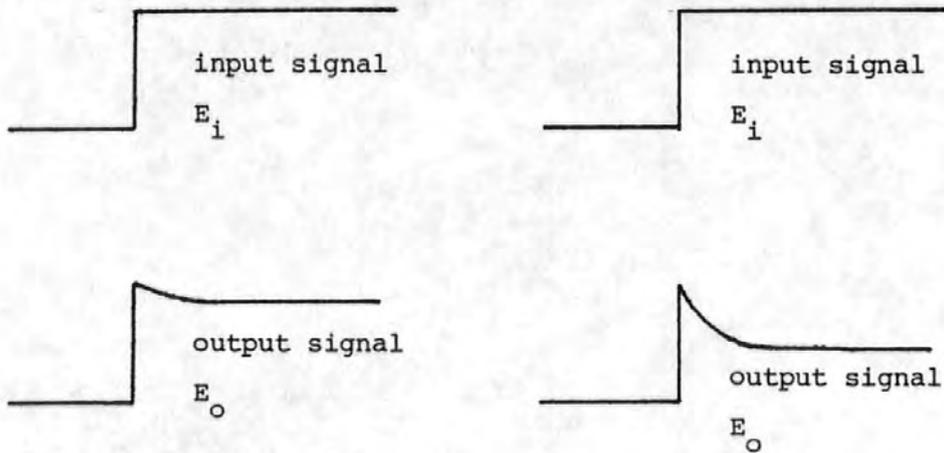
Normal situation when R_1 is large in comparison with $R_f + W$.

The situation when R_1 is small.

Figure 5-2   The effect of electrode loading.

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Some of the above work has been published [4].

A more detailed account has also been written as a longer paper with the title "Comparison of Methods for Removing Eye Movement Artefact from the EEG" for submission to the IEEE Transactions on Biomedical Engineering. This paper has not yet been submitted at the request of the National Research Development Corporation who have awarded a grant towards the development of a Commercial EEG Eye Movement Artefact Corrector based on the above work which they intend to patent.

5.2 Auditory Evoked Potentials

64 pre-stimulus and 64 post-stimulus realisations each of length 0.512 s were recorded at the two levels of stimulus for three different subjects.

Following the earlier work [5-8], the pre- and post-stimulus realisations were given the statistical test described in 2.2.3.1 above, the test for changes in signal energy, and phase histograms were also plotted for the first six harmonic frequency components. The statistical test showed that only one out of the six sets of results (3 subjects x 2 stimulus levels) exhibited a significant energy difference and in the sense that the energy in the post-stimulus case exceeded that in the pre-stimulus case.

The results of these tests are shown in table 5-3.

Table 5-3

Comparison of Pre- and Post- Stimulus AEP Energy

	Subject	Mean of difference $\times 10^{-8}$	ν (degrees of freedom)	T Statistic	% Significance
LOW	1	0.0075	63	0.129	N-S
LEVEL	2	- .1305	63	-0.709	N-S
STIMULUS (+ 40dB)	3	0.6817	63	2.729	1.0
HIGH	1	0.1265	63	1.548	20
LEVEL	2	0.2238	63	1.129	N-S
STIMULUS (+ 70dB) *	3	0.2558	63	0.886	N-S

* 65dB. above threshold

The results obtained were in accord with Sayers' findings [5] since he could not establish any consistent difference between the pre- and post- stimulus energies of the averaged waveform. This result led Sayers to the important conclusion that if there were no additional energy in the evoked response, then the characteristic shape of the AEP must be due to some form of phase alignment of certain background components.

However, this test was not considered very reliable since the contribution of every harmonic component was included in the energy calculation and the higher harmonics were probably representative of background noise. Thus the effects of background noise were likely to mask the presence of the AEP. Furthermore, while the phase histograms indicated phase ordering they did not reveal the cause. For these reasons the findings of the previous workers [5-8] although confirmed, were not considered conclusive.

The data was also subjected to the other statistical tests described in sections 2.2.2 and 2.2.3. These tests held potential advantages over the previous test since they were applied to individual harmonic components. They could therefore be used to investigate the first few harmonics which would be expected to constitute the major components of the AEP. The higher harmonics which were expected to be associated with the random background could be ignored. Typical pre- and post- stimulus phasor diagrams are shown in Figure 5-3. The triangles on the circles indicate the directions in which the phasors lie, while the crosses indicate the locations of the phasor tips. The results of the statistical tests carried out for harmonic numbers 1-6 are shown in Table 5-4. Each broad column of results contains the value of the test statistic, the number of degrees of freedom ν and the level at which the result is significant. A significant positive result in column (B) means that the nearest mean amplitude is greater than the furthest. A significant positive result in column (C) means that the post-stimulus amplitude is greater than the pre-stimulus

PRE STIM.   POST STIM.

HARMONIC 1

PRE STIM.   POST STIM.
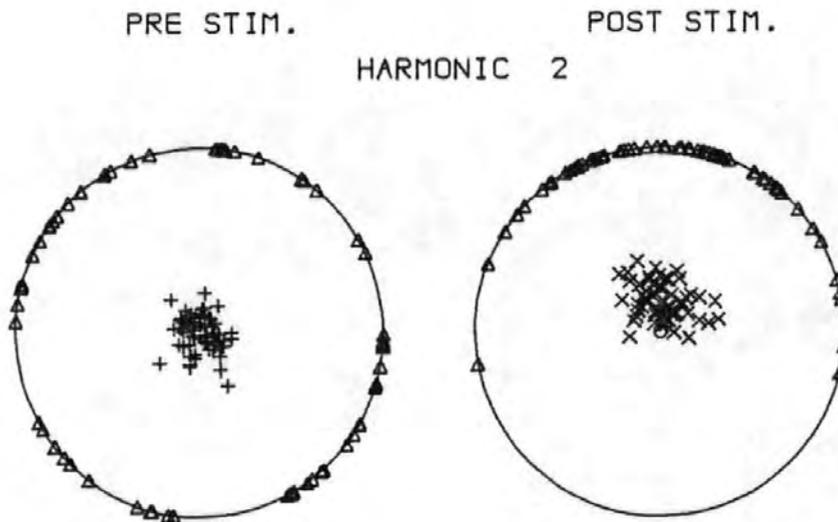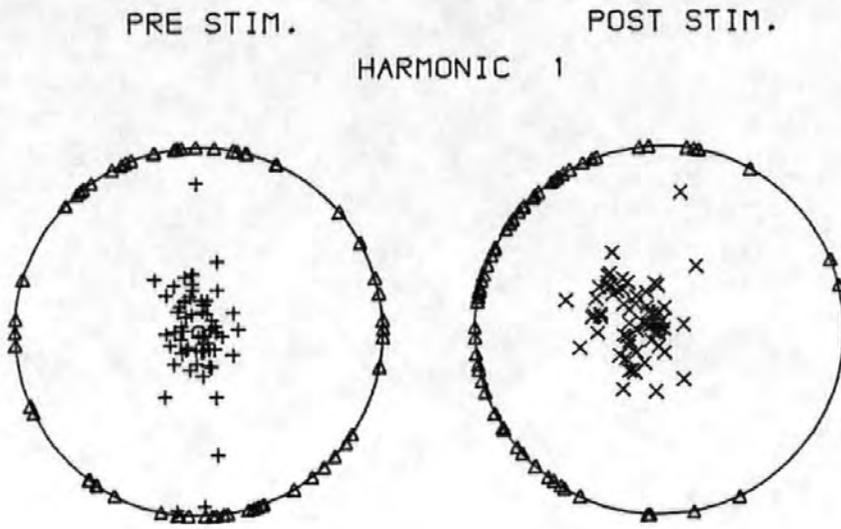
HARMONIC 2

Figure 5-3

Typical Pre- and Post-Stimulus AEP phasor

diagrams

Table 5-4

TEST STATISTICS AND LEVELS OF SIGNIFICANCE FOR STATISTICAL TESTS

ON AEP PHASOR DIAGRAMS BY HARMONIC NUMBER,

STIMULUS LEVEL AND SUBJECT

HARMONIC NUMBER & FREQUENCY	STIMULUS LEVEL	SUBJECT	NEAREST-FURTHEST MEAN AMPLITUDE (B)			PRE-POST MEAN AMPLITUDE DIFFERENCES (C)			RAYLEIGH CIRCULAR VARIANCE (D)		HODGES-AJNE (E)		MODIFIED RAYLEIGH CIRCULAR VARIANCE (F)	
			T	v	%	T	v	%	So	%	m	%	Uo	%
1 1.953 Hz	LOW	1	-0.294	63	N-S	-0.273	63	N-S	0.735	5	19	2.5	0.677	1
		2	3.67	64	.05	3.96	63	0.1	0.612	0.1	12	0.001	0.439	0.1
		3	1.69	63	5	1.01	63	N-S	0.398	0.1	7	0	0.345	0.1
	HIGH	1	1.55	62	10	2.80	63	1	0.538	0.1	13	0.005	0.477	0.1
		2	0.550	61	N-S	5.35	63	0.1	0.278	0.1	4	0	0.224	0.1
		3	-0.136	38	N-S	2.50	63	2	0.332	0.1	5	0	0.336	0.1
2 3.906 Hz	LOW	1	1.68	64	5	2.27	63	5	0.584	0.1	14	0.019	0.512	0.1
		2	0.992	58	N-S	4.13	63	0.1	0.487	0.1	11	0	0.461	0.1
		3	0.700	64	N-S	6.78	63	0.1	0.204	0.1	2	0	0.198	0.1
	HIGH	1	-0.513	59	N-S	4.96	63	0.1	0.440	0.1	10	0	0.340	0.1
		2	5.09	55	.05	3.84	63	0.1	0.445	0.1	12	0.001	0.308	0.1
		3	0.851	64	N-S	5.85	63	0.1	0.266	0.1	6	0	0.205	0.1
3 5.893 Hz	LOW	1	2.33	62	2.5	3.57	63	0.1	0.370	0.1	9	0	0.264	0.1
		2	0.480	64	N-S	2.16	63	5	0.605	0.1	17	0.45	0.504	0.1
		3	0.498	63	N-S	0.632	63	N-S	0.643	0.1	16	0.17	0.594	0.1
	HIGH	1	2.83	64	0.5	3.50	63	0.1	0.303	0.1	5	0	0.199	0.1
		2	0.0	63	N-S	1.60	63	20	0.580	0.1	14	0.019	0.550	0.1
		3	-0.763	42	N-S	1.91	63	10	0.572	0.1	13	0.005	0.502	0.1
4 7.812 Hz	LOW	1	1.51	64	10	0.0	63	N-S	0.735	5	20	5.1	0.648	1
		2	-0.362	63	N-S	-0.310	63	N-S	0.757	5	20	5.1	0.789	N-S
		3	3.08	61	0.5	1.75	63	10	0.542	0.1	14	0.019	0.421	0.1
	HIGH	1	1.75	63	5	1.81	63	10	0.403	0.1	7	0	0.282	0.1
		2	-1.18	61	N-S	-1.40*	63	20	0.777	5	22	20	0.797	N-S
		3	0.995	64	N-S	1.75	63	10	0.458	0.1	11	0	0.417	0.1
5 9.765 Hz	LOW	1	-1.21	47	N-S	1.90	63	10	0.787	10	23	20	0.812	N-S
		2	0.07	64	N-S	-0.092	63	N-S	0.848	N-S	24	N-S	0.763	10
		3	0.814	64	N-S	1.81	63	10	0.713	1	17	0.45	0.662	1
	HIGH	1	1.25	59	N-S	-0.772	63	N-S	0.705	1	20	5.1	0.612	0.1
		2	-0.02	64	N-S	-0.983	63	N-S	0.885	N-S	26	N-S	0.891	N-S
		3	0.551	63	N-S	1.81	63	10	0.463	0.1	11	0	0.456	0.1
6 11.718 Hz	LOW	1	1.65	64	10	2.96	63	1	0.686	1	17	0.45	0.566	0.1
		2	0.821	59	N-S	-2.98*	63	1	0.957	N-S	28	N-S	0.932	N-S
		3	1.49	64	10	1.83	63	10	0.638	0.1	17	0.45	0.523	0.1
	HIGH	1	1.19	57	N-S	-1.18	63	N-S	0.875	N-S	26	N-S	0.839	N-S
		2	1.37	64	10	-1.64*	63	20	0.799	10	21	9.8	0.708	5
		3	-1.31*	61	10	1.79	63	10	0.861	N-S	25	N-S	0.934	N-S

amplitude. Positive significant results in the remaining columns indicate phase ordering.

N-S means non-significant. While all levels of significance were recorded in order to extract maximum information, levels in excess of 5% were regarded as non-significant. Some of the test statistics in columns (B) and (C) are negative. The ones marked by an asterisk were significant in a negative direction. This occurred in column (C) and meant that the post-stimulus amplitude was less than the pre-stimulus one. This also occurred once in column (B) and indicated that the more widely spaced phasors were larger than the "grouped" ones. However, examination of the corresponding columns (D), (E) and (F) reveals that no phase ordering i.e. grouping had in fact occurred and the test would therefore be unreliable. (See also section 2.2.3.3). The level of significance between columns (B) and (C) do not always agree. The Nearest and Furthest Mean Amplitude Test (one-tailed) depends specifically upon the details of the assumed additive model and is not infallible, vide statistical Test B. By comparison the Pre- and Post- Stimulus Mean Amplitude Differences Test (two-tailed) tests for an additive effect irrespective of the mechanism by which it occurs. Inspection of column (C) showed that thirteen out of the eighteen results obtained for harmonics 1-3 were significant at the 5% level (i.e. additive signal detected in 72% of cases), while for harmonics 4-6 only two out of the eighteen results were significant. For column (B) the corresponding figures were six out of eighteen and two out of eighteen. Inspection

of column (C) showed that only in one case was the mean of the amplitude differences significantly less than zero (i.e. the pre- stimulus phasors were larger than the post stimulus ones). The remaining twenty-one cases were not significant in either direction. On an individual basis and ignoring significance levels nine cases showed a post-stimulus decrease in energy. Taken together these results indicated that additive energy could be detected in a large percentage of the cases for harmonics 1-3. Interestingly the Pre- and Post- Stimulus Mean Amplitude Differences Test applied to the second harmonic gave a positive significant result for each subject and for both levels of stimulus, and was the only test to do this. This may be a useful result audiologically but further investigation would be advised.

Columns (D), (E) and (F) revealed that the Rayleigh Test of Circular Variance, the Hodges-Ajne, and the Modified Rayleigh Test of Circular Variance were all in good agreement for the first three harmonics. However, the modified Rayleigh Test statistic was less than the Rayleigh statistic in 17 cases out of 18 which suggested that the amplitudes were orientated towards the preferred direction. This was not true for harmonics 4-6. In these cases the Rayleigh and Hodges-Ajne tests agreed but the modified Rayleigh Test did not always agree with them. Inspection of the tabulated results revealed that harmonic components 1-3 were strongly phase ordered while harmonics 4-6 showed less phase ordering. Overall, post-stimulus phase ordering was seen to be significant at the 5% level in all but seven of the thirty six cases observed.

Reflection upon all the observations so far made it apparent that harmonics 1-3 exhibited different amplitude and phase properties to harmonics 4-6. Harmonics 4-6 showed less evidence of phase ordering and even less evidence of additive energy. All of this was regarded as evidence that harmonics 4-6 were more representative of the noisy background EEG than of the evoked response. This in turn lent further support to the previously stated opinion that the comparison of pre- and post- stimulus realisation energies was unlikely to provide a reliable means for the investigation of additive energy, due to the masking effects of the higher harmonic noise.

Returning to Table 5-4, Column (C) taken together with Column (D) showed that when the AEP contained an additive component there was also phase ordering. This finding agreed well with the proposed additive model. Thus out of 29 cases exhibiting phase ordering 14 (or 48.3%) contained an additive component. There was also a pronounced tendency for additive and phase ordering effects to be concentrated in the first three harmonics. In other respects the occurrence of ordering or additivity appeared random. For example, for an individual the occurrence of ordering or an additive component in a particular harmonic at one level of stimulus did not necessarily mean that it would be found in the same harmonic for a different level of stimulus.

5.3 The CNV's of Normal Subjects

CNV responses were recorded from a total of five normal

subjects between the ages of 18 and 60 years. Both one and four second interstimulus intervals were used according to the procedure described in section 3.5. Prior to further processing all the individual CNV responses were corrected for the effects of eye movement artefact as described in section 2.5.

5.3.1 The Averaged CNV's

After processing to remove eye movement artefact the CNV's were averaged, filtered with the low pass digital filter described in section 3.6 and plotted. The resulting averaged CNV's are shown in Figures 5-4 a-e (1 second ISI) and Figures 5-5 a-e (4 second ISI). The averaged CNV waveforms were then used to determine the section of the response to be analysed in the subsequent sections i.e. the 'Negative Variation' section excluding the evoked responses. This section was determined in terms of 'sample numbers' and for the one second ISI was found to lie between samples 472 and 536 (The stimuli being given concurrently with samples 407 and 532), whereas for the four second ISI it was found to lie between samples 295 and 695 (The stimuli being given concurrently with samples 219 and 719). Since the digital filter was used in most of the subsequent analysis, the sample numbers obtained from the averaged CNV responses included a delay due to the filter identical to that which would be obtained in the subsequent processing. Any processing carried out on unfiltered data used points 462 and 526 (1 second ISI) or points 285 and 685 (4 second ISI).
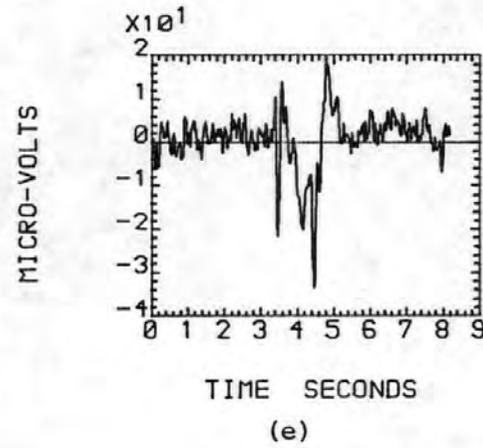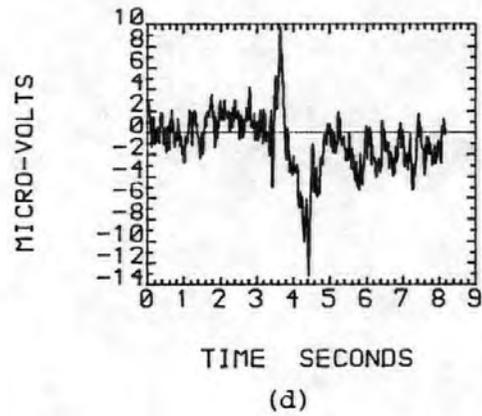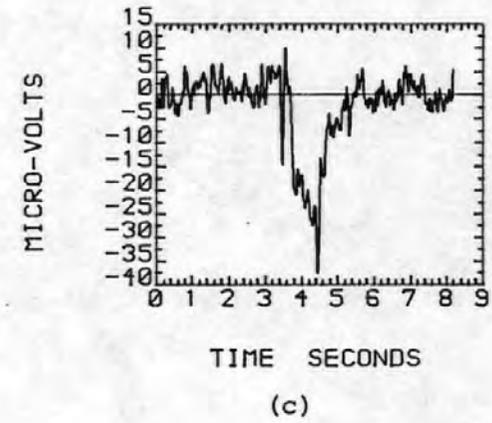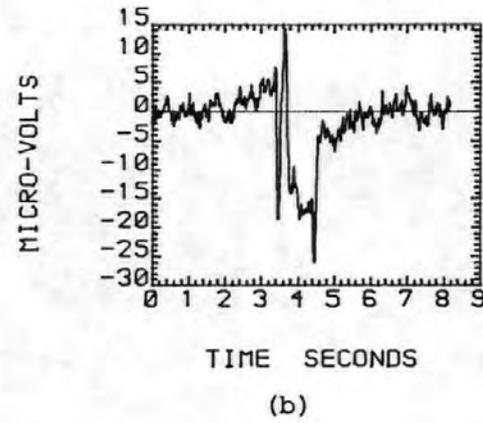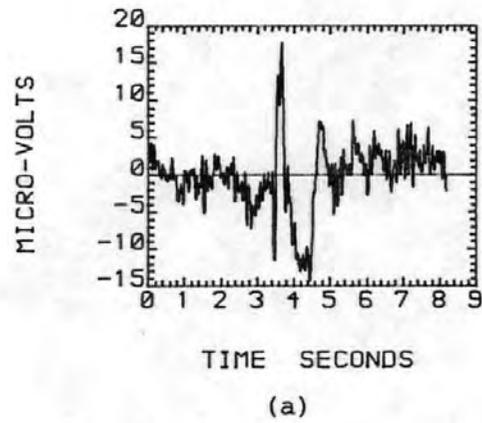
Figure 5-4

The averaged one second ISI CNV's
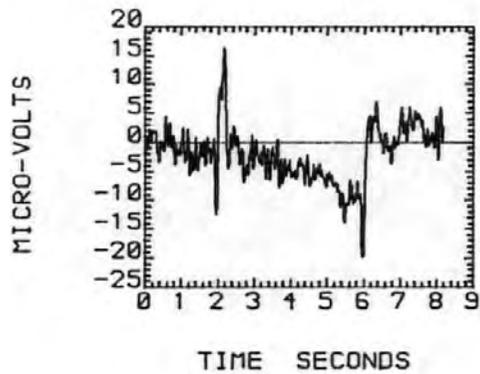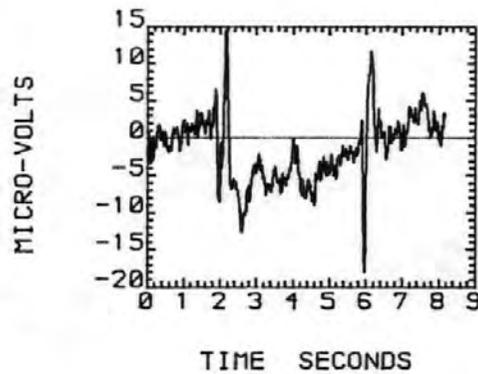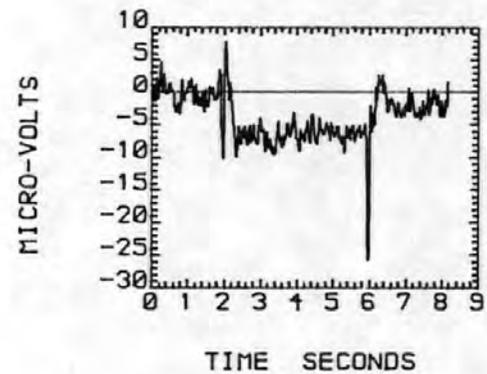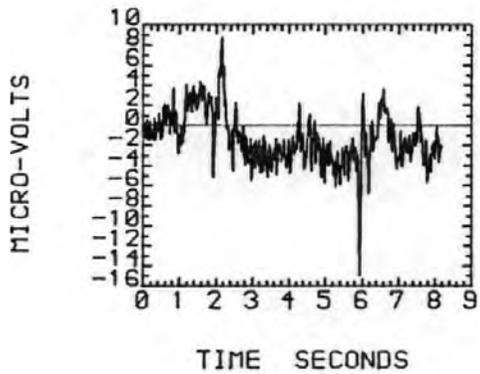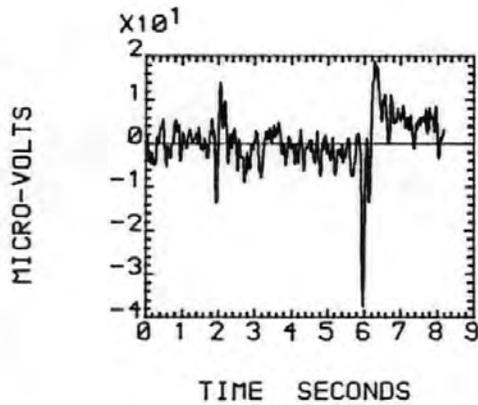
of normal subjects.

Figure 5-5

The averaged four second ISI CNV's

of normal subjects.

5.3.2 Energy Tests

These tests were performed to establish whether any additive component could be detected in the CNV response.

5.3.2.1 Broadband Energy Tests

Prior to the calculation of the mean energy for the pre- and post- stimulus sections of the CNV's, the data was corrected for the effects of eye movements and filtered in the usual manner. One of the side effects of the eye movement correction procedure was to remove any d.c. component present in the data epoch and, where an individual CNV response contained a marked negative shift, the effect of this was to cause a positive shift of the pre- and post-stimulus baselines. Thus prior to the calculations described in section 2.2.3.1 it was necessary to re-establish the true baseline. This was achieved by subtracting the mean signal level, calculated over that section of the data prior to the S1 stimulus, from the data. Furthermore, to allow for any small d.c. drift during the acquisition of the data, the mean signal level was also calculated for that section of the data from a point one second after the S2 stimulus (to allow the S2 evoked response and the CNV to return to the zero level) to the end of the data record. This value was subtracted from this section of the data. Between these two mean values the data was corrected by subtracting the appropriate fraction of the difference between these values. The overall correction was thus:-

Section of data (sample numbers)	Corrections used
$1 \leqslant k \leqslant S1$	$x_k = x_k - \dfrac{1}{S1} \sum\limits_{i=1}^{S1} x_i$
$S1 < k \leqslant S2+D$	$x_k = x_k - \left[\dfrac{\left(\dfrac{1}{(N-S2-D)} \sum\limits_{S2+D}^{N} x_i\right) - \left(\dfrac{1}{S1} \sum\limits_{1}^{S1} x_i\right)}{S2 + D - S1} \right](k-S1)$
$S2+D < k \leqslant N$	$x_k = x_k - \dfrac{1}{(N-S2-D)} \sum\limits_{S2+D}^{N} x_i$

Where S1   is the sample number corresponding to the instant of the S1 stimulus application.

S2   as above for S2.

D   is the delay after S2 to allow the responses to settle. (a figure of one second (D = 125) was used).

x_i is the ith data point.

N   is the total number of data points.

This correction is subsequently referred to as the base-line correction.

After applying this correction to each CNV response the mean energy values were calculated and subjected to a T-test as previously described. The results of these tests are shown in Tables 5-5a and 5-5b.

Table 5-5a

Broadband energy tests of normal subjects

One second ISI CNV's

Subject	Number of Responses	T Statistic	Significance Level %	Number of* Responses Post < pre
1	31	2.91	1.0	7
2	32	7.05	<<0.1	1
3	19	5.22	<<0.1	3
4	32	2.18	5.0	10
5	32	4.69	<<0.1	6

Table 5-5b

Broadband energy tests of normal subjects

Four second ISI CNV's

Subject	Number of Responses	T Statistic	Significance Level %	Number of* Responses Post < pre
1	32	2.47	2.0	11
2	32	3.47	0.2	3
3	32	4.39	<<0.1	5
4	32	3.72	0.1	7
5	32	5.55	<<0.1	5

* The number of individual responses where the post-stimulus energy was less than the pre-stimulus energy.

They show that for both ISI's and to a level of significance of at least 5%, and mostly considerably better, the CNV response contained more energy than the background EEG prior to stimulation. The conclusion drawn from this was that the CNV must contain additional energy. On an individual basis however, 58 out of 306 (18.9%) of the CNV responses contained less energy than the background EEG. This possibly reflected the variability of the background EEG and of the CNV rather than it implied the CNV energy might have been less than the background.

5.3.2.2 Amplitude Histograms

The background EEG has a virtually random amplitude and phase but an added signal component due to the CNV might be expected to have a constant amplitude and phase. If the amplitude of the added component were the same for each stimulus and were large in comparison with the background EEG, then the nth harmonic component of each response would be similar. Hence the nth harmonic amplitude histogram for a sequence of CNV's should exhibit a peak about some preferred value. Amplitude histograms were plotted to test this hypothesis. It was found that the amplitude histogram of the first harmonic of the one second ISI CNV's showed some similarities. In particular most exhibited a lower amplitude limit while the most probable amplitudes were different for different subjects. A typical histogram is shown in Figure 5-6. None of the other harmonics showed any obvious patterns. It was thought that the absence of definite patterns in the histograms of the higher harmonics might indicate the masking effects of the background EEG. Accordingly a comparison of
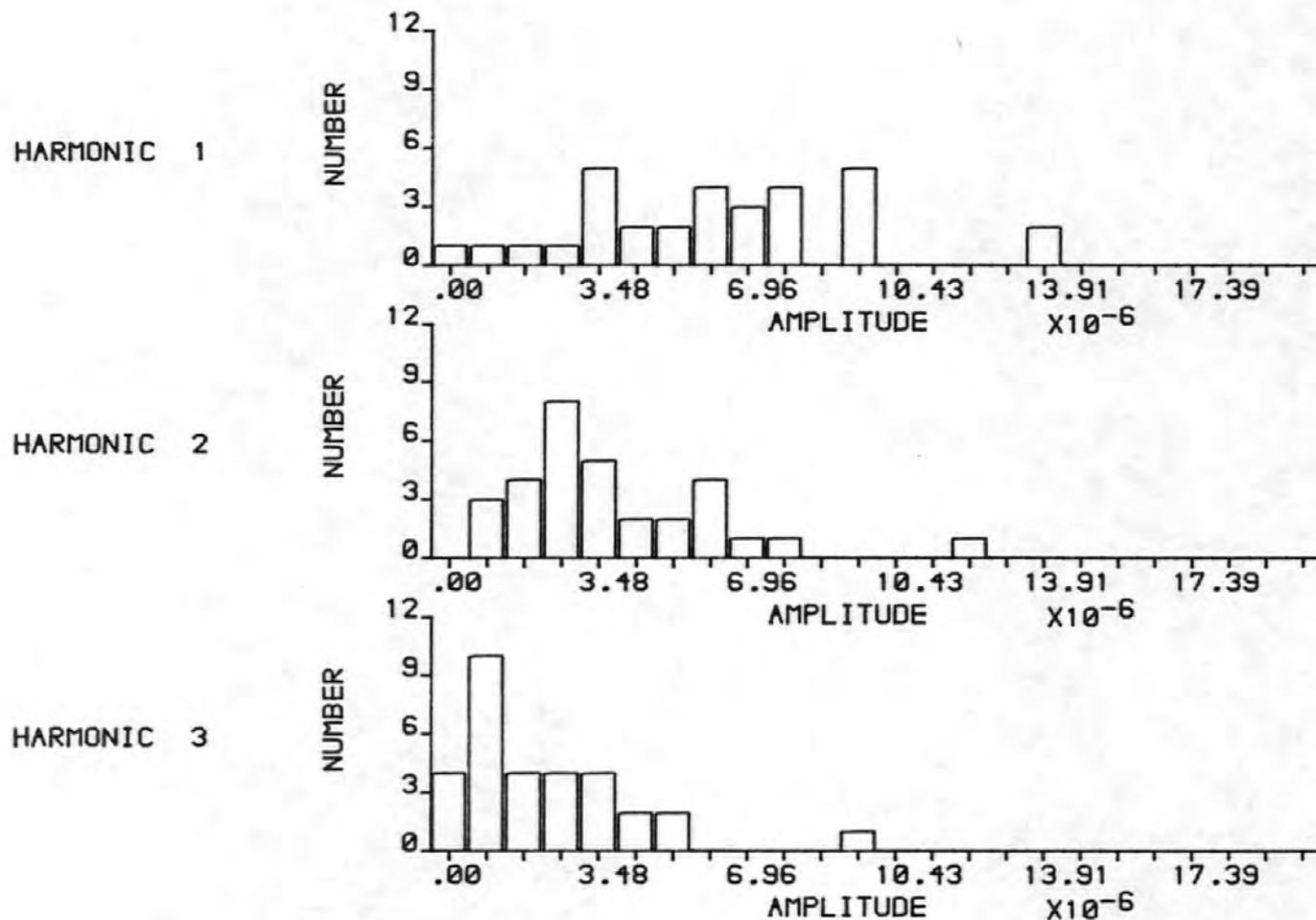
Figure 5-6 Typical amplitude histograms of a one second ISI CNV, Harmonics 1 to 3.

the spectra of the background EEG was made with the spectrum of the averaged CNV. The latter spectrum would be relatively free of background EEG due to the averaging process.

The spectrum of the averaged CNV's displayed the presence of signal power at frequencies of up to 12 Hz. Over this frequency range the signal levels were about 0.5 - 6.5 μV Hz.$^{-\frac{1}{2}}$ By comparison the background EEG contained signal levels of 1.5 - 13.8 μV Hz.$^{-\frac{1}{2}}$ over the same range. Thus the frequency components of the background EEG were indeed compatible to or greater in amplitude than those of the CNV, and were therefore capable of masking it.

5.3.2.3 <u>Pre- and Post- Stimulus Mean Amplitude Differences</u> <u>Test</u>

These tests were performed on the mean of the amplitude differences of the pre- and post- stimulus phasors as described in section 2.2.3.2. Because of the limited amount of pre-stimulus information available these tests were not carried out on the four second ISI CNV's. The results of the tests are shown in Table 5-6. The column giving the significance level of any detected difference shows that additivity was only detected in 11 of the 30 results. Furthermore, only 2 of these 11 were significant at the 5% or higher level. Surprisingly however, 13 of the 30 results showed decreased amplitudes in the post-stimulus case (denoted by asterisks in the table) although only 2 of these results were statistically significant at the 5% level.

Table 5-6

Pre- and Post-stimulus Mean Amplitude Differences Tests

For Normal Subjects

Subject Number	Mean of Differences $\times 10^{-5}$	Stand.Dev. of Differences $\times 10^{-5}$	Harmonic Number	T	ν	Significance %
1	0.1586	0.4696	1	1.88	30	10
	0.0144	0.3228	2	0.248	30	N-S
	-0.0381	0.2387	3	-0.888*	30	N-S
	0.0709	0.2889	4	1.37	30	20
	0.0974	0.4162	5	1.30	30	N-S
	-0.1399	0.2229	6	-3.49*	30	0.2
2	0.1561	0.4827	1	1.83	31	10
	0.0651	0.2817	2	1.31	31	20
	0.0449	0.1978	3	1.28	31	N-S
	0.0110	0.1883	4	0.33	31	N-S
	-0.0079	0.1341	5	-0.33*	31	N-S
	-0.0261	0.1218	6	-1.21*	31	N-S
3	-0.0974	0.4229	1	-1.00*	18	N-S
	0.0362	0.4806	2	0.33	18	N-S
	0.0884	0.2425	3	1.59	18	20
	-0.0780	0.2308	4	-1.47*	18	20
	-0.0451	0.1543	5	-1.27*	18	N-S
	0.0292	0.1971	6	0.65	18	N-S
4	0.0880	0.3578	1	1.39	31	20
	0.0797	0.2526	2	1.79	31	10
	0.0435	0.1776	3	1.39	31	20
	-0.0532	0.1367	4	-2.20*	31	5
	-0.0355	0.2242	5	-0.896*	31	N-S
	-0.0412	0.1477	6	-1.58*	31	20
5	0.2115	0.8769	1	1.36	31	20
	0.2965	0.6157	2	2.72	31	2
	0.2428	0.4536	3	3.03	31	1
	-0.1074	0.3109	4	-1.95*	31	10
	-0.0951	0.3153	5	-1.71*	31	10
	-0.0671	0.2202	6	-1.72*	31	10

* denotes that the post-stimulus amplitudes were smaller than the pre-stimulus amplitudes.

5.3.2.4 Nearest and Furthest Mean Amplitude Test

These tests were performed on the amplitudes of post-stimulus phasors for the one and four second ISI CNV's described in section 2.2.3.3. The results are shown in Tables 5-7a and 5-7b for the one and four second ISI's respectively. For the one second ISI the significance column shows that additivity was detected in 7 cases out of 30, but of these only 4 were significant at the 5% level. In one case (i.e. subject 4, harmonic 3), the furthest phasors had larger amplitudes than the nearest. For the four second ISI CNV's additivity was detected in 4 cases and of these only 2 were significant at the 5% level. The furthest phasors had larger amplitudes than the nearest in 2 cases.

Table 5-7a

Nearest and Furthest Mean Amplitude Test

For 1 second ISI CNV's of Normal Subjects

Subject Number	Nearest		Furthest		Harmonic	T	ν	Significance %
	Mean $\times 10^{-5}$	St.Dev. $\times 10^{-5}$	Mean $\times 10^{-5}$	St.Dev. $\times 10^{-5}$				
1	1.04	0.353	0.761	0.523	1	1.76	28	5
	0.650	0.361	0.514	0.269	2	1.19	28	N-S
	0.380	0.251	0.382	0.328	3	-0.017	30	N-S
	0.485	0.311	0.560	0.380	4	-0.609	31	N-S
	0.807	0.431	0.831	0.535	5	-0.137	30	N-S
	0.418	0.168	0.354	0.234	6	0.882	29	N-S
2	1.24	0.457	0.769	0.363	1	3.23	30	0.5
	0.643	0.368	0.456	0.301	2	1.58	31	10
	0.439	0.237	0.415	0.192	3	0.322	31	N-S
	0.308	0.202	0.309	0.217	4	-0.017	32	N-S
	0.293	0.134	0.211	0.114	5	1.86	31	5
	0.276	0.107	0.216	0.107	6	1.58	32	10
3	0.805	0.434	0.781	0.337	1	0.131	17	N-S
	0.660	0.288	0.675	0.426	2	-0.09	18	N-S
	0.575	0.258	0.554	0.318	3	0.165	19	N-S
	0.362	0.200	0.241	0.149	4	1.48	16	10
	0.274	0.156	0.303	0.162	5	-0.396	19	N-S
	0.329	0.219	0.253	0.257	6	0.690	19	N-S
4	0.813	0.388	0.641	0.383	1	1.26	32	N-S
	0.525	0.337	0.419	0.254	2	1.00	30	N-S
	0.332	0.168	0.432	0.171	3	-1.65*	32	10
	0.243	0.162	0.259	0.101	4	-0.337	27	N-S
	0.298	0.110	0.359	0.258	5	-0.868	21	N-S
	0.202	0.142	0.239	0.125	6	-0.777	32	N-S
5	2.16	0.813	1.52	0.800	1	2.24	32	2.5
	1.17	0.463	1.47	0.817	2	-1.26	25	N-S
	0.985	0.541	0.973	0.607	3	0.061	32	N-S
	0.603	0.247	0.506	0.274	4	1.05	32	N-S
	0.548	0.276	0.456	0.305	5	0.895	32	N-S
	0.340	0.216	0.335	0.164	6	0.08	30	N-S

Table 5-7b

Nearest and Furthest Mean Amplitude Test

For 4 second ISI CNV's of Normal Subjects

Subject	Nearest		Furthest		Harmonic	T	ν	Significance %
	Mean x10^{-5}	St.Dev. x10^{-5}	Mean x10^{-5}	St.Dev. x10^{-5}				
1	0.740	0.304	0.491	0.267	1	2.47	32	1
	0.370	0.219	0.448	0.243	2	-0.958	32	N-S
	0.451	0.246	0.324	0.120	3	1.85	23	5
	0.357	0.125	0.308	0.163	4	0.954	30	N-S
	0.430	0.176	0.460	0.221	5	-0.429	30	N-S
	0.342	0.252	0.432	0.190	6	-1.03	30	N-S
2	1.119	0.554	0.912	1.13	1	0.663	23	N-S
	0.943	1.05	0.744	0.349	2	0.721	19	N-S
	0.347	0.230	0.624	0.583	3	-1.77*	20	5
	0.721	0.744	0.462	0.260	4	1.32	19	N-S
	0.531	0.514	0.327	0.152	5	1.52	18	10
	0.383	0.221	0.354	0.213	6	0.369	32	N-S
3	0.806	0.382	0.879	0.373	1	-0.547	32	N-S
	0.715	0.324	0.741	0.372	2	-0.214	31	N-S
	0.510	0.323	0.606	0.280	3	-0.903	31	N-S
	0.475	0.237	0.401	0.176	4	1.00	29	N-S
	0.437	0.177	0.341	0.152	5	1.65	31	10
	0.370	0.152	0.333	0.171	6	0.648	32	N-S
4	0.554	0.226	0.503	0.259	1	0.615	31	N-S
	0.428	0.235	0.449	0.268	2	-0.227	31	N-S
	0.419	0.177	0.378	0.141	3	0.738	30	N-S
	0.330	0.176	0.279	0.160	4	0.845	32	N-S
	0.331	0.192	0.435	0.219	5	-1.43*	31	10
	0.312	0.184	0.320	0.124	6	-0.147	28	N-S
5	1.06	0.951	1.09	0.806	1	-0.114	31	N-S
	0.864	0.499	0.930	0.488	2	-0.382	32	N-S
	0.789	0.444	0.684	0.479	3	0.642	32	N-S
	0.887	0.353	0.866	0.645	4	0.110	24	N-S
	0.728	0.418	0.663	0.330	5	0.485	30	N-S
	0.577	0.377	0.602	0.452	6	-0.166	31	N-S

* denotes that the furthest phasors were larger than the nearest phasors.

5.3.2.5. Discussion of Results of Energy Tests

The results of the Pre- and Post- Stimulus Mean
Amplitude Differences tests and of the Nearest and
Furthest Mean Amplitude tests, which indicated additivity
for only a minority of the harmonic components, were in
contrast to those of the pre-stimulus and CNV broadband
energy tests which offered strong evidence of additivity.
The differences may be attributed to either the effects
of the background EEG or to the suitability of the tests.
For example, the Nearest and Furthest Mean Amplitude test
could be prone to error and while positive results supported
the additivity model, negative ones did not necessarily dis-
prove it. It was assumed that for each trial the noise and
signal amplitudes were the same and that the response was
the same in both amplitude and phase. These assumptions
may not have been sufficiently true and if, for example,
the response had a random phase there would be no detectable
preferred direction even though added energy was present.
Also in the additive model a phasor could have been reversed
from a large phasor in one direction to a small phasor in
the preferred direction. This would have been contrary to
the general assumption that phasors would be larger in the
preferred direction. Thus the test was not infallible and
there may have been added energy in some of the other cases.
The Pre- and Post-Stimulus Mean Amplitude Differences test
could have been affected by variations in the background
EEG and thus made unreliable. Alternatively the extra energy
detected by the broadband tests could have been at frequencies
other than those examined.

5.3.3 Tests for Phase Ordering

The following tests were performed to establish whether any phase ordering could be detected in the CNV response.

5.3.3.1 Phase Histograms

It was found that the phase histograms of the first harmonic of the CNV's were visually similar for all subjects and for both one second and four second ISI's as predicted in Section 2.2.1 and Appendix 8.1. Typical phase histograms for both ISI's are shown in Figures 5-7a and 5-7b. The patterns observed in these histograms are evidence for phase ordering. Similar histograms, for the higher harmonic frequency components, did not exhibit any noticeable phase patterns or ordering. Because of the limited number of observations made and the relatively large number of phase intervals necessary to observe patterns and ordering, the phase histograms were not considered to be very reliable indicators of these effects. Furthermore, since it was necessary to judge visually the presence (or absence) of phase patterns only limited credence could be given to these histograms.

5.3.3.2 Rayleigh Test of Circular Variance

The results of this test are given in tables 5-8a and 5-8b for the one second and four second ISI CNV's respectively. For the one second ISI the test gave a significant result in 10 out of the 30 cases studied while of these only 6 were significant at the 5% level. In the case of the

Figure 5-7a A typical one second ISI phase histogram of a normal subject

Figure 5-7b A typical four second ISI phase histogram of a normal subject

Table 5-8a

Circular Variance for 1 second ISI CNV's of Normal Subjects

Subject	Harmonic	Number of Trials	So	Significance %
1	1	31	0.202	0.1
	2	31	0.554	1.0
	3	31	0.787	N-S
	4	31	0.916	N-S
	5	31	0.713	10.0
	6	31	0.806	N-S
2	1	32	0.683	5.0
	2	32	0.893	N-S
	3	32	0.940	N-S
	4	32	0.804	N-S
	5	32	0.848	N-S
	6	32	0.796	N-S
3	1	19	0.642	10
	2	19	0.699	N-S
	3	19	0.781	N-S
	4	19	0.425	1.0
	5	19	0.694	N-S
	6	19	0.855	N-S
4	1	32	0.747	N-S
	2	32	0.695	10.0
	3	32	0.841	N-S
	4	32	0.700	10.0
	5	32	0.902	N-S
	6	32	0.780	N-S
5	1	32	0.354	0.1
	2	32	0.990	N-S
	3	32	0.661	5.0
	4	32	0.792	N-S
	5	32	0.877	N-S
	6	32	0.771	N-S

Table 5-8b

Circular Variance for 4 second ISI CNV's of Normal Subjects

Subject	Harmonic	Number of Trials	So	Significance %
1	1	32	0.599	1.0
	2	32	0.973	N-S
	3	32	0.807	N-S
	4	32	0.935	N-S
	5	32	0.926	N-S
	6	32	0.945	N-S
2	1	32	0.867	N-S
	2	32	0.882	N-S
	3	32	0.779	N-S
	4	32	0.699	10.0
	5	32	0.799	N-S
	6	32	0.916	N-S
3	1	32	0.822	N-S
	2	32	0.877	N-S
	3	32	0.993	N-S
	4	32	0.897	N-S
	5	32	0.914	N-S
	6	32	0.896	N-S
4	1	32	0.957	N-S
	2	32	0.724	N-S
	3	32	0.856	N-S
	4	32	0.790	N-S
	5	32	0.861	N-S
	6	32	0.883	N-S
5	1	32	0.808	N-S
	2	32	0.793	N-S
	3	32	0.835	N-S
	4	32	0.896	N-S
	5	32	0.949	N-S
	6	32	0.811	N-S

four second ISI CNV's only 2 out of the 30 cases were significant and of them only 1 was significant at the 5% level. Thus phase ordering appeared to be less pronounced in the case of the four second ISI CNV's. This difference reflected the more complex composition of the longer ISI CNV's.

5.3.3.3 Modified Rayleigh Test of Circular Variance

The results of these tests are shown in tables 5-9a and 5-9b for the two ISI's used. For the one second ISI phase ordering was significant in 10 out of the 30 cases, being significant at the 5% level in 7 cases. For the four second ISI the figures were 4 and 3 respectively. Thus the phase again appeared to be less pronounced in the four second ISI CNV's.

5.3.3.4 Hodges-Ajne Test

Tables 5-10a and 5-10b show the results of these tests for the one and four second ISI CNV's respectively. The one second ISI CNV's exhibited ordering in 5 cases out of 30 and of these 4 were significant at the 5% level. There were only 2 cases of ordering in the results for the four second ISI CNV's and only 1 was significant at the 5% level.

Table 5-9a

The Modified Circular Variance Tests for the 1 second
ISI CNV's of Normal Subjects

Subject	Harmonic	Number of Trials	Uo	Significance %
1	1	31	0.166	0.1
	2	31	0.453	0.1
	3	31	0.739	N-S
	4	31	0.961	N-S
	5	31	0.721	N-S
	6	31	0.672	10.0
2	1	32	0.530	1.0
	2	32	0.795	N-S
	3	32	0.807	N-S
	4	32	0.802	N-S
	5	32	0.727	N-S
	6	32	0.715	N-S
3	1	19	0.526	5.0
	2	19	0.806	N-S
	3	19	0.828	N-S
	4	19	0.307	0.1
	5	19	0.726	N-S
	6	19	0.818	N-S
4	1	32	0.672	10.0
	2	32	0.607	5.0
	3	32	0.915	N-S
	4	32	0.743	N-S
	5	32	0.863	N-S
	6	32	0.731	N-S
5	1	32	0.216	0.1
	2	32	0.949	N-S
	3	32	0.678	10.0
	4	32	0.777	N-S
	5	32	0.892	N-S
	6	32	0.772	N-S

Table 5-9b

The Modified Circular Variance Tests for the 4 second

ISI CNV's of Normal Subjects

Subject	Harmonic	Number of Trials	Uo	Significance %
1	1	32	0.506	1.0
	2	32	0.929	N-S
	3	32	0.717	N-S
	4	32	0.848	N-S
	5	32	0.873	N-S
	6	32	0.832	N-S
2	1	32	0.743	N-S
	2	32	0.970	N-S
	3	32	0.857	N-S
	4	32	0.651	5.0
	5	32	0.623	5.0
	6	32	0.848	N-S
3	1	32	0.959	N-S
	2	32	0.912	N-S
	3	32	0.953	N-S
	4	32	0.788	N-S
	5	32	0.827	N-S
	6	32	0.790	N-S
4	1	32	0.947	N-S
	2	32	0.679	10.0
	3	32	0.845	N-S
	4	32	0.777	N-S
	5	32	0.966	N-S
	6	32	0.921	N-S
5	1	32	0.816	N-S
	2	32	0.770	N-S
	3	32	0.746	N-S
	4	32	0.796	N-S
	5	32	0.962	N-S
	6	32	0.758	N-S

Table 5-10a

The Hodges-Ajne test for the 1 second ISI CNV's of normals

Subject	Harmonic	Number of Trials	M	Significance %
1	1	31	2	0.001
	2	31	4	0.067
	3	31	10	N-S
	4	31	13	N-S
	5	31	9	N-S
	6	31	11	N-S
2	1	32	10	N-S
	2	32	12	N-S
	3	32	14	N-S
	4	32	10	N-S
	5	32	12	N-S
	6	32	11	N-S
3	1	19	4	16.0
	2	19	5	N-S
	3	19	5	N-S
	4	19	2	0.9
	5	19	6	N-S
	6	19	6	N-S
4	1	32	10	N-S
	2	32	9	N-S
	3	32	12	N-S
	4	32	9	N-S
	5	32	12	N-S
	6	32	12	N-S
5	1	32	3	0.006
	2	32	13	N-S
	3	32	9	N-S
	4	32	10	N-S
	5	32	12	N-S
	6	32	10	N-S

Table 5-10b

The Hodges-Ajne test for the 4 second ISI CNV's of normals

Subject	Harmonic	Number of Trials	M	Significance %
1	1	32	6	0.8
	2	32	13	N-S
	3	32	10	N-S
	4	32	12	N-S
	5	32	13	N-S
	6	32	14	N-S
2	1	32	12	N-S
	2	32	12	N-S
	3	32	11	N-S
	4	32	8	7·8
	5	32	11	N-S
	6	32	13	N-S
3	1	32	11	N-S
	2	32	12	N-S
	3	32	14	N-S
	4	32	12	N-S
	5	32	13	N-S
	6	32	13	N-S
4	1	32	13	N-S
	2	32	10	N-S
	3	32	11	N-S
	4	32	12	N-S
	5	32	12	N-S
	6	32	12	N-S
5	1	32	11	N-S
	2	32	10	N-S
	3	32	11	N-S
	4	32	12	N-S
	5	32	13	N-S
	6	32	12	N-S

5.3.4. Discussion of Energy and Phase Results

Table 5-11 summarises the additivity and phase order-
ing results which were found to be significant at the 5%
level.

That part of the table concerned with phase ordering
was inspected in order to compare the results of the diff-
erent tests. Asterisks were used to indicate similar
results which were given by either two or three of the tests.
Scanning of the rows showed that the results of the phase
ordering tests were mainly consistent and therefore pro-
bably reliable. The Modified Rayleigh test tended to pro-
duce more results which were significant than either of the
other two tests and this was because it took into account
both amplitude and phase information. For the one second
ISI CNV's phase ordering was detected in 8 cases out of 30
at the 5% level. For the four second ISI CNV's only 3 of
the 30 were significant at the 5% level.

It was stated above (Section 5.3.3.1) that the phase
histograms of the first harmonic for both the one and four
second ISI CNV's had similar patterns which were evidence
of phase ordering, but that the effect was less obvious for
the higher harmonics. Inspection of the results of the stat-
istical tests for phase ordering partly confirms those find-
ings. Table 5-12 shows the mean directions of the phasors
and the levels of significance for some of the results. It
can be seen that for the one second ISI CNV's the mean dir-
ection of the phasors falls in the theoretically predicted

Table 5-11

Summary of Additivity and Phase Ordering Results Significant

at the 5% level for Normal Subjects

		ADDITIVITY		PHASE ORDERING		
ISI	SUBJECT NUMBER	NEAREST & FURTHEST MEAN AMPLITUDE	PRE & POST MEAN AMPLITUDE DIFFERENCES	RAYLEIGH CIRCULAR VARIANCE	MODIFIED RAYLEIGH CIRCULAR VARIANCE	HODGES-AJNE
1	1	H1		H1*, H2*	H1*, H2*	H1*, H2*
	2	H1, H5+		H1*	H1*	
	3			H4*	H1, H4*	H4*
	4				H2	
	5	H1	H2+, H3	H1*, H3	H1*	H1*
4	1	H1, H3+		H1*	H1*	H1*
	2				H4 ,H5	

Hn   indicates that the nth harmonic had a significant result.

+   indicates additivity with no accompanying ordering.

*   indicates agreement between two or more tests.

Table 5-12

Mean Directions and Significance for Selected Cases

ISI	HARMONIC NUMBER	SUBJECT NUMBER	NUMBER OF RESPONSES	MEAN DIRECTION	SIGNIFICANCE OF PHASE ORDERING+
1	1	1	31	-70	S
		2	32	-75	S
		3	19	106	S
		4	32	-82	N-S
		5	32	-81	S
	2	1	31	-102	S
		2	32	114	N-S
		3	19	116	N-S
		4	32	-76	S
		5	32	51	N-S
	3	1	31	140	N-S
		2	32	-24	N-S
		3	19	-125	N-S
		4	32	-36	N-S
		5	32	57	S
4	1	1	32	-57	S
		2	32	108	N-S
		3	32	138	N-S
		4	32	-129	N-S
		5	32	-159	N-S
	2	1	32	-5	N-S
		2	32	-125	N-S
		3	32	7	N-S
		4	32	10	N-S
		5	32	131	N-S
	3	1	32	155	N-S
		2	32	104	N-S
		3	32	95	N-S
		4	32	-150	N-S
		5	32	36	N-S

+ S   indicates phase ordering detected by any of the three tests
       significant at the 5% level.

N-S   indicates no significant phase ordering.

range of 0° to -90° in 4 out of 5 cases and for 3 of these there was also significant phase ordering. Hence a distinctive pattern would indeed be anticipated in the phase histogram. The mean direction is less likely to be in the predicted range and the degree of ordering is also seen to be decreased as the harmonic number increases. This is in agreement with the reduced observable phase ordering in the phase histograms of the higher harmonics. The results for the four second ISI CNV's showed little phase ordering and many of the angles were outside the predicted range. This did not agree with the conclusion reached by visual inspection of the phase histograms. This discrepancy was probably due to the unreliability of the phase histograms for the reasons previously mentioned.

Table 5-11 was also inspected to check whether additivity was always accompanied by phase ordering as the additivity model would suggest. It was noted that in three cases additivity was detected in the absence of detectable phase ordering. This may have been due to the limitations of the tests or it may indicate that the CNV response cannot be described by the additivity model.

Overall it appears that the CNV responses of normal subjects may contain a certain amount of added random energy and are therefore probably less deterministic in nature then, for example, an auditory evoked response.

5.4 The CNV's of Abnormal Subjects

CNV responses were also recorded from a total of five patients for whom Huntington's chorea had been diagnosed. Once again two interstimulus intervals were used (one and four seconds) and prior to further processing the individual responses were corrected for the effects of eye movement as described in Section 2.5

5.4.1 The Averaged CNV's

After processing to remove eye movement artefact the CNV's were averaged, filtered with the low pass digital filter described in Section 3.6 and plotted. The results of this procedure are shown in Figures 5-8 a-e and 5-9 a-e. A characteristic feature of some of these CNV's was the slow return to the baseline subsequent to the S2 stimulus. This feature, known as the Post Imperative Negative Variation, has been described elsewhere [9] although not in connection with Huntington's chorea. Some of the averaged CNV's were generally similar to those obtained from normal subjects (e.g. Figure 5-8c) whilst others (e.g. Figure 5-8b) showed very little evidence of a CNV response at all. The differences in the averaged waveforms of normals and patients were exploited in distinguishing between the two categories as described in Section 5.5

5.4.2. Energy Tests

These tests were performed to establish whether any additive component could be detected in the CNV response of the H.C. patient group.
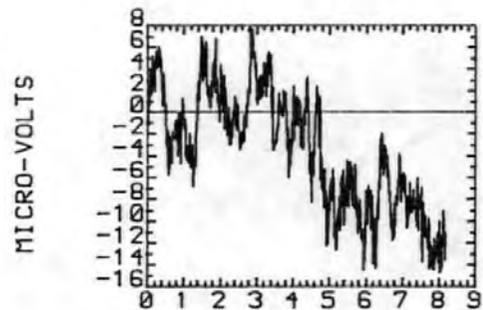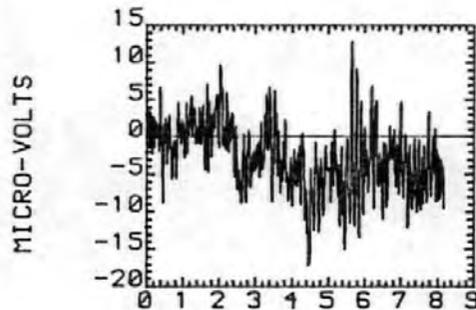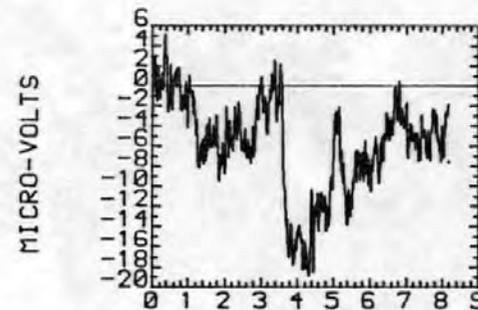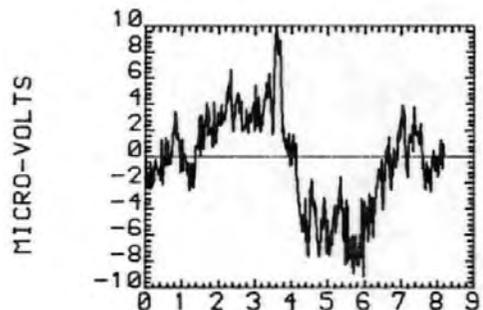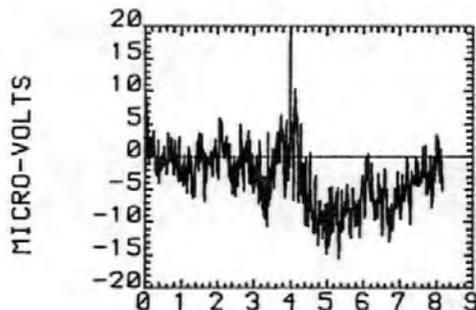
Figure 5-8

The averaged one second ISI CNV's
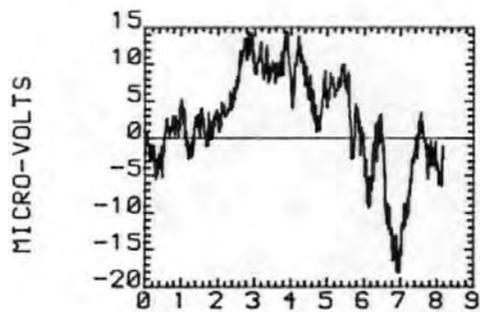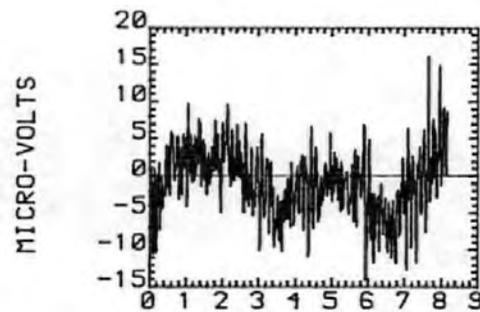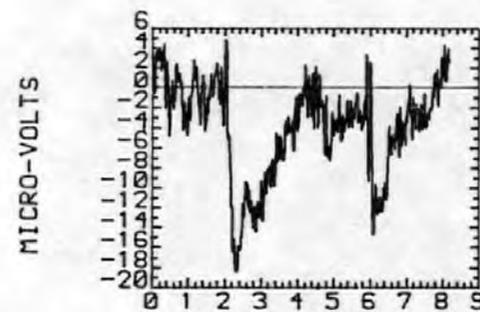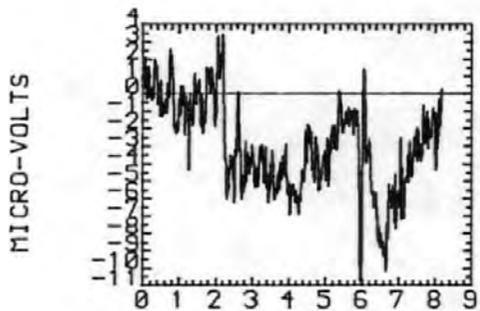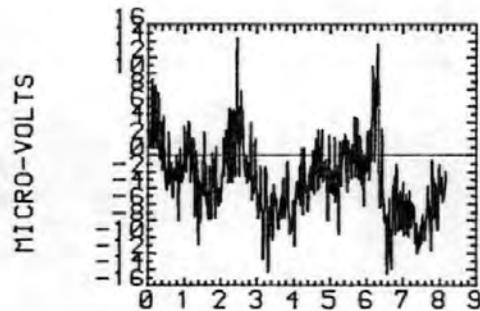
of abnormal subjects.

Figure 5-9

The averaged four second ISI CNV's

of abnormal subjects.

5.4.2.1 Broadband Energy Tests

The same processing procedure was used in these tests as that described in Section 5.3.2.1. The results of the tests are shown in Tables 5-13a and 5-13b. In the case of the one second ISI CNV's there was evidence of added energy at the 5% level of significance in 3 cases out of the 5 subjects investigated. There was considerably more added energy in the case of subject 5. For the four second ISI CNV's 4 of the subjects showed evidence of added energy at the 5% significance level. Thus for both ISI's the majority of the subjects showed increased energy in the post stimulus realizations. However, as indicated by the right most column in Tables 5-13a and 5-13b, there were a number of individual responses where the pre-stimulus energy was greater than the post-stimulus energy.

5.4.2.2 Amplitude Histograms

Some amplitude histograms were produced as it was thought that they might have shown some differences to those of normal subjects. However, they did not exhibit any characteristic feature which could be of diagnostic value.

5.4.2.3 Pre- and Post-stimulus Mean Amplitude Differences Test

The results of this test on the one second ISI CNV's are shown in Table 5-14. All but one of the results showed evidence of added energy in at least one harmonic at the 5% level. It was not possible to discover any pattern in the occurrence of significant results. Once more it was noted

Table 5-13a

Broadband Energy Tests of Abnormal Subjects one second ISI CNV's

Subject	Number of Responses	T Statistic	Significance Level %	Number of Responses Post < Pre *
1	32	1.89	10	10
2	32	1.81	10	10
3	32	3.75	0.1	8
4	32	3.47	0.2	7
5	32	4.82	<<0.1	4

Table 5-13b

Broadband Energy Tests of Abnormal Subjects four second ISI CNV's

Subject	Number of Responses	T Statistic	Significance Level %	Number of Responses Post < Pre *
1	30	3.73	0.1	4
2	32	2.56	2.0	9
3	32	1.64	20	7
4	32	5.16	<<0.1	6
5	32	3.16	1.0	8

* The number of individual responses where the post-stimulus energy was LESS than the pre-stimulus energy.

Table 5-14

Pre- and Post-Stimulus Mean Amplitude Differences Test

for Abnormal Subjects

1 second ISI

Subject Number	Mean of Differences x 10^{-5}	St.Dev. of Differences x 10^{-5}	Harmonic Number	T	ν	Significance %
1	0.178	1.02	1	0.990	31	N-S
	0.179	0.403	2	2.52	31	2.0
	-0.003	0.318	3	-0.059*	31	N-S
	-0.053	0.260	4	-1.15 *	31	N-S
	0.019	0.252	5	0.434	31	N-S
	0.069	0.209	6	1.86	31	10
2	0.189	0.576	1	1.94	31	10
	0.065	0.509	2	0.727	31	N-S
	-0.064	0.646	3	-0.557*	31	N-S
	0.379	0.887	4	2.42	31	5.0
	-0.168	0.724	5	-1.31 *	31	20
	-0.010	0.504	6	-0.118*	31	N-S
3	-0.067	0.666	1	-0.568*	31	N-S
	0.029	0.555	2	0.297	31	N-S
	-0.139	0.356	3	-2.21 *	31	5
	0.035	0.336	4	0.585	31	N-S
	-0.089	0.337	5	-1.49 *	31	20
	-0.070	0.252	6	-1.58 *	31	20
4	-0.016	0.502	1	-0.184*	31	N-S
	0.147	0.242	2	3.44	31	0.2
	0.05	0.136	3	2.08	31	5
	-0.017	0.113	4	-0.85 *	31	N-S
	-0.051	0.117	5	-2.46 *	31	2
	-0.021	0.159	6	-0.747*	31	N-S
5	0.202	0.622	1	1.84	31	10
	0.213	0.572	2	2.11	31	5
	0.409	0.664	3	3.49	31	0.2
	0.901	0.731	4	6.98	31	<<0.1
	0.507	0.677	5	4.23	31	<<0.1
	0.246	0.580	6	2.40	31	5

* denotes a reduction in the post stimulus amplitude

that subject 5 showed enhanced evidence of additivity in each of the harmonics. Those cases in which the energy showed a decrease were marked by an asterisk in the table.

5.4.2.4 Nearest and Furthest Mean Amplitude Test

The results of these tests are shown in Tables 5-15a and 5-15b. The single tailed paired t-test produced only one result which was significant for the one second ISI CNV's and this was evidence that the nearest phasors were smaller than the furthest. Thus this test provided no evidence for increased energy. In the case of the four second ISI CNV's there were 5 significant cases and 4 of these were significant at the 5% level.

5.4.2.5 Discussion of Results of Energy Tests

Comparison of the results in Tables 5-13a, 5-14 and 5-15a for the one second ISI CNV's did not reveal any noticeable correlations. However, it was noted that the Pre- and Post-Stimulus Mean Amplitude Differences tests offered more evidence of additivity than the Nearest and Furthest Mean Amplitude test. The results obtained from it were therefore more in agreement with the detection of added energy by the Broadband Energy test. However, there were discrepancies between these tests although they were based on exactly the same pre- and post- stimulus data. For example according to Table 5-14 there was no evidence of additivity for subject 3 but according to the Broadband Energy test additivity was detected at a level of significance of 0.1%. It was thought that this discrepancy may have occurred because the added energy of the response was located in higher harmonics than those considered.

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Table 5-15a

Nearest and Furthest Mean Amplitude Test for Abnormal Subjects

1 second ISI

| Subject Number | Nearest | | Furthest | | Harmonic | T | ν | Significance % |
---	Mean x10⁻⁵	St.Dev. x 10⁻⁵	Mean x10⁻⁵	St.Dev. x 10⁻⁵				
1	1.24	0.657	1.07	0.977	1	0.599	28	N-S
	0.564	0.496	0.550	0.290	2	0.100	25	N-S
	0.312	0.192	0.267	0.213	3	0.631	32	N-S
	0.191	0.090	0.265	0.133	4	-1.84	28	* 5
	0.204	0.149	0.229	0.231	5	-0.367	27	N-S
	0.233	0.232	0.226	0.094	6	0.110	21	N-S
2	0.874	0.386	0.802	0.398	1	0.519	32	N-S
	0.596	0.540	0.569	0.395	2	0.166	29	N-S
	0.483	0.309	0.581	0.497	3	-0.673	26	N-S
	1.02	0.857	0.869	0.799	4	0.504	32	N-S
	0.423	0.368	0.482	0.473	5	-0.399	30	N-S
	0.439	0.454	0.326	0.219	6	0.894	23	N-S
3	0.667	0.236	0.681	0.393	1	-0.116	26	N-S
	0.476	0.196	0.437	0.270	2	0.466	29	N-S
	0.220	0.137	0.220	0.118	3	0.014	31	N-S
	0.354	0.282	0.309	0.159	4	0.553	25	N-S
	0.307	0.163	0.269	0.134	5	0.713	31	N-S
	0.176	0.126	0.242	0.191	6	-1.15	28	N-S
4	0.498	0.352	0.498	0.319	1	0.00	32	N-S
	0.430	0.200	0.364	0.214	2	0.899	32	N-S
	0.251	0.159	0.224	0.137	3	0.511	31	N-S
	0.129	0.088	0.166	0.088	4	-1.16	32	N-S
	0.133	0.078	0.154	0.062	5	-0.821	30	N-S
	0.143	0.079	0.173	0.099	6	-0.947	31	N-S
5	0.972	0.534	0.908	0.486	1	0.352	32	N-S
	0.803	0.555	0.695	0.415	2	0.620	30	N-S
	0.980	0.682	0.776	0.500	3	0.966	29	N-S
	1.55	0.730	1.25	0.650	4	1.20	32	N-S
	1.00	0.601	1.10	0.628	5	-0.453	32	N-S
	0.625	0.324	0.725	0.746	6	-0.493	21	N-S

* denotes that the furthest phasors were larger than the nearest phasors.

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Table 5-15b

Nearest and Furthest Mean Amplitude Test for Abnormal Subjects

4 second ISI

Subject Number	Nearest		Furthest		Harmonic	T	ν	Significance %
	Mean $\times 10^{-5}$	St.Dev. $\times 10^{-5}$	Mean $\times 10^{-5}$	St.Dev. $\times 10^{-5}$				
1	1.59	0.774	1.00	0.451	1	2.52	24	1
	1.17	0.736	1.49	0.584	2	-1.33	28	* 10
	1.18	0.504	1.07	0.471	3	0.613	30	N-S
	0.857	0.600	0.952	0.508	4	-0.467	29	N-S
	0.814	0.392	0.919	0.382	5	-0.741	30	N-S
	0.783	0.344	0.752	0.422	6	0.225	29	N-S
2	1.51	0.857	1.42	1.25	1	0.233	28	N-S
	1.46	1.44	1.06	0.583	2	1.02	20	N-S
	0.909	0.670	0.727	0.467	3	0.895	28	N-S
	0.567	0.416	0.609	0.326	4	-0.318	30	N-S
	0.541	0.390	0.482	0.327	5	0.467	31	N-S
	0.403	0.181	0.475	0.258	6	-0.908	28	N-S
3	1.30	0.869	0.847	0.317	1	1.96	19	5
	1.10	0.578	0.574	0.252	2	3.33	21	0.5
	0.781	0.541	0.794	0.477	3	-0.069	32	N-S
	0.685	0.529	0.581	0.450	4	0.600	31	N-S
	0.493	0.428	0.560	0.377	5	-0.474	32	N-S
	0.616	0.232	0.555	0.256	6	0.703	32	N-S
4	0.457	0.225	0.667	0.356	1	-1.99	27	* 5
	0.617	0.361	0.484	0.284	2	1.16	30	N-S
	0.399	0.211	0.459	0.274	3	-0.693	30	N-S
	0.381	0.230	0.449	0.151	4	-0.989	27	N-S
	0.288	0.166	0.373	0.220	5	-1.24	30	N-S
	0.409	0.261	0.312	0.168	6	1.24	27	N-S
5	1.05	0.504	0.949	0.416	1	0.632	31	N-S
	1.19	0.557	0.870	0.409	2	1.87	29	5
	0.699	0.273	0.811	0.400	3	-0.922	28	N-S
	0.876	0.399	0.655	0.342	4	1.69	31	10
	0.647	0.270	0.608	0.348	5	0.350	30	N-S
	0.421	0.334	0.742	0.409	6	-2.43	31	* 2.5

* denotes that the furthest phasors were larger than the nearest phasors.

However it was considered unlikely that CNV energy would be found at higher harmonics without also being present in the lower harmonics (i.e. those more near to the fundamental frequency of the response). Hence the added energy may have been associated with a random element of the response or to an artefact. In other cases the test results on the harmonic components may have been subject to errors in either the transformation process or the subsequent testing (e.g. the limitations of the Nearest and Furthest Mean Amplitude test described in Section 2.2.3.3). While much of this remains conjecture a clear conclusion must be that although the responses of abnormal subjects may sometimes contain added energy it is not possible to exploit this in any useful way because the results are essentially random.

Comparison of the results for the four second ISI CNV's given in Tables 5-13b and 5-15b confirmed the lack of correlation between the Broadband Energy test and the Nearest and Furthest Mean Amplitude test. The former of these tests offered far more evidence of additivity, again suggesting that the added energy may have been present mainly in the higher harmonics.

5.4.3 Tests for Phase Ordering

The tests described below were carried out in an attempt to detect any phase ordering present in the CNV responses of the patient group.

5.4.3.1 Phase Histograms

From the one second ISI CNV phase histograms it was noticed that angles of about 10° tended not to occur. A similar minimum in the phase pattern had been observed in the case of normal subjects. By contrast to the histograms of normals, those of the abnormals showed an accumulation of values in the vicinity of $+180^{\circ}$. They also exhibited a smaller peak at negative angles $(-80^{\circ}$ to $180^{\circ})$. Thus it appeared that there might be a method, based on phase angles, to at least partially differentiate between patients and normals. A typical one second ISI CNV phase histogram for an abnormal is shown in Figure 5-10a.

The four second ISI CNV phase histograms of the abnormals showed a larger peak in the vicinity of 150° than either the one second ISI CNV phase histograms of abnormals or normals. A typical phase histogram is shown in Figure 5-10b.

Thus whilst for normal subjects the one and four second ISI CNV phase histograms were similar those for the patients were not.

5.4.3.2 Rayleigh Test of Circular Variance

Tables 5-16a and 5-16b show that there was very little evidence for phase ordering for either ISI CNV. At the 5% significance level there were only 2 (out of 30) positive results for the one second ISI and only 4 (out of 30) positive results for the four second ISI CNV's.
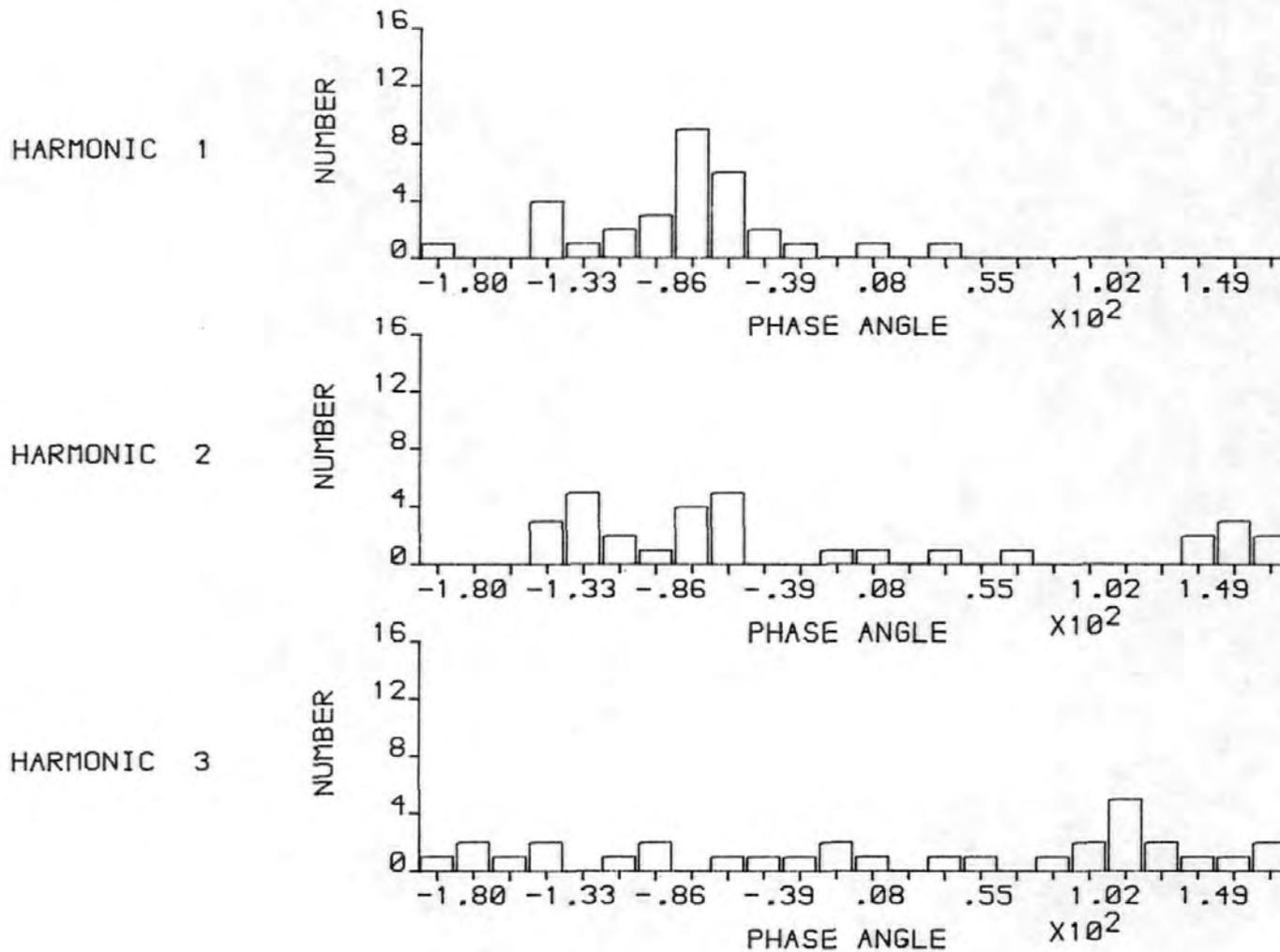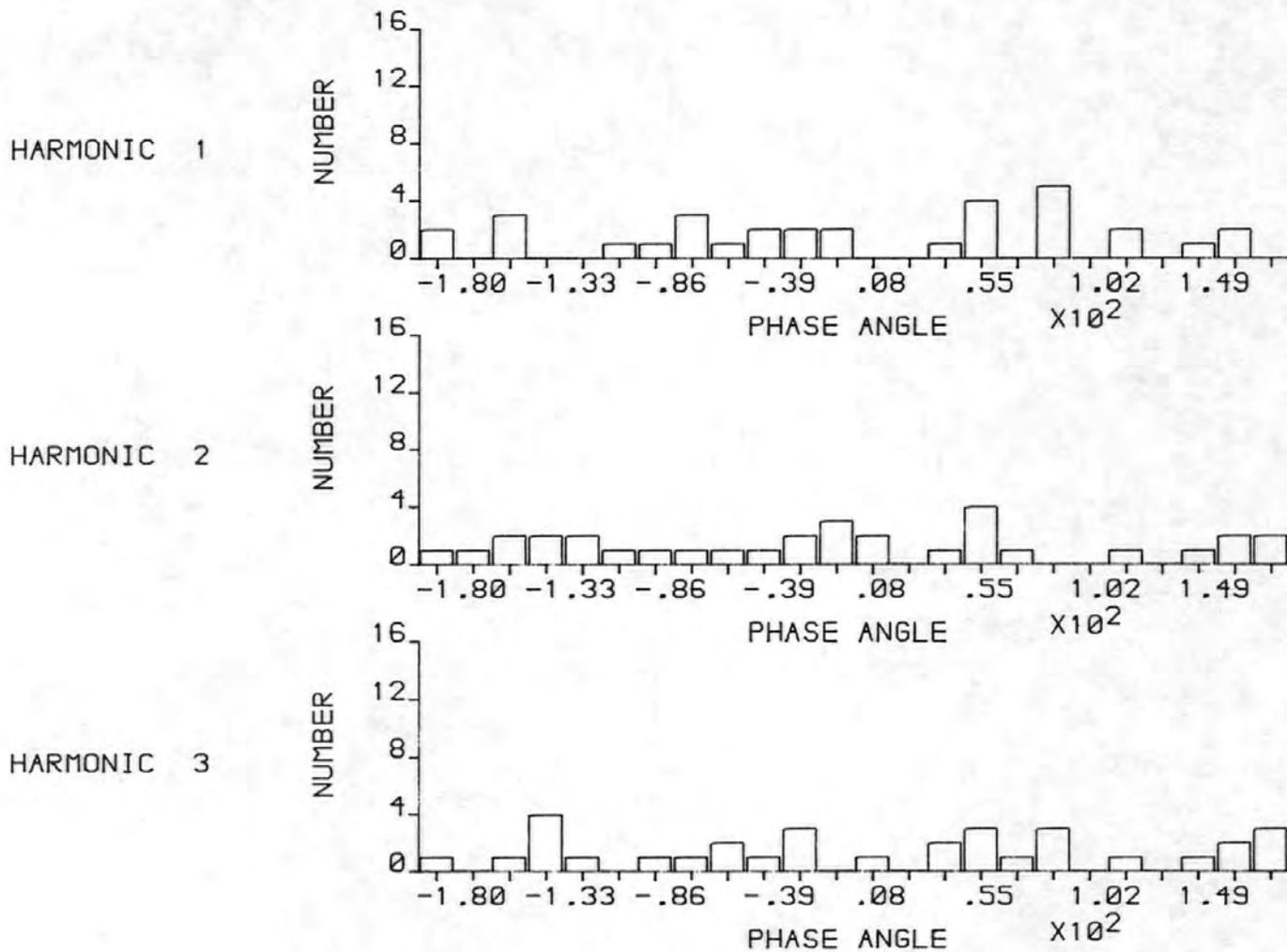
Figure 5-10a   A typical one second ISI phase histogram of an abnormal subject
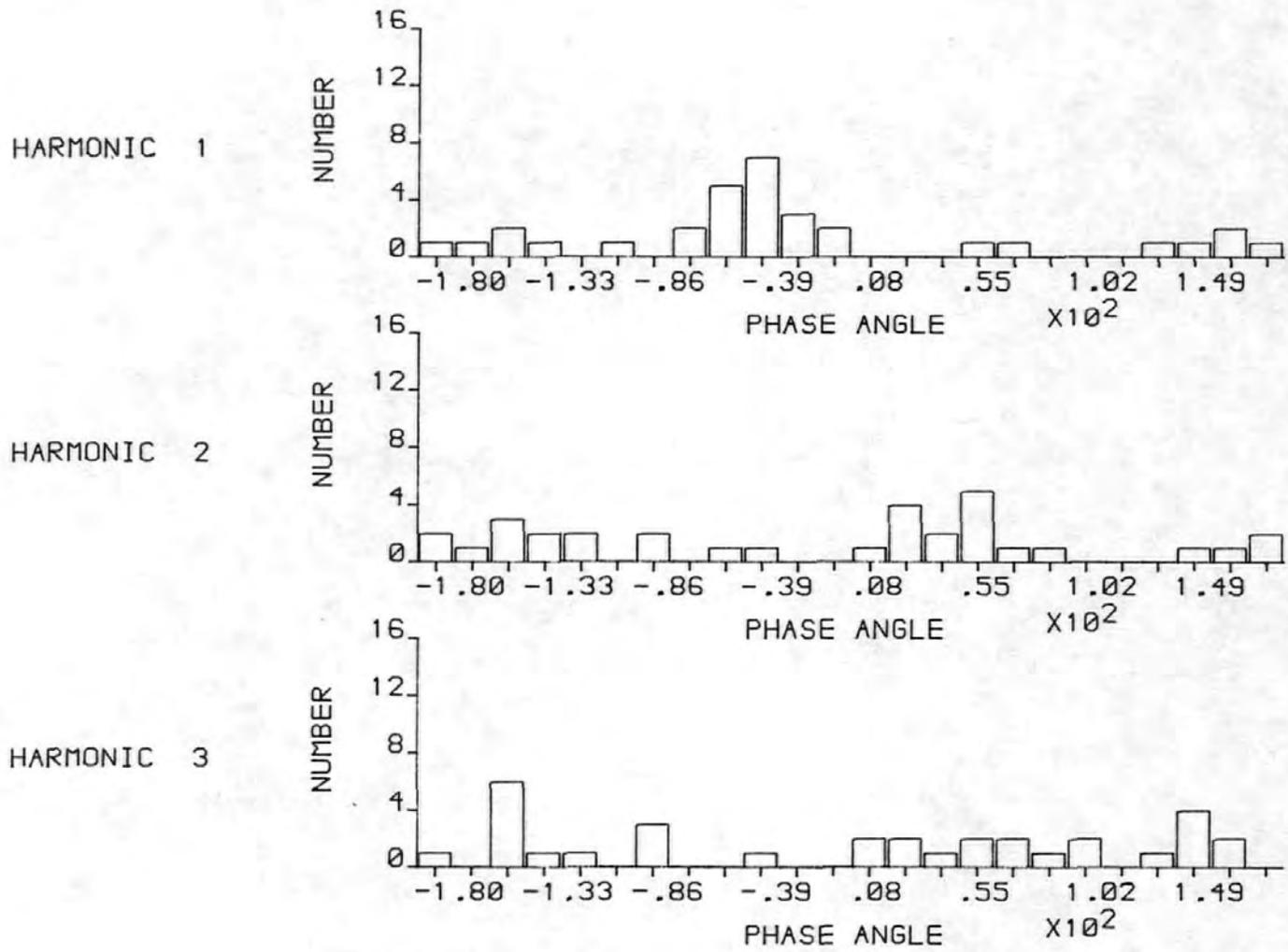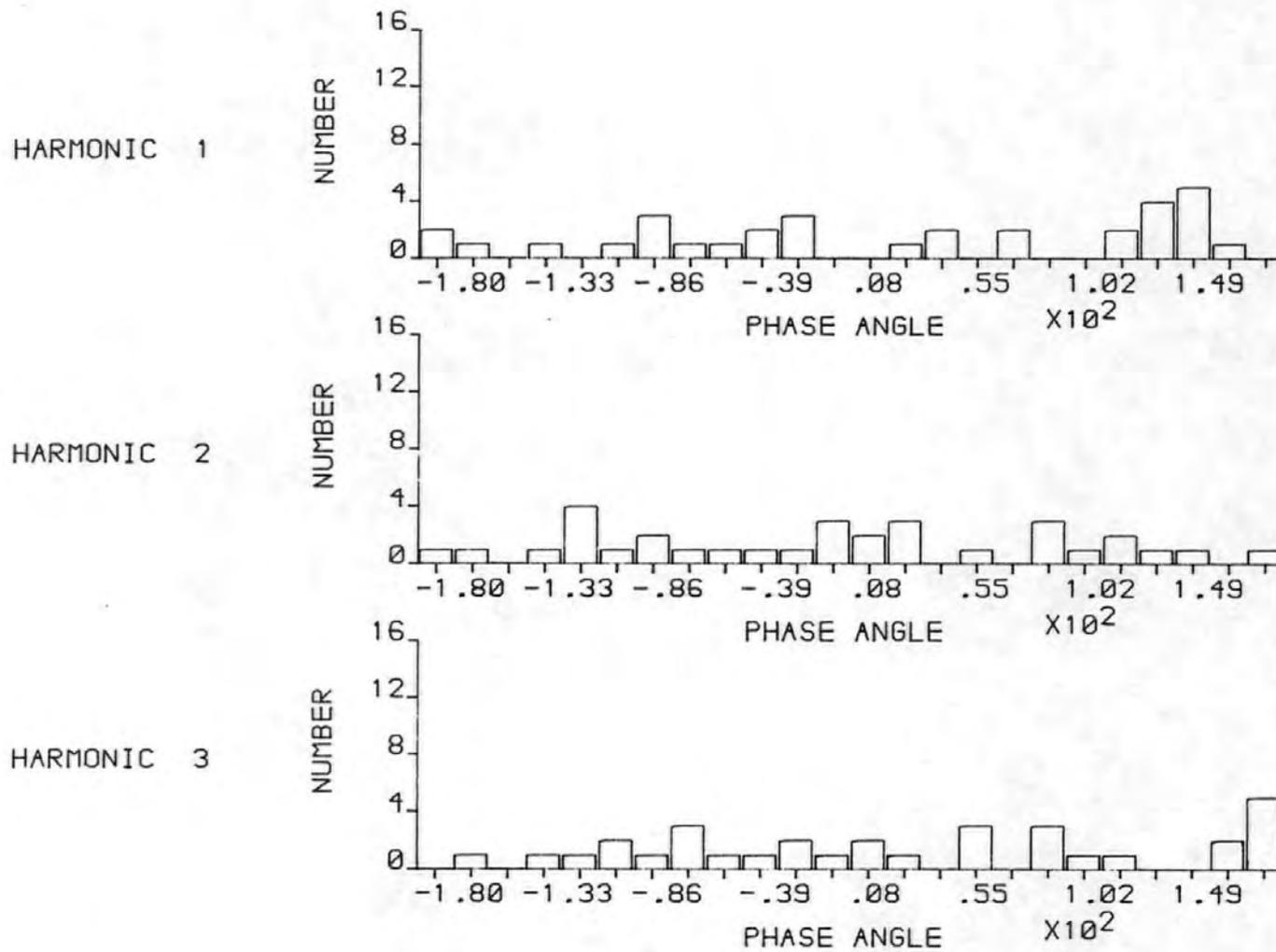
Figure   5-10b   A typical four second ISI phase histogram of an abnormal subject

Table 5-16a

Circular Variance for 1 second ISI CNV's

of Abnormal Subjects

Subject	Harmonic	Number of Trials	So	Significance %
1	1	32	0.868	N-S
	2	32	0.873	N-S
	3	32	0.737	N-S
	4	32	0.829	N-S
	5	32	0.624	5
	6	32	0.869	N-S
2	1	32	0.889	N-S
	2	32	0.896	N-S
	3	32	0.991	N-S
	4	32	0.807	N-S
	5	32	0.874	N-S
	6	32	0.808	N-S
3	1	32	0.966	N-S
	2	32	0.744	N-S
	3	32	0.946	N-S
	4	32	0.847	N-S
	5	32	0.870	N-S
	6	32	0.895	N-S
4	1	32	0.805	N-S
	2	32	0.771	N-S
	3	32	0.858	N-S
	4	32	0.788	N-S
	5	32	0.681	5
	6	32	0.995	N-S
5	1	32	0.694	10
	2	32	0.809	N-S
	3	32	0.751	N-S
	4	32	0.800	N-S
	5	32	0.794	N-S
	6	32	0.762	N-S

Table 5-16b

Circular Variance for 4 second ISI CNV's

of Abnormal Subjects

Subject	Harmonic	Number of Trials	So	Significance %
1	1	30	0.844	N-S
	2	30	0.901	N-S
	3	30	0.761	N-S
	4	30	0.934	N-S
	5	30	0.812	N-S
	6	30	0.885	N-S
2	1	32	0.874	N-S
	2	32	0.853	N-S
	3	32	0.954	N-S
	4	32	0.720	10
	5	32	0.925	N-S
	6	32	0.983	N-S
3	1	32	0.403	0.1
	2	32	0.653	5
	3	32	0 859	N-S
	4	32	0.771	N-S
	5	32	0.963	N-S
	6	32	0.857	N-S
4	1	32	0.738	N-S
	2	32	0.811	N-S
	3	32	0.897	N-S
	4	32	0.868	N-S
	5	32	0.784	N-S
	6	32	0.784	N-S
5	1	32	0.657	5
	2	32	0.689	5
	3	32	0.910	N-S
	4	32	0.815	N-S
	5	32	0.863	N-S
	6	32	0.858	N-S

5.4.3.3 Modified Rayleigh Test of Circular Variance

These results (Tables 5-17a and 5-17b) were similar to those of the Rayleigh Test. There were no cases of significance at the 5% level for the one second ISI CNV's and only 3 cases for the four second ISI CNV's.

5.4.3.4 Hodges-Ajne Test

This test indicated only one case of phase ordering at the 5% level for the one second ISI CNV's and only one case for the four second ISI CNV's. The results are shown in Tables 5-18a and 5-18b.

5.4.4 Discussion of Energy and Phase Results

Table 5-19 summarises the results of energy and phase tests applied to the harmonics which were significant at the 5% (or better) level. Harmonic numbers which are asterisked indicate those cases in which phase ordering was detected by at least two of the tests. The Rayleigh test indicated some results to be significant which the other two tests did not substantiate. Examination of the additivity results shows that the Nearest and Furthest Mean Amplitude test did not reveal any cases of significant additivity for the one second ISI CNV's although the Pre- and Post- Stimulus Mean Amplitude Differences test did. It is even more interesting to note that the former test however did indicate cases of significant additivity for the four second ISI CNV's. This contrasting result probably reflected the different composition of the one and four second ISI CNV's. In fact the averaged four second ISI CNV responses were more like the averaged four

Table 5-17a

The Modified Rayleigh Test of Circular Variance for

1 second ISI CNV's of Abnormal Subjects

Subject	Harmonic	Number of Trials	Uo	Significance %
1	1	32	0.764	N-S
	2	32	0.856	N-S
	3	32	0.662	10
	4	32	0.894	N-S
	5	32	0.682	10
	6	32	0.874	N-S
2	1	32	0.773	N-S
	2	32	0.805	N-S
	3	32	0 925	N-S
	4	32	0.799	N-S
	5	32	0.906	N-S
	6	32	0.801	N-S
3	1	32	0.909	N-S
	2	32	0.671	10
	3	32	0.900	N-S
	4	32	0.829	N-S
	5	32	0.879	N-S
	6	32	0.958	N-S
4	1	32	0.806	N-S
	2	32	0.672	10
	3	32	0.771	N-S
	4	32	0.833	N-S
	5	32	0.695	N-S
	6	32	0.947	N-S
5	1	32	0.691	10
	2	32	0.810	N-S
	3	32	0.706	N-S
	4	32	0.726	N-S
	5	32	0.805	N-S
	6	32	0.696	N-S

Table 5-17b

The Modified Rayleigh Test of Circular Variance for

4 second ISI CNV's of Abnormal Subjects

Subject	Harmonic	Number of Trials	Uo	Significance %
1	1	30	0.665	10
	2	30	0.858	N-S
	3	30	0.698	N-S
	4	30	0.867	N-S
	5	30	0.846	N-S
	6	30	0.861	N-S
2	1	32	0.835	N-S
	2	32	0.901	N-S
	3	32	0.920	N-S
	4	32	0.765	N-S
	5	32	0.813	N-S
	6	32	0.914	N-S
3	1	32	0.338	0.1
	2	32	0.484	0.1
	3	32	0.860	N-S
	4	32	0.674	10
	5	32	0.939	N-S
	6	32	0.812	N-S
4	1	32	0.831	N-S
	2	32	0.787	N-S
	3	32	0.914	N-S
	4	32	0.913	N-S
	5	32	0.823	N-S
	6	32	0.695	N-S
5	1	32	0.704	N-S
	2	32	0.590	5
	3	32	0.886	N-S
	4	32	0.736	N-S
	5	32	0.821	N-S
	6	32	0.932	N-S

Table 5-18a

Results of the Hodges-Ajne Test for 1 second ISI CNV's

of Abnormal Subjects

Subject	Harmonic	Number of Trials	M	Significance %
1	1	32	12	N-S
	2	32	12	N-S
	3	32	9	18
	4	32	12	N-S
	5	32	7	2.8
	6	32	12	N-S
2	1	32	12	N-S
	2	32	13	N-S
	3	32	14	N-S
	4	32	11	N-S
	5	32	11	N-S
	6	32	11	N-S
3	1	32	13	N-S
	2	32	9	18
	3	32	13	N-S
	4	32	12	N-S
	5	32	12	N-S
	6	32	12	N-S
4	1	32	11	N-S
	2	32	9	18
	3	32	13	N-S
	4	32	11	N-S
	5	32	8	7.8
	6	32	14	N-S
5	1	32	8	7.8
	2	32	11	N-S
	3	32	10	N-S
	4	32	11	N-S
	5	32	10	N-S
	6	32	10	N-S

Table 5-18b

Results of the Hodges-Ajne Test for 4 second ISI CNV's

of Abnormal Subjects

Subject	Harmonic	Number of Trials	M	Significance %
1	1	30	10	N-S
	2	30	11	N-S
	3	30	10	N-S
	4	30	13	N-S
	5	30	10	N-S
	6	30	12	N-S
2	1	32	11	N-S
	2	32	12	N-S
	3	32	12	N-S
	4	32	8	7.8
	5	32	13	N-S
	6	32	13	N-S
3	1	32	4	0
	2	32	9	18
	3	32	12	N-S
	4	32	10	N-S
	5	32	12	N-S
	6	32	12	N-S
4	1	32	9	18
	2	32	9	18
	3	32	12	N-S
	4	32	10	N-S
	5	32	11	N-S
	6	32	11	N-S
5	1	32	8	7.8
	2	32	10	N-S
	3	32	13	N-S
	4	32	10	N-S
	5	32	11	N-S
	6	32	11	N-S

Table 5-19

Summary of Additivity and Phase Ordering Results Significant

at the 5% level for the Patient Group

		ADDITIVITY		PHASE ORDERING		
ISI	SUBJECT NUMBER	NEAREST & FURTHEST MEAN AMPLITUDE	PRE-POST MEAN AMPLITUDE DIFFERENCES	CIRCULAR VARIANCE	MODIFIED CIRCULAR VARIANCE	HODGES-AJNE
1	1		$H2^+$	H5 •		H5 •
	2		$H4^+$			
	3					
	4		$H2^+$ $H3^+$	H5		
	5		$H2^+H3^+H4^+$ $H5^+H6^+$			
4	1	$H1^+$				
	2					
	3	H1 H2		$H1^*H2^*$	$H1^*H2^*$	H1 •
	4					
	5	H2		H1 H2•	H2•	

Hn indicates that the nth harmonic had a significant result.

+ denotes additivity without phase ordering.

* denotes two or more ordering tests are in agreement.

second ISI CNV responses of normals than were the one second
ISI responses. The table also shows that a number of instances
of additivity without phase ordering occurred. For the one
second ISI CNV's there were 9 spread between 4 different sub-
jects and for the four second ISI CNV's there was only 1 case.

The conclusions must therefore be that (i) the CNV
responses of abnormals may contain added energy but that this
may be random in nature rather than part of a true CNV response,
(ii) the responses show very little phase ordering and (iii)
additivity may occur unaccompanied by phase ordering.

5.5 Distinction Between Patients and Normals on the Basis
of their CNV's

The previous two sections have shown that the CNV responses
of patients tend to be more random than those of normals. It
has also been shown that their averaged CNV waveforms were
generally different (Section 5.4.1). Further attempts were
therefore made to distinguish between the two subject categories
in a quantitative manner on the basis of their averaged CNV
responses. In particular (i) the distribution of amplitude and
phase of the individual harmonics of the averaged CNV were com-
pared and (ii) plots of amplitude verses phase angle with sub-
ject as a parameter were also compared. Attempts to disting-
uish between patients and normals on the basis of the trial-
by-trial development of the CNV's are described in the next
section.

In the case of the first three harmonics of the one second
ISI CNV's of normals (see Table 5-20) it was found that with

Table 5-20

Phase Angles of the Fourier Components of the Averaged one

second ISI CNV's of Normal and Abnormal Subjects

Subject No.	Harmonic	NORMAL SUBJECTS Phase Angle °	ABNORMAL SUBJECTS Phase Angle °
1	1	- 63.9	159.6
	2	- 79.4	40.0
	3	- 99.4	25.0
2	1	- 43.1	88.0
	2	-103.7	73.6
	3	-175.7	88.9
3	1	- 87.8	-136.1
	2	-104.6	67.5
	3	12.2	- 72.9
4	1	-103.5	-109.5
	2	- 42.3	- 36.0
	3	- 92.8	- 99.8
5	1	- 78.9	-139.6
	2	-157.6	- 54.4
	3	-141.2	44.4

only one exception the phase angles were negative. By contrast the patients had phase angles covering a wider range ($+160^{\circ}$ to -140° compared with -176° to $+12^{\circ}$ for normals).

Plots of amplitude verses phase angle with subject as a parameter indicated on the graphs are shown in Figures 5-11a and 5-11b for the one and four second ISI's respectively. The baseline correction procedure used in obtaining these plots was different to that described in Section 5.3.2.1 and used previously. The reason for this change was that the slow return to baseline found in some of the abnormal subjects averaged CNV's made it difficult to obtain a meaningful post S2 average background EEG level. Therefore the averaged CNV's of both patients and normals were baseline adjusted by subtracting the mean value calculated over a one second length of background EEG preceeding the S1 stimulus. This is a technique which has been adopted previously by other workers [10].

Inspection of Figures 5-11a and 5-11b reveals that separate areas of the graphs may be ascribed to the normals and patients, although there are instances where the points for the two groups are close together. This method of distinguishing between normals and patients therefore requires more research in order to establish its reliability and usefulness. Similar comments apply in the case of the second harmonic where there is slightly more of an overlap between the areas ascribed to patients and normals (Figures 5-12a and 5-12b). It is possible that such plots may offer useful additional diagnostic evidence for the clinician. It is really necessary first,

Figure 5-11a

Amplitude vs. Phase for the averaged
1 second ISI CNV's

Harmonic 1

Figure 5-11b

Amplitude vs. Phase for the averaged
4 second ISI CNV's

Harmonic 1

x   DENOTES A NORMAL SUBJECT

o   DENOTES AN ABNORMAL SUBJECT

Abnormal region

PHASE   ANGLE   (DEGREES)

Figure 5-12a

Amplitude vs. Phase for the averaged
1 second ISI CNV's

Harmonic 2

Figure 5-12b

Amplitude vs. Phase for the averaged
4 second ISI CNV's

Harmonic 2

however, to investigate much larger populations of patients and normals.

5.6 The Development of the CNV from trial-to-trial in Normals and Patients

In order to examine the trial-by-trial development of the CNV plots of harmonic amplitude and phase verses trial number were produced for both normal and abnormal subjects. In the case of the one second ISI CNV's of normal subjects the plots for harmonic two, subjects 1 and 2 exhibited slight evidence for increased amplitudes i.e. a plateau, over the range of trial numbers 9 to 20 and 12 to 22 respectively. These plots are shown in Figures 5-13a and 5-13b. None of the other amplitude plots, either of normal or abnormal subjects, showed any obvious patterns.

There was some evidence in the plots of phase verses trial number that the development of the one second ISI CNV response was different in abnormal subjects to that in normal subjects. Thus whilst for the normals there was a tendency in the case of harmonic 1 for only negative phase angles to occur in the earlier trials with positive angles only occurring in the subsequent trials, (see Figure 5-14), the abnormals showed that both positive and negative phase angles could occur throughout the acquisition sequence (see Figure 5-15). There was also some evidence from the amplitudes verses phase plots for the averaged CNV's to suggest that those normals whose amplitude and phase co-ordinates were furthest from those of patients had trial-by-trial phase angles which were negative up to the final few trials. Thus the phase angles
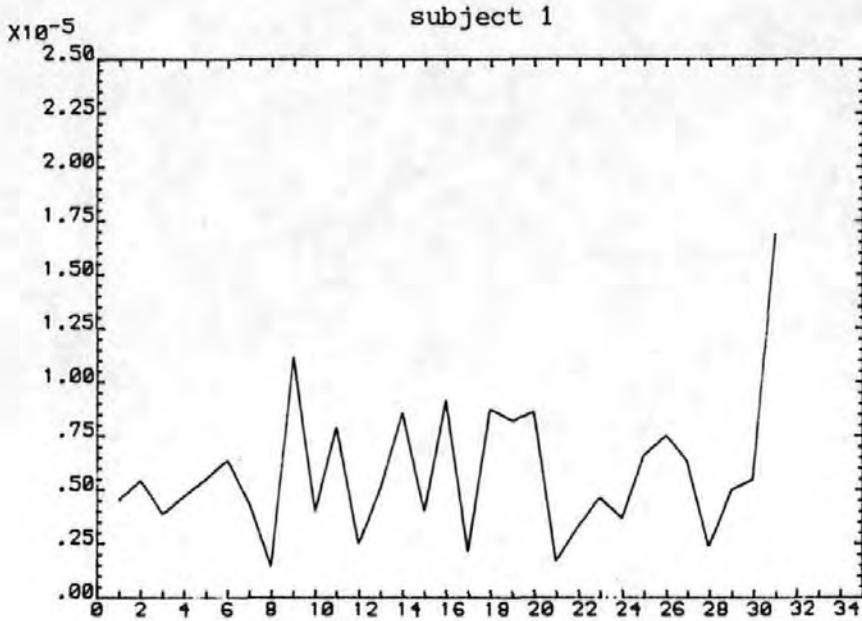
subject 1

Figure   5-13a

Amplitude vs Trial number for a 1sec. ISI CNV of
a normal subject. Harmonic 2.
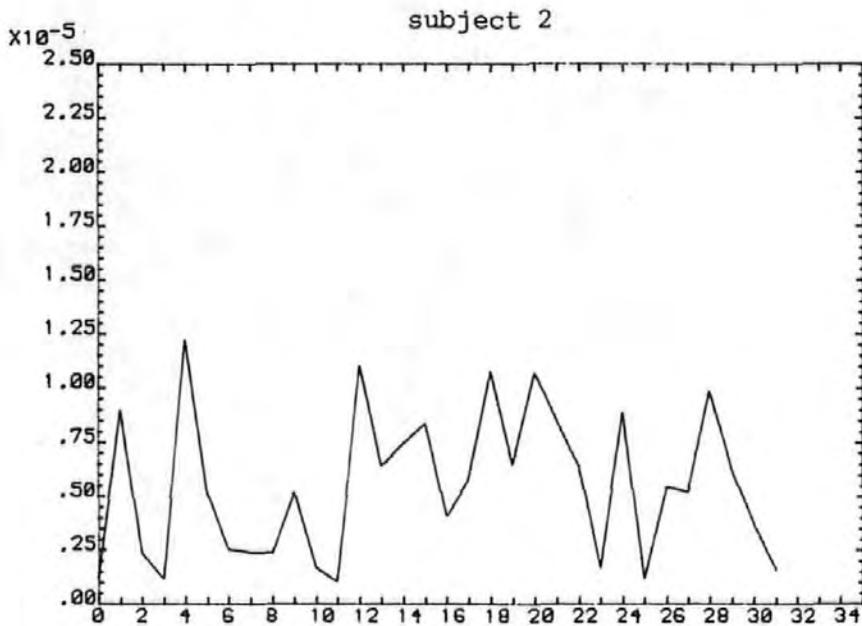
subject 2

Figure   5-13b

Amplitude vs Trial number for a 1sec. ISI CNV of
a normal subject. Harmonic 2.
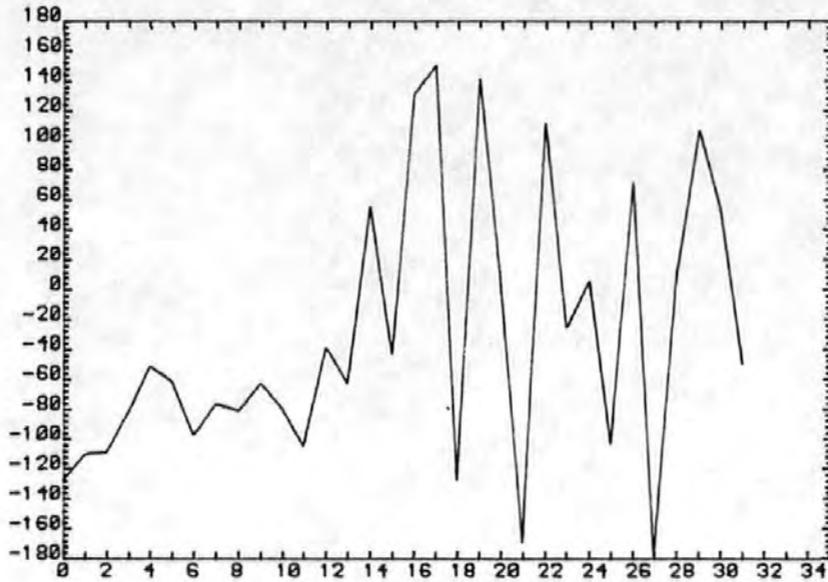
subject 2

Figure 5-14

Phase vs Trial number for a 1sec. ISI CNV of a
normal subject.
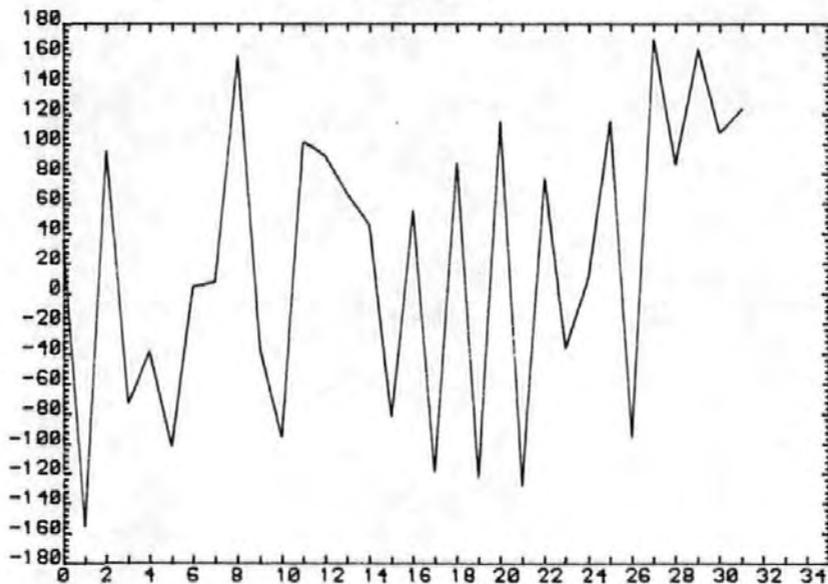
subject 1

Figure 5-15

Phase vs Trial number for a 1sec. ISI CNV of an
abnormal subject.

of the most "normal" subjects were characteristically negative for the earlier trials whilst those of the abnormals were characteristically randomly positive or negative. This difference may provide another means for differentiating between the two groups but again more results would be required to confirm these findings. In the case of harmonic 2 both positive and negative phase angles were found throughout the acquisition sequence and for both normals and patients (see Figure 5-16a and 5-16b).

Plots of amplitude verses trial number for the first harmonic of the four second ISI CNV's of the normals did not reveal any definite pattern, although in some cases the mid-trial values may be slightly larger (see Figure 5-17). No similar evidence could be found for the abnormal subjects.

The plots of phase angle verses trial number for the first harmonic of the four second ISI CNV's were inspected. The phase angles for the initial trials were either negative or positive for the normal subjects (see Figure 5-18) but were positive for each of the abnormal subjects (see Figure 5-19). Again this may be useful but more results would be required to confirm these findings.

The corresponding plots of amplitude and phase for the second harmonic of the four second ISI CNV's of both patients and normals revealed little further information.

In conclusion it would appear that the phase properties of the harmonic components are more significant than those of the amplitude. In particular the phase properties of the
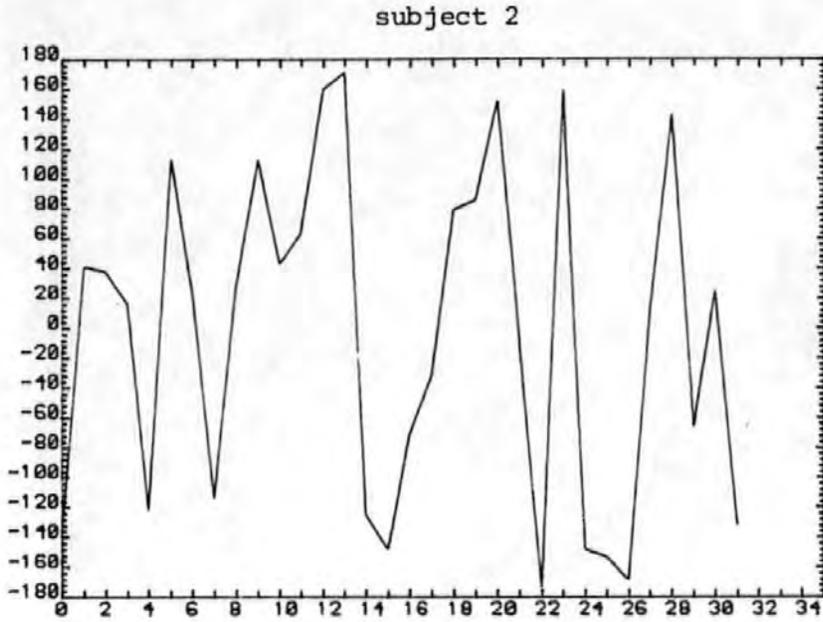
subject 2

Figure   5-16a

Phase vs Trial number for a 1sec. ISI CNV of a
normal subject.

subject 2

Figure   5-16b

Phase vs Trial number for a 1sec. ISI CNV of an
abnormal subject.
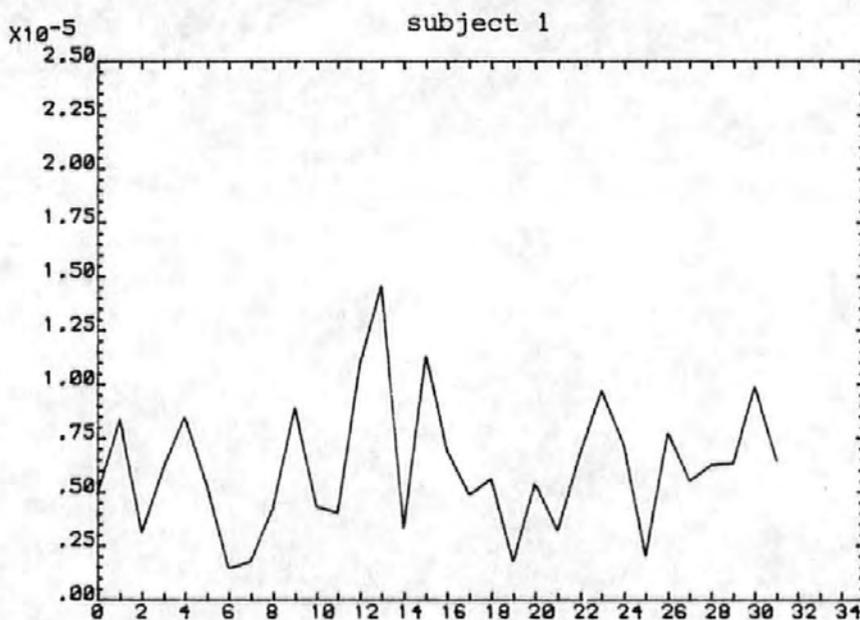
subject 1

Figure 5-17

Amplitude vs Trial number for a 4sec. ISI CNV of
a normal subject.

PHASE VS TRIAL NUMBER   HARMONIC 1
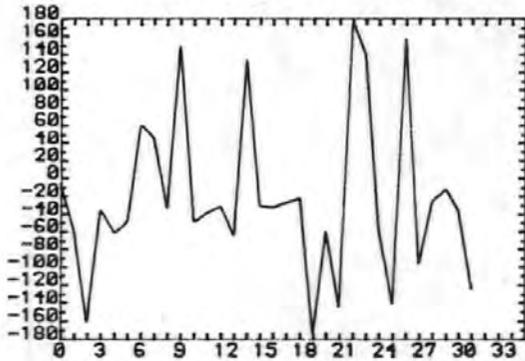
subject 1

PHASE VS TRIAL NUMBER   HARMONIC 1
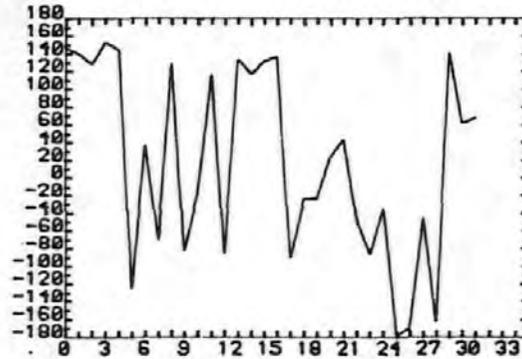
subject 2

PHASE VS TRIAL NUMBER   HARMONIC 1
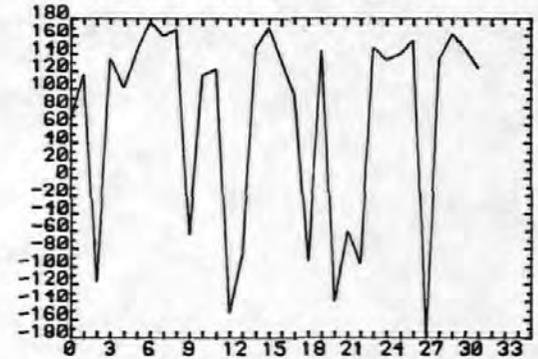
subject 3

PHASE VS TRIAL NUMBER   HARMONIC 1
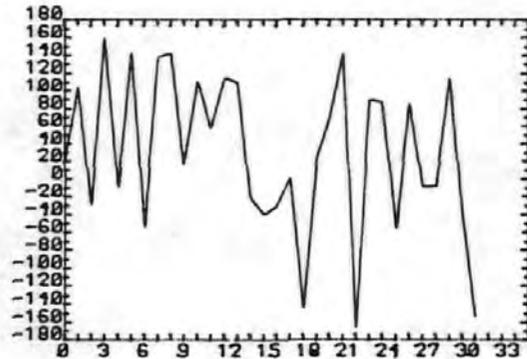
subject 4

PHASE VS TRIAL NUMBER   HARMONIC 1

subject 5

Figure 5-18

Phase vs Trial number for the 4sec.
ISI CNV's of the normal subjects.
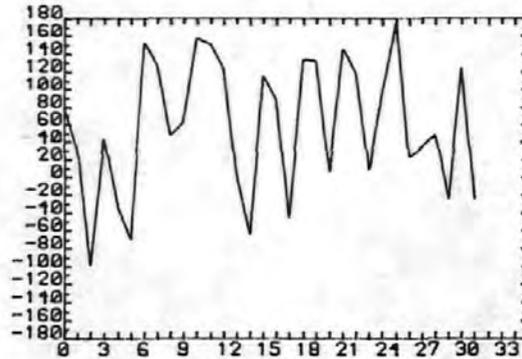
Figure 5-19

Phase vs Trial number for the 4sec.
ISI CNV's of the abnormal subjects.

first harmonic of the one second ISI CNV response may, subject to confirmation, allow differentiation between the normal and patient groups. In this case the initial phase angles are negative for the normals and either positive or negative for the patients. The onset of positive phase values occurs at much later trial numbers for normals than for the patients.

References for Section 5

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6.   Conclusions

6.1   Eye Movement Artefact Removal

A method of testing the effectiveness of eye movement artefact removal techniques has been derived. This procedure was used to test four methods of removing eye movement artefact from the EEG. These four methods were (i) the analogue method using a potentiometer due to McCallum and Walter [1], (ii) The computational method due to Quilter et al [2], (iii) our extension of Quilters method to incorporate three EOG components, (iv) our extension of Quilters to incorporate four EOG components. Recordings were made from normal volunteer subjects who were asked to make deliberate eye movements and the various methods of removing the artefact from the EEG were compared.

It was found that the computational correction method gave excellent results particularly when the horizontal and vertical components of the EOG of both eyes were taken into account. However it was possible to obtain good artefact removal using both horizontal, but only one vertical EOG component (i.e. the three EOG components method). The reduction in the computational effort obtained by this simplification may be important in an on-line multi-channel situation.

The four EOG component method of eye movement artefact removal was used in all the subsequent investigations.

6.2 Evoked Potentials

New models have been developed to describe the fund-
amental nature of evoked potentials in terms of additive
and phase re-ordered components. The models showed that
a repetitive additional component or an alignment of exist-
ing background EEG components could give rise to observable
phase ordering in the post stimulus response. Tests were
then contrived in an attempt to determine which of these
mechanisms was operative in both auditory evoked potentials
and the much longer Contingent Negative Variations.

6.3 Auditory Evoked Potentials

The tests mentioned above were applied to the auditory
evoked potentials recorded from normal volunteer subjects.
Of the 36 sets of results (3 subjects, 2 stimulus levels, 6
harmonics) 29 exhibited phase ordering. Some of the harmonic
components were found to contain additional energy and all
of these exhibited phase ordering. This finding was consist-
ent with the proposed additivity model although a combination
of the additive and phase re-ordered models could give the
same results. However, 15 of the 29 results showing phase
ordering did not show any additive effects. Thus either the
additivity tests were not sufficiently sensitive to detect
small additional components, or pure phase re-ordering was
also present.

For all the subjects tested, and for both levels of aud-
itory stimulation, the first three harmonic components all
showed significant phase ordering. Furthermore, in all but

one harmonic for one subject, the results of all three phase ordering tests were significant at 0.1% or better. This result may be useful in the diagnosis of audiological defects or establishing auditory thresholds, since the statistical results give a quantitative indication of the presence or absence of a response whereas inspection of the averaged waveform is rather subjective.

6.4 The CNV's of Normal Subjects

The pre- and post- stimulus (i.e. broadband) energy tests showed that all the CNV's of the normal subjects contained additional energy. However only a small proportion of the harmonics examined showed any evidence of this feature. Thus the additional energy must have been at frequencies other than those studied. Some of the harmonics exhibited phase ordering although this feature was much less pronounced than the phase ordering observed in the auditory evoked potentials. The one second ISI CNV's showed more ordering than the four second and most of the ordering observed was confined to the lower harmonics. There were some examples of phase ordering without any accompanying additivity. Thus like the auditory responses the CNV's might be explained in terms of a mixture of the additive and phase re-ordered models.

However some results were in conflict with this conclusion. There were instances where additivity was detected in the absence of any phase ordering. This may have been the effect of a non-repetitive additional component.

The trial-by-trial analysis of the phase components of the CNV's revealed that for the first harmonic negative phase angles tended to occur in the early trials. Some of the second harmonic amplitude components showed a plateau in the middle of the acquisition sequence.

6.5   The CNV's of Abnormal Subjects

The broadband energy tests revealed fewer instances of additivity in the CNV's of the abnormal subjects than for the normal subjects. However the individual harmonics showed a slightly higher number with detectable additivity than those of the normals.

There were fewer cases of phase ordering than for the CNV's of the normal subjects. Thus the CNV's of the abnormal subjects did not fit either the additive or phase re-ordered models so well as those of the normal subjects. This may have been due to the limitations of the models or it may have indicated the differing nature of the responses obtained from the Huntingtons Chorea group.

The averaged CNV waveforms tended to support the latter theory since the one second CNV's showed little similarity with those of the normals. The four second CNV's however, particularly those for subjects three and five, did appear slightly more like the normal CNV's. These observations are supported by the phase ordering tests. The one second ISI CNV's exhibited no phase ordering in the lower harmonics whereas those of subjects three and five for the four second

ISI CNV's did.

Generally the CNV's of the patient group were most easily characterised by their averaged waveforms. These waveforms sometimes showed a slow return to baseline.

6.6 Distinctions between the CNV's of Normals and Patients

As stated above the averaged CNV waveforms of the HC patients tended to be rather different to those of the normal group. This may be a sufficient difference to aid the detection of H.C. However, the patients for whom H.C. had only recently been diagnosed (i.e. those at an early stage of the illness) showed more normal averaged CNV's than did those for whom the disease was at an advanced stage. (Compare the recently diagnosed H.C. of Figure 5-8c with Figures 5-4a-e).

Another feature of the averaged waveforms of the patient group was that of the slow return to baseline subsequent to the S2 stimulus exhibited by some of the subjects. This may also be a useful diagnostic feature.

An alternative to the averaged waveform was provided by the plots of amplitude verses phase for the various normal and abnormal subjects. It may be possible to ascribe certain areas of these graphs to each of the two populations.

The analysis of the phase angle of the first harmonic on a trial-by-trial nature may also be of diagnostic value since all the normal subjects tested produced negative phase

angles for the initial trials whereas the patient group
did not.

6.7 Future Work

6.7.1 Eye Movement Artefact Removal

As previously mentioned hardware to perform the eye
movement artefact removal procedure is to be developed and
produced commercially. There are a number of improvements
and tests which should be carried out before this is done.
The method should first be tested to ensure that any frontal
EEG activity which may be present in the EOG signals is not
superimposed on the EEG by the correction procedure. One
possible way of achieving this would be to experiment with
the placement of EOG electrodes in order to find electrode
positions which maximise the EOG and minimise the EEG ampli-
tudes.

The presence of harmonics of the EOG in the corrected
EEG signal may be due to a frequency selective path between
the eye and the scalp. The most likely characteristic of
such a path would be that of a low pass filter. The correct-
ion procedure assumes that the path between the eye and the
scalp is linear and has an infinite bandwidth. The correct-
ion method may thus overcorrect the higher harmonics of the
EOG and hence leave traces of these components in the corr-
ected signal. A possible cure for this phenomena would be
to introduce a filter (either electrical or digital) into
the EOG signal path. The filter would have to have the same

properties as those of the electrical path between the eye and the scalp. This may simply be of a frequency selective nature or may include non-linearities. It might even be possible for the correction procedure to have a 'set-up' mode whereby the nature of this network is determined by the correction system before the corrector is used.

6.7.2 Auditory Evoked Potentials

The statistical tests for phase ordering should be applied to a much larger sample of auditory evoked potentials covering a wide range of auditory stimulation levels. The results of the statistical tests should then be correlated with the findings of audiologists to determine whether the statistical tests for phase ordering would be audiologically useful.

6.7.3 The CNV's of Patients and Normals

Although several possible diagnostic procedures have been suggested, much larger samples of normals, patients with H.C. and patients with other neurological defects must be examined before these procedures could safely be adopted.

Further research should be aimed at establishing why the broadband energy tests do show additional energy whereas the tests on the individual harmonics sometimes do not. It should be possible to account for this extra energy and hence balance the energy figures. The extra energy may be contained in the d.c. term or in the higher harmonics.

The time to return to the baseline should be measured to establish whether any correlation can be detected between this and the severity of the disease.

References for Section 6

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     and Distraction on the Contingent Negative Variation
     in Normal and Neurotic Subjects"
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Calculation of Expected Phase Values for Idealized CNV's

By considering the CNV as one of the simple shapes shown below it is possible to calculate the resulting phase angles for each of the harmonic frequency components. These calculations were performed using a microcomputer to compute the discrete Fourier transform of each of the possible CNV shapes. The listing of the computer programme and the results are given below.

WAVESHAPE   HARMONIC
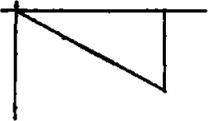
	1	2	3	4	5	6
Type 0	-90	-90	-90	-90	-90	-90
Type 1	-57.4	-89.6	-77.5	-89.3	-81.9	-88.9
Type 2	0	*	0	*	0	*
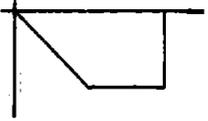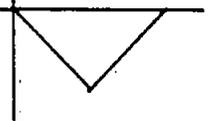
* Phase angles are indeterminate due to zero amplitudes of these harmonic components.

```
10 PI=3.14159265
20 INPUT " NUMBER OF POINTS ";N
30 DIM FT(N-1)
40 INPUT " MAXIMUM AMPLITUDE ";K
50 INPUT " WHICH TYPE OF CNV WAVESHAPE ";Q
60 IF Q=0 THEN SL=K/N
70 IF Q>0 THEN SL=2*K/N
80 INPUT " HARMONIC NUMBER ";H
90 FOR I=0 TO N-1
100 IF I < N/2 THEN FT(I)=SL*I : GOTO 140
110 IF Q=0 THEN FT(I)=SL*I
120 IF Q=1 THEN FT(I)=K
130 IF Q=3 THEN FT(I)=-SL*I+2*K
140 NEXT I
150 C=0
160 S=0
170 FOR I=0 TO N-1
180 C=C+FT(I)*COS(2*PI*I*H/N)
190 S=S-FT(I)*SIN(2*PI*I*H/N)
200 NEXT I
210 C=C/N
220 S=S/N
230 PRINT "REAL=";C;"    ";"IMAG=";S
240 TH=180/PI*ATN(S/C)
250 IF C>0  GOTO 290
260 IF S>0  THEN TH=TH+180 : GOTO 290
270 TH=TH-180
280 GOTO 290
290 PRINT "THETA=";TH
300 GOTO 80
```

APPENDIX 8.2

Transformation of the Rayleigh Probabilities to those of Circular Variance

Using the definitions given in section 2.2.2.1 a relationship may be derived between the Rayleigh statistic R and the circular variance statistic S_O. For a set of N angles $\{\theta_i\}$ the Rayleigh statistic is given by

$$R = \sqrt{\left[\sum_{i=1}^{N} \cos \theta_i\right]^2 + \left[\sum_{i=1}^{N} \sin \theta_i\right]^2}$$

Clearly this is simply N times $\bar{R}$ as defined by equation 6 of section 2.2.2.1.

since $S_O = 1 - \bar{R}$

then $S_O = 1 - \dfrac{R}{N}$

Hence a table of critical values of S_O may be compiled from a table of critical values of R by dividing each 'R' value by N and subtracting the resulting value from unity.

A table thus obtained is given overleaf.

Table of Critical Values of S_0

N	P			
	0.10	0.05	0.01	0.001
5	0.333	0.246	0.121	0.009
6	0.382	0.310	0.175	0.060
7	0.428	0.358	0.229	0.109
8	0.465	0.398	0.275	0.153
9	0.496	0.431	0.313	0.192
10	0.552	0.460	0.335	0.225
11	0.544	0.484	0.373	0.257
12	0.563	0.506	0.398	0.284
13	0.580	0.525	0.420	0.308
14	0.595	0.542	0.440	0.331
15	0.609	0.557	0.458	0.351
16	0.621	0.571	0.475	0.370
17	0.633	0.583	0.490	0.387
18	0.643	0.595	0.540	0.403
19	0.652	0.606	0.516	0.417
20	0.661	0.615	0.528	0.431
21	0.669	0.625	0.539	0.444
22	0.677	0.633	0.549	0.456
23	0.684	0.641	0.559	0.467
24	0.691	0.649	0.568	0.478
25	0.697	0.656	0.577	0.488
30	0.723	0.685	0.613	0.530
35	0.744	0.708	0.641	0.564
40	0.760	0.727	0.664	0.591
45	0.774	0.743	0.682	0.614
50	0.786	0.756	0.699	0.633
64	0.810	0.784	0.732	0.672

APPENDIX 8.3

Probability Levels for the Modified Rayleigh Test

The following table gives the critical values of U_O as derived from Moore [section 2 reference 5]. The derivations are calculated from

$$U_O = 1 - \frac{2 \sqrt{N} \ R^*}{(N+1)}$$

Table of Critical Values of U_O

N	P			
	0.1	0.05	0.01	0.001
5	0.264	0.192	0.094	
6	0.320	0.248	0.139	
7	0.365	0.295	0.181	
8	0.404	0.334	0.219	
9	0.436	0.368	0.253	
10	0.462	0.397	0.282	0.176
12	0.506	0.444	0.332	0.224
14	0.541	0.483	0.375	0.266
16	0.570	0.515	0.412	0.304
18	0.594	0.541	0.443	0.336
20	0.614	0.563	0.469	0.365
22	0.631	0.583	0.491	0.389
24	0.647	0.600	0.512	0.413
30	0.684	0.641	0.560	0.470
32	0.692	0.652	0.573	0.485
40	0.725	0.688	0.617	0.535
60	0.774	0.744	0.684	0.617
64	0.782	0.752	0.695	0.629
80	0.804	0.778	0.726	0.667
100	0.826	0.802	0.755	0.700

Probability Levels for the Hodges-Ajne Test

The following table gives the critical values of m for the Hodges-Ajne test.

Table of Critical Values of m

N	P			
	0.10	0.05	0.025	0.01
9	0	0	0	0
10	1	0	0	0
11	1	0	0	0
12	1	1	0	0
13	1	1	1	0
14	2	1	1	0
15	2	2	1	1
16	2	2	1	1
17	3	2	2	1
18	3	3	2	2
19	3	3	2	2
20	4	3	3	2
21	4	4	3	2
22	5	4	3	3
23	5	4	4	3
24	5	5	4	3
25	6	5	4	4
30	7	7	6	5
35	9	9	8	7
40	11	10	10	9
50	15	14	13	12
60	19	18	14	13

The Paired t-Test

Where a set of experimental results fall naturally
into pairs the above statistical test may be employed to
establish whether a consistent difference between each of
the paired values exists. An example will best illustrate
the method.

Two students, X and Y, measured the resistance of
twelve resistors. Each student measured all the resistors
and the results they obtained are shown in the table.

STUDENT	RESISTOR											
	1	2	3	4	5	6	7	8	9	10	11	12
X	100	90	130	110	117	75	32	88	41	57	18	67
Y	105	91	128	109	119	77	32	87	36	60	21	72

Are one students results consistently higher than the
others?

The differences are first calculated;

$$x = \quad -5 \quad -1 \quad 2 \quad 1 \quad -2 \quad -2 \quad 0 \quad 1 \quad 5 \quad -3 \quad -3 \quad -5$$

If there was no consistent difference between the
students measurements then the differences should form a
zero mean normal distribution. The t-test is used to test
this hypothesis.

Mean value $= \bar{x} = \dfrac{\Sigma x}{N}$

$$= \dfrac{-12}{12}$$

$$\bar{x} = -1$$

An estimate of the variance is given by

$$\hat{\sigma}^2 = \dfrac{1}{N-1}\left[\Sigma x^2 - \dfrac{(\Sigma x)^2}{N}\right]$$

$$= \dfrac{1}{12-1}\left[108 - \dfrac{(-12)^2}{12}\right]$$

$$= 8.73$$

$$\therefore \hat{\sigma} = 2.95$$

The t statistic is given by

$$t = \dfrac{|\bar{x} - \mu|}{\dfrac{\hat{\sigma}}{\sqrt{N}}}$$

$$= \dfrac{|-1 - 0|}{2.95} \quad 12$$

$$t = 1.17 \text{ with (N-1) degrees of freedom.}$$

Tables of the t statistic show that with 11 degrees of freedom a value of 1.17 is not significant. Hence there is no evidence that one students measurements are higher than the others.

The t-Test

Because of the relatively small number of obser-
vations made in some of our tests the t statistic was
used in preference to the normal Z statistic. Frequently
the question to be resolved was "could these two sets
of observiatons have come from the same parent population?"

Where this was so the test statistic was calculated
according to the formula

$$t = \frac{\overline{X}_A - \overline{X}_B}{\sqrt{\dfrac{S_A^2}{N_A} + \dfrac{S_B^2}{N_B}}}$$

where $\overline{X}_A$ was the calculated mean of the N_A observations

$\overline{X}_B$ was the calculated mean of the N_B observations

S_A was the standard deviation of the 'A' observations

S_B was the standard deviation of the 'B' observations

Furthermore since the variances S_A^2 and S_B^2 were only
estimates of the variances of the entire population, a
'pooled sum of squares' method was used to estimate the
number of degrees of freedom to be used with the t statistic.
This was calculated from the formula

$$\nu = \frac{\left[\dfrac{S_A^2}{N_A} + \dfrac{S_B^2}{N_B} \right]^2}{\dfrac{\left[\dfrac{S_A^2}{N_A}\right]^2}{N_A+1} + \dfrac{\left[\dfrac{S_B^2}{N_B}\right]^2}{N_B+1}} \quad - 2$$

which although rather complex, caused no extra work since both the t statistic and the number of degrees of freedom were calculated by computer. (Had the calculations been made by hand then the F test would have been used to establish whether the variances S_A^2 and S_B^2 were sufficiently different to warrant calculation of ν by the formula given in place of $N_A + N_B - 2$).

When the appropriate values of t and ν had been ascertained then the tables were consulted to determine whether the test was significant or not. If the test was "is $\overline{X}_A$ less than $\overline{X}_B$?" or "is $\overline{X}_A$ greater than $\overline{X}_B$?" then a 'one tailed' test was performed whereas if the test was "is $\overline{X}_A$ different from $\overline{X}_B$?" then a two tailed test was performed. The only difference between these two tests is that the tables give areas (i.e. probabilities) for one tail only. Thus for two tailed tests the probabilities must be doubled.

FORTRAN Programme 'DATAPLOT'

This programme was used for plotting the raw
EOG/EEG data on a graphics terminal or graph plotter.
The programme uses the GINO graphics subroutines.
Listings of subroutines 'DATIN' and 'GETNAM' which are
used to read the data in from a data file and to obtain
a filename from the user are given in Appendix 8.12.

The listing of programme 'DATAPLOT' follows.

```
C               A PROGRAMME TO PLOT THE EOG / EEG DATA
C               ON THE TEKTRONIX 4010.
C
      INTEGER*2 INP(1024),RNAME(20),IBATNO
      LOGICAL CSE
      DATA CSE/.FALSE./
    1 WRITE(1,2)
    2 FORMAT('TEKTRONIX(0) OR CALCOMP(1) OUTPUT')
      READ(1,*,ERR=1)IDEVIC
C               NOMINATE THE REQUIRED DEVICE
      IF(IDEVIC.EQ.1)CALL CC906
      IF(IDEVIC .EQ. 0)CALL T4010
      IBAUD=1200
      CALL DEVSPE(IBAUD)
      CALL UNITS(0.24)
      CALL GETNAM(RNAME)
   18 WRITE(1,20)
   20 FORMAT('WHICH BATCH')
   22 READ(1,*,ERR=18)IBATNO
      IF(IBATNO .LT. 0)GO TO 999
      IF(FLOAT(IBATNO/6) .NE. FLOAT(IBATNO)/6.)GO TO 18
   24 WRITE(1,27)
   27 FORMAT('SCALE FACTOR')
      READ(1,*,ERR=24)SCALE
C               SET FOR SOLID LINES.
C               AND CLEAR THE SCREEN.
      CALL PICCLE
      CALL BROKEN(0)
      STX=150.
      X=STX
      STY=70.
      Y=0.
      CALL MOVTO2(X,Y)
      DO 200 I=1,6
      Y=Y+20.
      CALL MOVTO2(X,Y)
      Y=Y+100.
  200 CALL LINTO2(X,Y)
      Y=70.
      DO 300 I=1,6
      X=STX
      CALL MOVTO2(X,Y)
      X=950.
      CALL LINTO2(X,Y)
  300 Y=Y+120.
      KBAT=IBATNO
      CALL MOVTO2(40.,740.)
      CALL CHAHOL('DATA FROM FILE *.')
      CALL CHAARR(RNAME,20,2)
      CALL MOVTO2(0.,690.)
      CALL CHAHOL('VL EOG*.')
      CALL MOVTO2(20.,650.)
      CALL CHAINT(KBAT,3)
      CALL MOVTO2(0.,570.)
      CALL CHAHOL('VR EOG*.')
      KBAT=KBAT+1
      CALL MOVTO2(20.,530.)
      CALL CHAINT(KBAT,3)
      CALL MOVTO2(0.,450.)
      CALL CHAHOL('HL EOG*.')
      KBAT=KBAT+1
      CALL MOVTO2(20.,410.)
      CALL CHAINT(KBAT,3)
      CALL MOVTO2(0.,330.)
      CALL CHAHOL('HR EOG*.')
      KBAT=KBAT+1
      CALL MOVTO2(20.,290.)
      CALL CHAINT(KBAT,3)
      CALL MOVTO2(0.,210.)
      CALL CHAHOL('M1 EEG*.')
      KBAT=KBAT+1
      CALL MOVTO2(20.,170.)
      CALL CHAINT(KBAT,3)
      CALL MOVTO2(0.,90.)
      CALL CHAHOL('M2 EEG*.')
      KBAT=KBAT+1
      CALL MOVTO2(20.,50.)
      CALL CHAINT(KBAT,3)
      YD=600.
      LE=IBATNO
```

```
      DO 400 L=1,6
      Y=STY+YD
      X=STX
      CALL MOVTO2(X,Y)
      CALL DATIN(LE,INP,RNAME,SF1,SF2,SAMRAT,CSE)
      DO 350 I=1,1024
      Y=FLOAT(INP(I))*SF1*SCALE
      IF(L .GE. 5)Y=Y*SF2/SF1
      Y=Y/10. + STY + YD
      X=X+0.78125
350   CALL LINTO2(X,Y)
      LE=LE+1
400   YD=YD-120.
      CALL MOVTO2(0.,0.)
      CALL CHAMOD
      GO TO 22
999   CALL PICCLE
      CALL DEVEND
      CSE=.TRUE.
      CALL DATIN(IBATNO,INP,RNAME,SF1,SF2,SAMRAT,CSE)
      CALL EXIT
      END
```

FORTRAN Programme used in the Analysis of the Eye

Movement Correction Methods

This programme was used to calculate the correction constants for the four channel eye movement correction method. The calculated constants were printed and applied to the data to give the corrected EEG signal. The auto-correlation function of the corrected signal was subsequently calculated and plotted on a graphic terminal. Subroutine 'MES1' was then used to measure both the a.c.c. and the frequency of the a.c.f. by means of the graphics cursor which was set by the user to the appropriate points on the graph.

The autocorrelation function of the signal corrected by the method of McCallum and Walter (and stored as the sixth data channel) was finally calculated and plotted. Once again subroutine 'MES1' was used to estimate the a.c.c. and the frequency of the a.c.f.

The subroutines used are listed after the main pro-gramme. Although having similar names these subroutines are not necessarily the same as some of those listed in Appendix 8.12.

The programme listing follows:-

```
C                    THIS PROGRAM IS INTENDED TO MINIMISE THE AMOUNT OF
C                    E.O.G POWER IN THE E.E.G. IT USES THE MODIFIED
C                    QUILTER TECHNIQUE. HORIZONTAL AND VERTICAL COMPONENTS
C                    OF BOTH EYES ARE TAKEN INTO CONSIDERATION.
C                    THE PROGRAM REMOVES ANY D.C OFFSET ON ANY OF
C                    THE INPUT DATA CHANELS.
      REAL M1M,M2M
      REAL VL(1024),VR(1024),HL(1024),HR(1024),M1(1024),M2(1024)
      DIMENSION X1(4,5),X2(4,5),RM1(4),RM2(4)
      DIMENSION CORl(1024)
      DIMENSION COVAR1(512),COVAR2(512)
      INTEGER*2 BATNO,INP(1024),FNAME(7)
      LOGICAL CSE
      CSE=.FALSE.
      N=1024
      NCORL=512
C                    READ THE NUMBER OF THE FIRST BATCH OF DATA
C                    TO BE PROCESSED.
C                    THE DATA IS ASSUMED TO BE IN THE FOLLOWING
C                    ORDER ; VL , VR , HL , HR , M1 , M2
C                    M1 IS THE CHANNEL TO BE CORRECTED BY THE
C                    MODIFIED QUILTER TECHNIQUE.
C                    M2 IS THE CHANNEL CORRECTED BY THE BURDEN TECHNIQUE.
C                    GET THE SCALE FACTORS FROM THE DATA FILE.
C                    SF1 FOR EOG DATA. SF2 FOR EEG DATA.
    5 WRITE(1,6)
    6 FORMAT('4 CHANNEL EYE MOVEMENT CORRECTION PROGRAM')
      CALL GETNAM(FNAME)
      WRITE(1,10)
   10 FORMAT('WHICH BATCH OR -1 TO QUIT')
      READ(1,*)BATNO
      IF(BATNO .LT. 0)GO TO 5000
C                    CHECK THAT THE BATCH NUMBER IS VALID.
      IF(BATNO .GT. 191)GO TO 2999
      IF(FLOAT(BATNO/6) .NE. FLOAT(BATNO)/6.)GO TO 2999
      WRITE(1,14)
   14 FORMAT('FILTER THE BURDEN SIGNAL(0) NO (1) YES')
      READ(1,*)IBRDFL
      WRITE(1,16)
   16 FORMAT('FILTER THE CORRECTED SIGNAL(0) NO (1) YES')
      READ(1,*)ICRRFL
      WRITE(1,18)
   18 FORMAT('PLOT THE CORRECTED WAVEFORM')
      READ(1,*)IPLTCR

   20 WRITE(1,22)BATNO
   22 FORMAT('EYE MOVEMENT CORRECTIONS 4 CHAN. BATCH',I5)
      WRITE(1,24)FNAME
   24 FORMAT('DATA FILE ',7A2,///)
      L=BATNO
C                    READ THE DATA AND CONVERT TO REAL FORMAT.
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 32 I=1,N
   32 VL(I)=FLOAT(INP(I))*SF1
      L=L+1
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 34 I=1,N
   34 VR(I)=FLOAT(INP(I))*SF1
      L=L+1
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 36 I=1,N
   36 HL(I)=FLOAT(INP(I))*SF1
      L=L+1
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 38 I=1,N
   38 HR(I)=FLOAT(INP(I))*SF1
      L=L+1
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 40 I=1,N
   40 M1(I)=FLOAT(INP(I))*SF2
      L=L+1
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 52 I=1,N
   52 M2(I)=FLOAT(INP(I))*SF2
      WRITE(1,56)SF1,SF2
   56 FORMAT('SF1= ',F8.6,'   SF2= ',F8.6)
C                    SUBTRACT THE MEAN OF EACH DATA BATCH FROM THE DATA.
      CALL SMEAN(N,VL,VLM)
      CALL SMEAN(N,VR,VRM)
      CALL SMEAN(N,HL,HLM)
```

```
      CALL SMEAN(N,HR,HRM)
      CALL SMEAN(N,M1,M1M)
C               FORM THE CORRELATION SUMS OF PRODUCTS.
      A=0.
      B=0.
      C=0.
      D=0.
      E=0.
      F=0.
      G=0.
      P=0.
      Q=0.
      R=0.
      S=0.
      T=0.
      U=0.
      V=0.
      DO 100 I=1,N
      A=A+VL(I)*VL(I)
      B=B+VL(I)*VR(I)
      C=C+VL(I)*HL(I)
      D=D+VL(I)*HR(I)
      E=E+VR(I)*VR(I)
      F=F+VR(I)*HL(I)
      G=G+VR(I)*HR(I)
      P=P+HL(I)*HL(I)
      Q=Q+HL(I)*HR(I)
      R=R+HR(I)*HR(I)
      S=S+M1(I)*VL(I)
      T=T+M1(I)*VR(I)
      U=U+M1(I)*HL(I)
      V=V+M1(I)*HR(I)
  100 CONTINUE
      X1(1,1)=A
      X1(1,2)=B
      X1(1,3)=C
      X1(1,4)=D
      X1(2,2)=E
      X1(2,3)=F
      X1(2,4)=G
      X1(3,3)=P
      X1(3,4)=Q
      X1(4,4)=R
      X1(1,5)=S
      X1(2,5)=T
      X1(3,5)=U
      X1(4,5)=V
C               SET UP SYMMETRICAL MATRIX.
      X1(2,1)=X1(1,2)
      X1(3,1)=X1(1,3)
      X1(4,1)=X1(1,4)
      X1(3,2)=X1(2,3)
      X1(4,2)=X1(2,4)
      X1(4,3)=X1(3,4)
C               SOLVE THE SIMULTANEOUS EQUATIONS BY THE
C               GAUSS PIVOTAL METHOD.
      MSIZE=4
      CALL GAUSS(MSIZE,X1,RM1)
      IF(IBRDFL .EQ. 1)CALL FILTER(N,M2)
      WRITE(1,150)
  150 FORMAT(' THE CORRECTION CONSTANTS ARE ',//)
      WRITE(1,160)
  160 FORMAT(10X,'VL * ',10X,'VR * ',10X,'HL * ',10X,'HR * ')
      WRITE(1,200)(RM1(I),I=1,4)
  200 FORMAT(4(3X,F12.5))
C               APPLY THE CORRECTIONS TO THE DATA.
      DO 220 I=1,N
      COR1(I)=M1(I) - (RM1(1)*VL(I) + RM1(2)*VR(I) + RM1(3)*HL(I)
     1+ RM1(4)*HR(I))
  220 CONTINUE
C               PLOT THE CORRECTED DATA.
C               CALCULATE AND PRINT THE CROSS CORRELATIONS
      IF(ICRRFL .EQ. 1)CALL FILTER(N,COR1)
      IF(IPLTCR .EQ. 1)CALL GRAPH3(N,COR1,SAMRAT)
      SC=200.
      CALL AUTCO(N,COR1,NCORL,COVAR1)
      CALL GRAPH3(NCORL,COVAR1,SAMRAT)
      WRITE(1,240)
  240 FORMAT('MEASURE(0) NO (1) YES')
      READ(1,*)IMES
```

```
      IF(IMES .EQ. 1)CALL MES1
      CALL AUTCO(N,M2,NCORL,COVAR2)
      CALL TNQUA('WAITING, BURDEN ACF NEXT',24)
      READ(1,*)IWT
      CALL GRAPH3(NCORL,COVAR2,SAMRAT)
      WRITE(1,240)
      READ(1,*)IMES
      IF(IMES .EQ. 1)CALL MES1
      GO TO 5
2999  WRITE(1,4000)BATNO
4000  FORMAT(' BATCH NUMBER INCORRECT',I6)
5000  CSE=.TRUE.
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      CALL DEVEND
      CALL EXIT
      END
```

```fortran
      SUBROUTINE MES1
C
C                    MEASURES THE ACC & FREQUENCY
C                    BY MEANS OF THE GRAPHICS CURSOR.
C
      WRITE(1,10)
   10 FORMAT('GIVE CO-ORDS. FOR ACF')
      CENLIN=0.
      XM=400.
      XS=100.
      YS=390.
      CALL CURSOR(ICOM,X,Y)
      X=X-XS
      Y=Y-YS
      CALL CURSOR(ICOM,X1,Y1)
      X1=X1-XS
      Y1=Y1-YS
      S1=(Y-Y1)/(X-X1)
      C1=Y1-S1*X1
C                    DRAW FIRST CONSTRUCTION LINE
C
      XL1=50.
      XL2=750.
      YL1=S1*XL1 + C1
      CALL MOVTO2(XL1+XS,YL1+YS)
      YL2=S1*XL2 + C1
      CALL LINTO2(XL2+XS,YL2+YS)
      CALL CURSOR(ICOM,X,Y)
      X=X-XS
      Y=Y-YS
      CALL CURSOR(ICOM,X1,Y1)
      X1=X1-XS
      Y1=Y1-YS
      S2=(Y-Y1)/(X-X1)
      C2=Y1-S2*X1
C                    DRAW SECOND CONSTRUCTION LINE
C
      YL1=S2*XL1 + C2
      CALL MOVTO2(XL1+XS,YL1+YS)
      YL2=S2*XL2 + C2
      CALL LINTO2(XL2+XS,YL2+YS)
C
      A=(ATAN(S1)+ATAN(S2))/2.
      S=SIN(A)/COS(A)
      C=(C1+C2)/2.
      IF(CENLIN .EQ. 1.)CALL MOVTO2(XL1+XS,YS+S*XL1+C)
      IF(CENLIN .EQ. 1.)CALL LINTO2(XL2+XS,YS+S*XL2+C)
C                    TEST FOR ZERO SLOPE
C
      IF(S .EQ. 0.)GO TO 100
      S3=-1./S
      YM=S*XM+C
      C3=YM-S3*XM
      XP1=(C1-C3)/(S3-S1)
      XP2=(C2-C3)/(S3-S2)
      YP1=S3*XP1 + C3
      YP2=S3*XP2 + C3
      DY=SQRT((XP1-XP2)*(XP1-XP2) + (YP1-YP2)*(YP1-YP2))/400.
      GO TO 200
  100 YP1=S1*XM + C1
      YP2=S2*XM + C2
      DY=ABS(YP1-YP2)/400.
  200 CALL MOVTO2(0.,700.)
      CALL CHAMOD
      WRITE(1,210)
  210 FORMAT('GIVE CO-ORDS. FOR TIME MEASUREMENT')
      CALL CURSOR(ICOM,X,Y)
      CALL CURSOR(ICOM,X1,Y1)
      DX=(ABS(X-X1)/800.)*4.096
      F=1./DX
      CALL MOVTO2(0.,650.)
      CALL CHAMOD
      WRITE(1,240)DY,F
  240 FORMAT('ACF = ',F8.4,10X,'FREQ = ',F9.6)
      RETURN
      END

      SUBROUTINE GETNAM(NAME)
C
C                    GETS A FILENAME FROM THE USER
```

A8-5

```
C
      INTEGER*2 NAME(7),TBUFF(7)
      DATA TBUFF / 'NO','NA','ME','GI','VE','N ','II'/
    6 WRITE(1,8)
    8 FORMAT('GIVE NAME OF FILE TO BE PROCESSED')
      READ(1,10)NAME
   10 FORMAT(7A2)
      IF(NAME(1) .EQ. '   ')GO TO 100
      DO 20 I=1,7
   20 TBUFF(I)=NAME(I)
      RETURN
  100 DO 120 I=1,7
  120 NAME(I)=TBUFF(I)
      RETURN
      END

      SUBROUTINE AUTCO(NPOINT,DATA,NCOREL,AUTOCF)
C
C              CALCULATES THE ACF
C
      DIMENSION DATA(NPOINT),AUTOCF(NCOREL),DATAZM(1024)
      INTEGER*2 Z1
      AMEAN=0.
      DO 10 I=1,NPOINT
   10 AMEAN=AMEAN+DATA(I)
      AMEAN=AMEAN/FLOAT(NPOINT)
      DO 15 I=1,NPOINT
   15 DATAZM(I)=DATA(I)-AMEAN
      DO 25 I=1,NCOREL
      II=I-1
      STORE=0.
      Z1=NPOINT-II
      DO 20 J=1,Z1
   20 STORE=STORE+DATAZM(J)*DATAZM(J+II)
   25 AUTOCF(I)=STORE
      STORE=ABS(AUTOCF(1))
      DO 30 I=1,NCOREL
   30 AUTOCF(I)=AUTOCF(I)/STORE
      RETURN
  999 WRITE(1,40)NPOINT,NCOREL
   40 FORMAT('ERROR IN NUMBER OF CORRELATIONS',2I8)
      STOP
      END

      SUBROUTINE SMEAN(NPTS,DATA,RMEAN)
C
C              SUBTRACTS THE MEAN VALUE FROM THE DATA.
C
      DIMENSION DATA(NPTS)
      RMEAN=0.
      DO 20 I=1,NPTS
   20 RMEAN=RMEAN+DATA(I)
      RMEAN=RMEAN/NPTS
      DO 30 I=1,NPTS
   30 DATA(I)=DATA(I)-RMEAN
      RETURN
      END

      SUBROUTINE FILTER(NPTS,XT)
C
C              LOW PASS FILTER THE DATA.
C
      DIMENSION XT(NPTS),ZA(11),ZB(21),DATOUT(1024)
      ZA(1)=0.03125
      ZA(2)=0.
      ZA(3)=-0.09375
      ZA(4)=0.
      ZA(5)=0.3125
      ZA(6)=0.5
      ZA(7)=0.3125
      ZA(8)=0.
      ZA(9)=-0.09375
      ZA(10)=0.
      ZA(11)=0.03125
      ZB(1)=0.03125
      ZB(2)=0.
      ZB(3)=0.
      ZB(4)=0.
      ZB(5)=-0.09375
      ZB(6)=0.
```

```
      ZB(7)=0.
      ZB(8)=0.
      ZB(9)=0.3125
      ZB(10)=0.
      ZB(11)=0.5
      ZB(12)=0.
      ZB(13)=0.3125
      ZB(14)=0.
      ZB(15)=0.
      ZB(16)=0.
      ZB(17)=-0.09375
      ZB(18)=0.
      ZB(19)=0.
      ZB(20)=0.
      ZB(21)=0.03125
      M=11
      DO 21 I=1,NPTS
      J=M
      STORE=0.
      IF(M .LT. I)GO TO 19
      STORE=XT(I)
      GO TO 21
19    DO 20 K=1,J
20    STORE=STORE + XT(I-K+1)*ZA(K)
21    DATOUT(I)=STORE
      DO 30 I=1,NPTS
30    XT(I)=DATOUT(I)
      M=21
      DO 41 I=1,NPTS
      J=M
      STORE=0.
      IF(M .LT. I)GO TO 39
      STORE=XT(I)
      GO TO 41
39    DO 40 K=1,J
40    STORE=STORE + XT(I-K+1)*ZB(K)
41    DATOUT(I)=STORE
      DO 50 I=1,NPTS
50    XT(I)=DATOUT(I)
      RETURN
      END

      SUBROUTINE GAUSS(K,B,X)
C                    A SUBROUTINE TO SOLVE SIMULTANEOUS
C                    EQUATIONS BY THE GAUSS PIVOTAL METHOD
      DIMENSION A(4,5),X(4),B(4,5)
      INTEGER*2 Z1,Z2,Z3,Z4,Z5,Z6,Z7
      Z1=K+1
      DO 10 I=1,K
      DO 10 J=1,Z1
10    A(I,J)=B(I,J)
C                    SAVE INPUT DATA
      Z2=K-1
      DO 35 I=1,Z2
      L=I
      DO 15 J=I,K
15    IF(ABS(A(L,I)) .LT. ABS(A(J,I)))L=J
      IF(ABS(A(L,I)) .EQ. 0.)GO TO 60
      IF(L .EQ. I)GO TO 21
      Z3=K+1
      DO 20 N=I,Z3
      SAVE=A(I,N)
      A(I,N)=A(L,N)
20    A(L,N)=SAVE
C                    PIVOTAL REDUCTION
21    Z4=I+1
      DO 35 M=Z4,K
      D=A(M,I)/A(I,I)
      Z5=I+1
      Z6=K+1
      DO 35 J=Z5,Z6
35    A(M,J)=A(M,J)-D*A(I,J)
C                    BACK SUBSTITUTION
      DO 50 L=1,K
      J=K+1-L
      IF(J .EQ. K)GO TO 45
      Y=A(J,K+1)
      Z7=K-1
      DO 40 M=J,Z7
40    Y=Y-A(J,M+1)*X(M+1)
```

```fortran
      X(J)= Y/A(J,J)
      IF(J .NE. K)GO TO 50
   45 X(J)=A(J,K+1)/A(J,J)
   50 CONTINUE
      RETURN
   60 WRITE(1,65)
   65 FORMAT('ERROR MESSAGE ZERO COLUMN FOUND')
      STOP
      END

      SUBROUTINE DATIN(IBATNO,IDATA,RNAME,SF1,SF2,SAMRAT,CSE)
C
C               GETS DATA FROM THE DATA FROM SPECIFIED
C               DATA FILE.
C
$INSERT SYSCOM>ASKEYS
      INTEGER*2 IDATA(1024),ONAME(7),RNAME(7),TITLE(36),NME(6)
      INTEGER*2 RWKEY,NLEN,NLEN2,PRIMNO,NBAT,IBATNO,IAA1(4)
      LOGICAL OPEN,NEOPEN,CSE
      DATA NEOPEN /.FALSE./
      RWKEY=1
      PRIMNO=1
      NLEN=14
      NLEN2=NLEN/2
      IF(NEOPEN)GO TO 1300
      IF(CSE)RETURN
  900 OPEN=OPEN$A(RWKEY,RNAME,NLEN,PRIMNO)
      IF(.NOT. OPEN)GO TO 1700
      DO 1000 IC=1,NLEN2
 1000 ONAME(IC)=RNAME(IC)
      NEOPEN=.TRUE.
      READ(5,3000,END=1800,ERR=1900)NME,SF1,SF2
      READ(5,3010,END=1800,ERR=1900)MAXBAT
      READ(5,3020,END=1800,ERR=1900)TITLE
      DO 234 IL=1,4
  234 IAA1(IL)=TITLE(IL+20)
      DECODE (8,236,IAA1)SAMRAT
  236 FORMAT(F8.4)
 1100 READ(5,END=1800,ERR=1900)NBAT
      READ(5,END=1800,ERR=1900)(IDATA(I),I=1,1024)
      IF(NBAT .NE. IBATNO)GO TO 1100
      NBAT=NBAT+1
      RETURN
 1200 OPEN=CLOS$A(PRIMNO)
      IF(.NOT. OPEN)GO TO 1600
      NEOPEN=.FALSE.
      RETURN
 1300 IF(CSE)GO TO 1200
      DO 1400 IC=1,NLEN2
 1400 IF(ONAME(IC) .NE. RNAME(IC))GO TO 1500
      IF(IBATNO .GE. NBAT)GO TO 1100
 1500 OPEN=CLOS$A(PRIMNO)
      IF(OPEN)GO TO 900
 1600 WRITE(1,1610)ONAME
 1610 FORMAT('*** CANT CLOSE FILE ',7A2,' ***')
      STOP 1
 1700 WRITE(1,1710)RNAME
 1710 FORMAT('*** CANT OPEN FILE ',7A2,' ***')
      STOP 2
 1800 WRITE(1,1810)RNAME
 1810 FORMAT('*** END OF FILE ',7A2,' ***')
      STOP 3
 1900 WRITE(1,1910)IBATNO,RNAME
 1910 FORMAT('*** ERROR TRYING TO READ BATCH ',I5,' FROM FILE ',7A2,
     +' ***')
      STOP 4
 3000 FORMAT(6A2,2F8.6)
 3010 FORMAT(I4)
 3020 FORMAT(36A2)
      END

      SUBROUTINE GRAPH3(N,DATA,SAMRAT)
C
C               PLOTS A GRAPH ON THE REQUESTED GRAPHICS DEVICE.
C
      DIMENSION DATA(N),XARRY(1024),YARRY(1024)
      INTEGER*2 IYLAB(7),IYLAB2(9)
      LOGICAL INIT
      DATA INIT/.FALSE./
      DATA IYLAB / 'MI','CR','O-','VO','LT','S ','*.' /
```

```
      DATA IYLAB2 / 'AU','TO','CO','RR','EL','AT','IO','NS','*.' /
      IACF=0
      IF(INIT)GO TO 50
      CALL T4010
      IBAUD=1200
      CALL DEVSPE(IBAUD)
      CALL UNITS(0.24)
   50 CALL PICCLE
      CALL WINDOW(0)
      CALL CHASIZ(15.,15.)
      DO 60 I=1,N
      XARRY(I)=FLOAT(I)/SAMRAT
      YARRY(I)=DATA(I)
   60 CONTINUE
      CALL MOVTO2(450.,0.)
      CALL CHAHOL('TIME  SECONDS*.')
      CALL MOVTO2(50.,300.)
      CALL CHAANG(90.)
      IF(IACF .EQ. 0)GO TO 100
      CALL CHAARR(IYLAB2,9,2)
      GO TO 150
  100 CALL CHAARR(IYLAB,7,2)
  150 CALL CHAANG(0.)
      CALL GRAF(XARRY,YARRY,N,0)
      CALL MOVTO2(0.,779.)
      CALL CHAMOD
      INIT=.TRUE.
      RETURN
      END
```

APPENDIX 8.9

Special Instructions for Peripheral Control

The following instructions were used to control the peripheral devices connected to the PDP8 minicomputer. Since these peripherals were not part of the standard PDP8 equipment, the instructions controlling them are described in detail in this appendix.

OCTAL CODE	MNEMONIC	DESCRIPTION
6056	OUTX	Load the 10 least significant bits of the accumulator into the X 10 bit D/A converter and convert to analogue. Pulse the Z modulation output. This instruction was used for X-Y display of stored data.
6066	OUTY	As above but for the Y D/A converter.
6412	SION*	Enable the interrupt facility from the hybrid computer interface Skip/Interrupt inputs.
6414	SIOF*	Disable the interrupt facility from the the hybrid computer interface Skip/ Interrupt inputs.
6441	ADINP*	Load the 12 bit word from the analogue to digital converter into the accumulator.
6442	STC *	Start the conversion process on the 12 bit A/D converter. (Conversion takes approximately 3.5µs)
6451	MXR *	Set the multiplexer to select the channel number given by the 3 least significant bits of the accumulator. (i.e. channels 0-7).
6501	ACOUT*	Load the accumulator into the output register available on the hybrid computer Patch Panel.

OCTAL CODE	MNEMONIC	DESCRIPTION
6504	ACIN*	Load the accumulator from the input register on the hybrid computer interface Patch Panel.
6511	SK1*	Skip the next instruction if the Patch Panel number one input is at a logical '1'.
6221	SDR	Skip the next instruction if the serial data transceiver has received a byte of data.
6622	DUI	Disable interrupts from the serial data transceiver.
6624	STR	Skip the next instruction if the serial data transceiver is ready to transmit a new data byte.
6631	RUD	Read the received data from the serial data transceiver into the 8 $\dagger^1$ least significant bits of the accumulator. Clear the SDR flag.
6632	ERI	Enable the received data interrupt facility on the serial data transceiver (i.e. allow interrupts to occur when serial data is received).
6634	LSTAT	Load the 5 least significant bits of the accumulator into the serial data transceiver status control register $\dagger^2$.
6641	SKERR	Skip the next instruction if either a praming, parity or over-run error has occurred in receiving serial data.
6642	ETI	Enable the transmitter interrupt facility on the serial data transceiver. (i.e. allow interrupts to occur whenever the serial data transmitter is not busy).
6644	OUT	Load the 8 $\dagger^1$ least significant bits of the accumulator into the serial data transmitter and transmit. Clear the STR flag.

Notes

*   These peripherals are part of the Hybrid Computer Interface [see Section 4 reference 3].

$\dagger^1$ May be less than 8 bits. This depends on the setting of the Universal Asynchronous Receiver Transmitter status control register.

$\dagger^2$ The 5 control bits have the following functions

ACCUMULATOR BIT	FUNCTION
11	Parity inhibit. A '1' disables the generation and checking of the parity bit.
10	Stop bit select. A '1' gives two stop bits. A '0' gives one stop bit.
9	Character length select. Bits 8 and 9 allow characters of either 5,6,7 or 8 bits to be transmitted and received.
8	bit 8 9

	bit 8	9	
	0	0	5 bits
	0	1	6 bits
	1	0	7 bits
	1	1	8 bits

| 7 | Even parity enable. A logical '1' selects even parity. A logical '0' selects odd parity. (Subject to bit 11 being a logical '1'. |

PAL 8 Computer Programme Used to Control the Data

Acquisition Process

This programme was used to control the A-D converter, the multiplexer, the serial interface, the stimulus presentation and an X-Y display during the acquisition of the EEG data. The programme was started and controlled by means of the console switches. The starting address is 200_8 in field zero. Two locations (131_8 and 132_8) must be set, by means of the console switch register, to contain the two's complement of the sample numbers at which time the stimulus pulses are to be presented.

    e.g. If the S1 stimulus is to be presented after
         200_{10} samples have been taken, then location
         131_8 must be set to contain 7470_8. ($200_{10} \equiv 310_8$)

Whilst running the programme will show on an X-Y display whichever channel is selected by the three least significant console switches.

The assembly language listing follows.

```
/ ON LINE CNV DATA AQUISITION PROGRAM
/ ------------------------------------
/
/
/   THIS PROGRAM CONTROLS
/   THE MULTIPLEXER, THE A-D CONVERTER
/   THE S1 AND S2 SIGNALS AND THE SERIAL
/   DATA OUTPUT DURING THE ACQUISITION OF 6
/   CHANNELS OF ANALOGUE DATA.
/ ,
/ '         MEMORY MAP
/ '         ----------
/
/ FIELD ZERO
/ ----------
/
/ 0000 TO 2777            AREA FOR PROGRAM
/
/ 3000 TO 3577            SOFTWARE STACK AREA
/
/ 3600 TO 5577            CHANNEL 4
/
/ 5600 TO 7577            CHANNEL 5
/
/ 7600 TO 7777            DEC SOFTWARE (RIM & BIN)
/
/ FIELD ONE
/ ---------
/
/ 0000 TO 1777            CHANNEL 0
/
/ 2000 TO 3777            CHANNEL 1
/
/ 4000 TO 5777            CHANNEL 2
/
/ 6000 TO 7777            CHANNEL 3
/
/----------------------------------------------------
        0000    *0
00000   0000            0
00001   5440            JMP I ISERV
        0020    *20
                                /
                                / SUBROUTINE POINTERS
                                /
00020   0517    IUARTT, UARTTX
00021   1101    ITTYRX, TTYRX
00022   1046    ITTYTX, TTYTX
00023   0464    ITIMR,  TIMER
00024   1000    ISAM,   SAMPLE
00025   1070    ICVRT,  CVRT
00026   1034    IMPXR,  MPXR
00027   0600    IINC,   INCR1
00030   0436    IRETN,  RETN
00031   0632    IPOIN1, POIN1
00032   0673    IPOIN2, POIN2
00033   0615    IINCR2, INCR2
00034   1102    IRSTIN, RSTIN
00035   1121    IRSTOU, RSTOU
00036   1047    IWTBL,  WTBL
00037   1061    IRNDWT, RNDWT
00040   0400    ISERV,  SERV
00041   0421    ISTRT,  STRT
00042   1200    IDISP,  DISPLA
00043   1157    IINC3,  INC3
00044   1232    IPOIN3, POIN3
00045   1140    IRSTD,  RSTD
                                /
                                / CONSTANTS ETC.
                                /
```

```
00046    0000    TAC,      0
00047    0000    TFG,      0
00050    0000    PRIOR,    0
00051    0000    P0,       0
00052    2000    P1,       2000
00053    4000    P2,       4000
00054    6000    P3,       6000
00055    3600    P4,       3600
00056    5600    P5,       5600
00057    0000    ZEROP,    0
00060    0000    ONEP,     0
00061    0000    TWOP,     0
00062    0000    THREEP,   0
00063    0000    FOURP,    0
00064    0000    FIVEP,    0
00065    0000    D0P,      0
00066    0000    D1P,      0
00067    0000    D2P,      0
00070    0000    D3P,      0
00071    0000    D4P,      0
00072    0000    D5P,      0
00073    0000    D0P,      0
00074    0000    D1P,      0
00075    0000    D2P,      0
00076    0000    D3P,      0
00077    0000    D4P,      0
00100    0000    D5P,      0
00101    0000    SAVE,     0
00102    0000    MADD,     0
00103    0000    OUCHN,    0
00104    0000    CURPNT,   0
00105    0000    CUROP,    0
00106    0000    SWSP,     0
00107    4400    SWSPL,    4400
00110    0001    D1,       1
00111    0003    D3,       3
00112    0007    D7,       7
00113    7777    M1,       7777
00114    7776    M2,       7776
00115    7775    M3,       7775
00116    7774    M4,       7774
00117    7773    M5,       7773
00120    6000    NOSAMS,   6000
00121    7772    LIMIT,    7772
00122    0000    TRIAL,    0
00123    7740    TRIALS,   7740
00124    0000    SW,       0
00125    0026    STATUS,   26
00126    3000    SP,       3000
00127    0052    STCODE,   52
00130    0001    LGT,      1
00131    7604    MS1,      7604
00132    6226    MS2,      6226
00133    0003    S1,       3
00134    0005    S2,       5
00135    0000    DISNUM,   0
00136    0000    XDIS,     0
00137    0000    CPTR,     0
         0200            *200
00200    6002    START,    IOF              / INITIALIZE CONSTANTS ETC.
00201    6622            DUI
00202    6414            SIOF
00203    4434            JMS I IRSTIN
00204    4435            JMS I IRSTOU
00205    7300            CLA CLL
00206    3102            DCA MADD
00207    3050            DCA PRIOR
00210    3122            DCA TRIAL
00211    3124            DCA SW
00212    3103            DCA OUCHN
00213    1126            TAD SP
00214    3106            DCA SWSP
00215    1125            TAD STATUS
```

```
00216  6634              LSTAT
00217  6631              RUD                      / DUMMY READ TO CLEAR UART BUFFER.
00220  6631              RUD
00221  6030              KCF
00222  6042              TCF
00223  4436              JMS I IWTBL
00224  4437              JMS I IRNDWT
00225  6412              SION
00226  6642              ETI
00227  6001              ION
00230  5442   WAIT,      JMP I IDISP
00231  7200   TRIEND,    CLA
00232  1126              TAD SP
00233  3106              DCA SWSP
00234  3102              DCA MADD
00235  3103              DCA OUCHN
00236  4434              JMS I IRSTIN
00237  4435              JMS I IRSTOU
00240  2122              ISZ TRIAL
00241  1122              TAD TRIAL
00242  1123              TAD TRIALS
00243  7650              SNA CLA
00244  5254              JMP FINSH
00245  4436              JMS I IWTBL
00246  4437              JMS I IRNDWT
00247  7300              CLA CLL
00250  3050              DCA PRIOR
00251  6412              SION
00252  6642              ETI
00253  5442              JMP I IDISP
00254  6002   FINSH,     IOF
00255  5442              JMP I IDISP
       0400              *400
00400  3506   SERV,      DCA I SWSP               / THIS SECTION SAVES THE
00401  6004              GTF                      / AC, LINK AND STATUS.
00402  2106              ISZ SWSP
00403  3506              DCA I SWSP
00404  2106              ISZ SWSP
00405  1000              TAD 0                    / GET RETURN ADDRESS
00406  3506              DCA I SWSP
00407  2106              ISZ SWSP
00410  1106              TAD SWSP
00411  1107              TAD SWSPL
00412  7700              SMA CLA
00413  7402              HLT
00414  1050              TAD PRIOR
00415  1041              TAD ISTRT
00416  3220              DCA .+2
00417  5620              JMP I .+1
00420  0000              0
00421  6511   STRT,      SK1                      / SKIP ON TIMER
00422  5224              JMP .+2
00423  5423              JMP I ITIMR
00424  6624              STR                      / SKIP ON UART TX
00425  5227              JMP .+2
00426  5420              JMP I IUARTT
00427  6031              KSF
00430  5232              JMP .+2
00431  5421              JMP I ITTYRX
00432  6041              TSF
00433  5235              JMP .+2
00434  5422              JMP I ITTYTX
00435  7402              HLT                      / SHOULD NOT GET HERE !!
                                       /
                                       / THIS SECTION RESTORES THE AC LINK
                                       / AND RETURNS TO THE INTERRUPTED
                                       / SECTION.
                                       /
00436  6002   RETN,      IOF
00437  6203              CDIO
00440  7340              CLA CLL CMA
00441  1106              TAD SWSP
00442  3106              DCA SWSP
```

```
00443   1506            TAD I SWSP
00444   3000            DCA 0
00445   7340            CLA CLL CMA
00446   1106            TAD SWSP
00447   3106            DCA SWSP
00450   1506            TAD I SWSP
00451   3047            DCA TFG
00452   7340            CLA CLL CMA
00453   1106            TAD SWSP
00454   3106            DCA SWSP
00455   1506            TAD I SWSP
00456   3046            DCA TAC
00457   1047            TAD TFG
00460   6005            RTF
00461   7200            CLA
00462   1046            TAD TAC
00463   5400            JMP I 0
                        /
                        / THIS SECTION SAMPLES AND STORES THE
                        / DATA IN THE CORE BUFFER.
                        /
00464   7300    TIMER,  CLA CLL
00465   6451            MXR                 / SET MULTIPLEXER TO CHAN. 0
00466   4424            JMS I ISAM          / SEND S1 OR S2 IF NECESSARY
00467   4425    NXCHNL, JMS I ICVRT         / CONVERT CURRENT CHAN.
00470   3101            DCA SAVE
00471   7327            CLA CLL CML IAC RTL
00472   6451            MXR                 / GROUND MULTIPLEXER INPUT TO
00473   6442            STC                 / MINIMISE CROSSTALK.
00474   7300            CLA CLL
00475   1102            TAD MADD
00476   4431            JMS I IPOIN1
00477   3104            DCA CURPNT
00500   1101            TAD SAVE
00501   3504            DCA I CURPNT
00502   4426            JMS I IMPXR
00503   7620            SNL CLA
00504   5267            JMP NXCHNL
00505   7327            CLA CLL CML IAC RTL
00506   6451            MXR
00507   4427            JMS I IINC
00510   7420            SNL
00511   5430            JMP I IRETN
00512   6414            SIOF                / TAKEN ALL SAMPLES SO DISABLE
00513   7300            CLA CLL             / TIMER INTERRUPT.
00514   1111            TAD 03
00515   3050            DCA PRIOR
00516   5430            JMP I IRETN
                        /


                        / THIS SECTION TAKES DATA FROM THE
                        / CORE BUFFER AND TRANSMITS IT OVER
                        / THE SERIAL DATA LINE.
                        /
00517   6622    UARTTX, DUI
00520   6001            ION
00521   7300            CLA CLL             / FIRST OR SECOND SIX BITS ?
00522   1124            TAD SW
00523   7640            SZA CLA
00524   5346            JMP SECND
00525   1057            TAD ZEROP           / WAIT TILL AT LEAST ONE SAMPLE
00526   7450            SNA                 / HAS BEEN TAKEN.
00527   5343            JMP TXEND
00530   7041            CIA
00531   1065            TAD OOP             / HAVE ALL THE SAMPLES SO FAR
00532   7700            SMA  CLA            / TAKEN BEEN SENT ?
00533   5343            JMP TXEND
00534   1103            TAD OUCHN
00535   4432            JMS I IPOIN2
00536   3105            DCA CUROP
00537   1505            TAD I CUROP
00540   6644            OUT
```

```
00541    7201              CLA IAC           / SET SWITCH FOR 2nd SIX BITS.
00542    3124              DCA SW
00543    6002    TXEND,    IOF
00544    6642              ETI
00545    5430              JMP I IRETN       / RESET SWITCH.
00546    3124    SECND,    DCA SW
00547    1103              TAD OUCHN
00550    4432              JMS I IPOIN2
00551    3105              DCA CUROP
00552    1505              TAD I CUROP
00553    7002              BSW
00554    6644              OUT
00555    7300              CLA CLL
00556    2103              ISZ OUCHN
00557    1103              TAD OUCHN
00560    1121              TAD LIMIT
00561    7710              SPA CLA
00562    5343              JMP TXEND
00563    3103              DCA OUCHN
00564    4433              JMS I IINCR2
00565    7420              SNL
00566    5343              JMP TXEND
00567    5777              JMP TRIEND
00577    0231
         0600    *600
00600    0000    INCR1,    0
00601    7300              CLA CLL
00602    2057              ISZ ZEROP
00603    2060              ISZ ONEP
00604    2061              ISZ TWOP
00605    2062              ISZ THREEP
00606    7000              NOP
00607    2063              ISZ FOURP
00610    2064              ISZ FIVEP
00611    1057              TAD ZEROP
00612    1120              TAD NOSAMS
00613    7200              CLA
00614    5600              JMP I INCR1
00615    0000    INCR2,    0
00616    7300              CLA CLL
00617    2065              ISZ 00P
00620    2066              ISZ 01P
00621    2067              ISZ 02P
00622    2070              ISZ 03P
00623    7000              NOP
00624    2071              ISZ 04P
00625    2072              ISZ 05P
00626    1065              TAD 00P
00627    1120              TAD NOSAMS
00630    7200              CLA
00631    5615              JMP I INCR2
00632    0000    POIN1,    0
00633    7041              CIA
00634    6211              CDF+10
00635    7450              SNA
00636    5271              JMP ZERO
00637    7001              IAC
00640    7450              SNA
00641    5267              JMP ONE
00642    7001              IAC
00643    7450              SNA
00644    5265              JMP TWO
00645    7001              IAC
00646    7450              SNA
00647    5263              JMP THREE
00650    6201              CDF+0
00651    7001              IAC
00652    7450              SNA
00653    5261              JMP FOUR
00654    7001              IAC
00655    7440              SZA
00656    7402              HLT
00657    1064              TAD FIVEP
```

```
00660  5632          JMP I POIN1
00661  1063  FOUR,   TAD FOURP
00662  5632          JMP I POIN1
00663  1062  THREE,  TAD THREEP
00664  5632          JMP I POIN1
00665  1061  TWO,    TAD TWOP
00666  5632          JMP I POIN1
00667  1060  ONE,    TAD ONEP
00670  5632          JMP I POIN1
00671  1057  ZERO,   TAD ZEROP
00672  5632          JMP I POIN1
00673  0000  POIN2,  0
00674  7041          CIA
00675  6211          CDF+10
00676  7450          SNA
00677  5332          JMP ZER
00700  7001          IAC
00701  7450          SNA
00702  5330          JMP O
00703  7001          IAC
00704  7450          SNA
00705  5326          JMP T
00706  7001          IAC
00707  7450          SNA
00710  5324          JMP TH
00711  6201          CDF+0
00712  7001          IAC
00713  7450          SNA
00714  5322          JMP F
00715  7001          IAC
00716  7440          SZA
00717  7402          HLT
00720  1072          TAD O5P
00721  5673          JMP I POIN2
00722  1071  F,      TAD O4P
00723  5673          JMP I POIN2
00724  1070  TH,     TAD O3P
00725  5673          JMP I POIN2
00726  1067  T,      TAD O2P
00727  5673          JMP I POIN2
00730  1066  O,      TAD O1P
00731  5673          JMP I POIN2
00732  1065  ZER,    TAD OOP
00733  5673          JMP I POIN2
       1000          *1000
01000  0000  SAMPLE, 0
01001  7300          CLA CLL
01002  1233          TAD LOGOUT
01003  7040          CMA
01004  6501          ACOUT            / AC TO PATCH PNL. 6501
01005  7340          CLA CLL CMA
01006  6501          ACOUT
01007  7300          CLA CLL
01010  1057          TAD ZEROP
01011  1131          TAD MS1
01012  7650          SNA CLA
01013  5225          JMP TS1
01014  1130          TAD LGT
01015  3233          DCA LOGOUT
01016  1057          TAD ZEROP
01017  1132          TAD MS2
01020  7650          SNA CLA
01021  5230          JMP TS2
01022  1130          TAD LGT
01023  3233          DCA LOGOUT
01024  5600          JMP I SAMPLE
01025  1133  TS1,    TAD S1
01026  3233          DCA LOGOUT
01027  5600          JMP I SAMPLE
01030  1134  TS2,    TAD S2
01031  3233          DCA LOGOUT
01032  5600          JMP I SAMPLE
01033  0001  LOGOUT, 1
```

```
01034   0000   MPXR,   0
01035   7300           CLA CLL
01036   2102           ISZ MADD
01037   1102           TAD MADD
01040   1121           TAD LIMIT
01041   7650           SNA CLA
01042   3102           DCA MADD
01043   1102           TAD MADD
01044   6451           MXR              / AC TO MULTIPLEXER. 6451
01045   5634           JMP I MPXR
01046   7402   TTYTX,  HLT
01047   0000   WTBL,   0
01050   7300           CLA CLL
01051   6621           SDR
01052   5251           JMP .-1
01053   6631           RUD
01054   7041           CIA
01055   1127           TAD STCODE
01056   7640           SZA CLA
01057   5251           JMP .-6
01060   5647           JMP I WTBL
01061   0000   RNDWT,  0
01062   7300           CLA CLL
01063   6504           ACIN
01064   0110           AND 01
01065   7650           SNA CLA
01066   5263           JMP .-3
01067   5661           JMP I RNDWT
01070   0000   CVRT,   0
01071   6442           STC              / START AD CONVERSION. 6442
01072   7300           CLA CLL
01073   7000           NOP
01074   7000           NOP
01075   7000           NOP
01076   7000           NOP
01077   6441           ADINP            / GET DATA FROM AD. 6441
01100   5670           JMP I CVRT
01101   7402   TTYRX,  HLT


01102   0000   RSTIN,  0
01103   7300           CLA CLL
01104   1051           TAD PO
01105   3057           DCA ZEROP
01106   1052           TAD P1
01107   3060           DCA ONEP
01110   1053           TAD P2
01111   3061           DCA TWOP
01112   1054           TAD P3
01113   3062           DCA THREEP
01114   1055           TAD P4
01115   3063           DCA FOURP
01116   1056           TAD P5
01117   3064           DCA FIVEP
01120   5702           JMP I RSTIN
01121   0000   RSTOU,  0
01122   7300           CLA CLL
01123   1051           TAD PO
01124   3065           DCA D0P
01125   1052           TAD P1
01126   3066           DCA D1P
01127   1053           TAD P2
01130   3067           DCA D2P
01131   1054           TAD P3
01132   3070           DCA D3P
01133   1055           TAD P4
01134   3071           DCA D4P
01135   1056           TAD P5
01136   3072           DCA D5P
01137   5721           JMP I RSTOU
01140   0000   RSTD,   0
01141   7300           CLA CLL
01142   1051           TAD PO
```

```
01143   3073            DCA DOP
01144   1052            TAD P1
01145   3074            DCA D1P
01146   1053            TAD P2
01147   3075            DCA D2P
01150   1054            TAD P3
01151   3076            DCA D3P
01152   1055            TAD P4
01153   3077            DCA D4P
01154   1056            TAD P5
01155   3100            DCA D5P
01156   5740            JMP I RSTD
01157   0000    INC3,   0
01160   7300            CLA CLL
01161   2073            ISZ DOP
01162   2074            ISZ D1P
01163   2075            ISZ D2P
01164   2076            ISZ D3P
01165   7000            NOP
01166   2077            ISZ D4P
01167   2100            ISZ D5P
01170   1073            TAD DOP
01171   1120            TAD NOSAMS
01172   7200            CLA
01173   5757            JMP I INC3
        1200    *1200
01200   7300    DISPLA, CLA CLL
01201   7604            LAS
01202   0112            AND 07
01203   3135            DCA DISNUM
01204   3136            DCA XDIS
01205   1135    NXLOC,  TAD DISNUM
01206   4444            JMS I IPOIN3
01207   3137            DCA CPTR
01210   7330            CLA CLL CML RAR
01211   1537            TAD I CPTR
01212   6201            CDF+0
01213   7110            CLL RAR
01214   7110            CLL RAR
01215   6062            OUTY
01216   7300            CLA CLL
01217   1136            TAD XDIS
01220   6052            OUTX
01221   2136            ISZ XDIS
01222   4443            JMS I IINC3
01223   1136            TAD XDIS
01224   7041            CIA
01225   1052            TAD P1
01226   7640            SZA CLA
01227   5205            JMP NXLOC
01230   4445            JMS I IRSTD
01231   5201            JMP NXLOC-4
01232   0000    POIN3,  0
01233   7041            CIA
01234   6211            CDF+10
01235   7450            SNA
01236   5271            JMP DZ
01237   7001            IAC
01240   7450            SNA
01241   5267            JMP DO
01242   7001            IAC
01243   7450            SNA
01244   5265            JMP DTWO
01245   7001            IAC
01246   7450            SNA
01247   5263            JMP DTHREE
01250   6201            CDF+0
01251   7001            IAC
01252   7450            SNA
01253   5261            JMP DFOUR
01254   7001            IAC
01255   7440            SZA
01256   7402            HLT
```

```
01257    1100            TAD D5P
01260    5632            JMP I POIN3
01261    1077    DFOUR,  TAD D4P
01262    5632            JMP I POIN3
01263    1076    DTHREE, TAD D3P
01264    5632            JMP I POIN3
01265    1075    DTWO,   TAD D2P
01266    5632            JMP I POIN3
01267    1074    DO,     TAD D1P
01270    5632            JMP I POIN3
01271    1073    DZ,     TAD DOP
01272    5632            JMP I POIN3
                       /
                       / SPECIAL INSTRUCTIONS
                       /
         6062            OUTY=6062
         6052            OUTX=6052
         6511            SK1=6511
         6621            SDR=6621
         6624            STR=6624
         6442            STC=6442
         6451            MXR=6451
         6501            ACOUT=6501
         6504            ACIN=6504
         6644            OUT=6644
         6634            LSTAT=6634
         6642            ETI=6642
         6632            ERI=6632
         6622            DUI=6622
         6641            SKERR=6641
         6441            ADINP=6441
         6412            SION=6412
         6414            SIOF=6414
         6631            RUD=6631
         6203            CDIO=6203
                 $
```

ACIN	6504	LIMIT	0121	SKERR	6641
ACOUT	6501	LOGOUT	1033	SK1	6511
ADINP	6441	LSTAT	6634	SP	0126
CDIO	6203	MADD	0102	START	0200
CPTR	0137	MPXR	1034	STATUS	0125
CUROP	0105	MS1	0131	STC	6442
CURPNT	0104	MS2	0132	STCODE	0127
CVRT	1070	MXR	6451	STR	6624
DFOUR	1261	M1	0113	STRT	0421
DISNUM	0135	M2	0114	SW	0124
DISPLA	1200	M3	0115	SWSP	0106
DO	1267	M4	0116	SWSPL	0107
DTHREE	1263	M5	0117	S1	0133
DTWO	1265	NOSAMS	0120	S2	0134
DUI	6622	NXCHNL	0467	T	0726
DZ	1271	NXLOC	1205	TAC	0046
DOP	0073	O	0730	TFG	0047
D1P	0074	ONE	0667	TH	0724
D2P	0075	ONEP	0060	THREE	0663
D3P	0076	OUCHN	0103	THREEP	0062
D4P	0077	OUT	6644	TIMER	0464
D5P	0100	OUTX	6052	TRIAL	0122
ERI	6632	OUTY	6062	TRIALS	0123
ETI	6642	OOP	0065	TRIEND	0231
F	0722	O1	0110	TS1	1025
FINSH	0254	O1P	0066	TS2	1030
FIVEP	0064	O2P	0067	TTYRX	1101
FOUR	0661	O3	0111	TTYTX	1046
FOURP	0063	O3P	0070	TWO	0665
ICVRT	0025	O4P	0071	TWOP	0061
IDISP	0042	O5P	0072	TXEND	0543
IINC	0027	O7	0112	UARTTX	0517
IINCR2	0033	POIN1	0632	WAIT	0230
IINC3	0043	POIN2	0673	WTBL	1047
IMPXR	0026	POIN3	1232	XDIS	0136

```
INCR1   0600      PRIOR   0050      ZER     0732
INCR2   0615      PO      0051      ZERO    0671
INC3    1157      P1      0052      ZEROP   0057
IPOIN1  0031      P2      0053
IPOIN2  0032      P3      0054
IPOIN3  0044      P4      0055
IRETN   0030      P5      0056
IRNDWT  0037      RETN    0436
IRSTD   0045      RNDWT   1061
IRSTIN  0034      RSTD    1140
IRSTOU  0035      RSTIN   1102
ISAM    0024      RSTOU   1121
ISERV   0040      RUD     6631
ISTRT   0041      SAMPLE  1000
ITIMR   0023      SAVE    0101
ITTYRX  0021      SDR     6621
ITTYTX  0022      SECND   0546
IUARTT  0020      SERV    0400
IWTBL   0036      SIOF    6414
LGT     0130      SION    6412
```

ERRORS DETECTED: 0
LINKS GENERATED: 1

APPENDIX 8.11

PAL 8 Computer Programme Used to Store the Data onto Disk

This programme was used to store the data on a magnetic disk. It made use of the OS8 operating system User Service Routine (USR) to create core image files into which the data were transferred. Details of the USR may be found in the OS8 Software Support Handbook available from the Digital Equipment Company.

The programme consists of two sections:-

a) Memory locations 0_8-3652_8 (Disk store programme). This section stores the data received over the high speed serial interface in a memory buffer, checks for transmission errors and calls the USR to create data files and store the data. Each data file is automatically given a new filename based on a "seed" name specified by the operator. (e.g. If the operator specified the "seed" name as MJN000 then the subsequent files would have the names MJN001, MJN002, MJN003........)

b) Memory locations 16000_8-16777_8 (Data examine and transfer programme).

This section is stored on disk with the data in every data file. Subsequent to the completion of the data acquisition process it allows the operator to display (via D-A converters and an X-Y display) any of the six stored channels in the data file. It also allows the

operator to send the data to floppy disk (or paper
tape) for transfer to the main computer. These
functions are controlled by simple commands typed
at the console terminal.

e.g. .R XYZ007 would cause OS8 to load the
data in file XYZ007.SV and start
the Data examine and transfer
programme.

D 0 would display channel zero on the
X-Y display.

H 48 would set the initial batch number
transferred onto floppy disk (or
paper tape) to 48.

P would transfer the data to floppy
disk or paper tape (depending on
which of these was connected).

Control & C would transfer control back to
OS8.

The programme is started by giving the OS8 command
"R DDS44".

The assembly language listing of the programme follows.

```
/ DISK DATA STORE.
/ ---------------
/
/
/ THIS PROGRAM STORES THE DATA RECEIVED FROM
/ THE SERIAL DATA INTERFACE ON AN RK05 DISK.
/
/
/           MEMORY MAP
/           ----------
/
/ FIELD ZERO
/ ----------
/
/ 0000 TO 0777          DISK STORE PROG.
/
/ 1000 TO 1377          CORE CONTROL BLOCK
/
/ 1400 TO 3377          CHANNEL 0
/
/           OVERLAY FOR FILENAME AT 2000
/           THIS IS ONCE ONLY CODE.
/
/ 3400 TO 5377          CHANNEL 1
/
/ 5400 TO 7377          CHANNEL 2
/
/ 7400 TO 7577          DEVICE HANDLER
/
/ 7600 TO 7777          DEC SOFTWARE
/
/ FIELD ONE
/ ---------
/
/ 0000 TO 1777          CHANNEL 3
/
/ 2000 TO 3777          CHANNEL 4
/
/ 4000 TO 5777          CHANNEL 5
/
/ 6000 TO 6777          DATA EX. AND PUNCH PROG.
/
/ 7600 TO 7777          DEC SOFTWARE
/
/---------------------------------------------------
/
/ SPECIAL INSTRUCTIONS.
/
```

6634		LSTAT=6634	/ LOAD UART CONTROL REGISTER.
6631		RUD=6631	/ READ UART DATA.
6644		OUT=6644	/ OUTPUT SERIAL DATA.
6621		SDR=6621	/ SKIP IF UART DATA READY.
6641		SKERR=6641	/ SKIP IF UART RX. ERROR.
6056		OUTX=6056	/ OUTPUT X TO D-A AND BR. UP.
6066		OUTY=6066	/ OUTPUT Y TO D-A AND BR. UP.
6624		STR=6624	/ SKIP IF TX. BUFFER MT.
	0000	*0	
00000	0000	0	
00001	7402	HLT	/ BEWARE OF INTERRUPTS.
	0020	*20	
00020	7700	USR, 7700	/ FIELD 1. USR CALL ADDRESS.
00021	7600	MONST, 7600	/ MONITOR RESTART ADDRESS.
00022	0026	STATUS, 26	/ UART CONTROL WORD.
00023	0000	TMPST, 0	
00024	0000	TRIALS, 0	
00025	0052	STCODE, 52	/ INDICATES TO 8F THAT 8L IS READY.
00026	0040	TRILIM, 40	/ NUMBER OF TRIALS TO BE STORED.
00027	0324	ZT, 324	
00030	0325	ZU, 325	
00031	0330	ZX, 330	

```
00032    0303    ZC,       303
00033    0305    ZE,       305
00034    7775    MCNC,     -3
00035    0336    UPARRO,   336
00036    0215    CR,       215
00037    0212    LF,       212
00040    0007    D7,       7
00041    0016    016,      16
00042    0017    017,      17
00043    0060    060,      60
00044    0077    077,      77
00045    0177    0177,     177
00046    0377    0377,     377
00047    4000    04000,    4000
00050    7700    07700,    7700
00051    7777    M1,       -1
00052    7776    M2,       -2
00053    7775    M3,       -3
00054    7774    M4,       -4
00055    7773    M5,       -5
00056    7772    M6,       -6
00057    7771    M7,       -7
00060    7766    M12,      -12
00061    7746    M32,      -32
00062    7720    M50,      -60
00063    7706    M72,      -72
00064    7677    M101,     -101
00065    0000    MADD,     0
00066    0000    CURPNT,   0
00067    6000    NOSAMS,   6000    / - NUMBER OF SAMPLES TO BE TAKEN.
00070    0000    SVE,      0
00071    0000    TEMP,     0
00072    0000    TEMP2,    0
00073    0000    TEMP3,    0
00074    0000    ACMLTR,   0
00075    7400    HANADR,   7400    / ADDRESS AT WHICH THE DEVICE HANDLER
                                   / MAY BE PLACED. NOTE THAT THIS IS A DUMMY
                                   / ADDRESS SINCE THE DEVICE (BEING THE
                                   / SYSTEM DEVICE) IS ALWAYS (?) RESIDENT.
00076    0317    DEVNME,   DEVICE COPY
00077    2031
00100    0101    NAMEP,    NAM1    / POINTS TO FILENAME.
00101    0401    NAM1,     401     / FILENAME  DEFAULTS TO
00102    2460    NAM2,     2460    / DAT000.SV

00103    6060    NAM3,     6060
00104    2326    NAM4,     2326
00105    1400    HK5,      1400    / START OF BUFFER AREA (FIELD 0).
00106    0000    CPYNUM,   0       / DEVICE NUMBER. DETERMINED BY 'FETCH'.
00107    0000    CPYNTY,   0       / HANDLER ENTRY ADDRESS. DETERMINED
                                   / BY 'FETCH'.
00110    0033    NUMBLK,   33      / NUMBER OF BLOCKS FOR EACH FILE.
00111    0000    STBLK,    0       / NEXT FREE BLOCK ON DISK.
00112    1000    CCBARA,   1000    / LOCATION AT WHICH THE CORE
                                   / IMAGE OF THE CCB IS STORED.
00113    4200    CCBFCW,   4200    / FUNCTION CONT. WORD  FOR STORING
                                   / THE CCB.
00114    7410    FCW1,     7410    / FUNCTION CONTROL WORD.
00115    7000    FCW2,     7000    / SEE OSB SOFTWARE SUPPORT MANUAL
                                   / PAGE 4-2.
00116    4000    PNTR,     4000
00117    0000    CARRY,    0
00120    0000    XDIS,     0
00121    0000    DISNUM,   0
                                   / INITIAL BUFFER ADDRESSES.
00122    1400    P0,       1400    / FIELD 0
00123    3400    P1,       3400    / FIELD 0
00124    5400    P2,       5400    / FIELD 0
00125    0000    P3,       0       / FIELD 1
00126    2000    P4,       2000    / FIELD 1
00127    4000    P5,       4000    / FIELD 1
                                   / CURRENT BUFFER POINTERS.
00130    0000    ZEROP,    0
```

```
00131  0000  ONEP,    0
00132  0000  TWOP,    0
00133  0000  THREEP,  0
00134  0000  FOURP,   0
00135  0000  FIVEP,   0
                                     / SUBROUTINE POINTERS.
00136  0347  ICHRO,   ZCHRO
00137  0660  INPRT,   NUMPNT
00140  0250  IRENME,  RENAME
00141  0400  IDSK,    DSK
00142  0542  IINCR,   INCR1
00143  0556  IMAINC,  MAINC
00144  0600  IPOIN1,  POIN1
00145  0566  IGTWRD,  GETWRD
00146  0703  IGETBY,  GETBY
00147  0641  IRSTIN,  RSTIN
00150  0000  SAVE1,   0
00151  0000  SAVE3,   0
00152  0240  ZSPCE,   240
00153  7000  NOPER,   7000
00154  0000  PTR,     0
00155  3000  PPTR,    3000
00156  0000  TPTR,    0
00157  4773  LIMIT,   -3005
       0200  *200
00200  7300           CLA CLL          / INITIALISE PROGRAM.
00201  6046           TLS
00202  1022           TAD STATUS
00203  6634           LSTAT
00204  6631           RUD
00205  6631           RUD              / ENSURE UART BUFFERS EMPTY.
00206  4777' GNME,    JMS     FNME
00207  7300           CLA CLL
00210  3024           DCA TRIALS
00211  3065  TRL,     DCA MADD         / GET DATA AND STORE IN CORE.
00212  4547           JMS I IRSTIN
00213  4537           JMS I INPRT      / PRINT NEXT BATCH NUMBER
00214  1025           TAD STCODE
00215  6644           OUT              / SEND "READY" SIGNAL.
00216  4545  NEXT,    JMS I IGTWRD
00217  3151           DCA SAVE3
00220  1065           TAD MADD
00221  4544           JMS I IPOIN1
00222  3066           DCA CURPNT
00223  1151           TAD SAVE3
00224  3466           DCA I CURPNT
00225  6201           CDF+0
00226  4543           JMS I IMAINC
00227  7620           SNL CLA          / SKIP IF ALL CHANNELS DONE.
00230  5216           JMP NEXT
00231  3065           DCA MADD
00232  4542           JMS I IINCR      / INCREMENT ALL POINTERS.
00233  7420           SNL              / SKIP IF ALL SAMPLES TAKEN.
00234  5216           JMP NEXT
00235  4541           JMS I IDSK       / TRANSFER CORE BUFFER TO DISK.
00236  4540           JMS I IRENME     / UPDATE FILE NAME.
00237  7301           CLA CLL IAC
00240  1024           TAD TRIALS
00241  3024           DCA TRIALS
00242  1026           TAD TRILIM
00243  7041           CIA
00244  1024           TAD TRIALS
00245  7640           SZA CLA          / SKIP IF ALL TRIALS COMPLETE.
00246  5211           JMP TRL
00247  5421           JMP I MONST      / JUMP BACK TO MONITOR.
                             /
                             / THIS SUBROUTINE UPDATES THE FILENAME.
                             /
00250  0000  RENAME,  0
00251  7300           CLA CLL
00252  1103           TAD NAM3
00253  4325           JMS INC
00254  7640           SZA CLA
```

```
00255   5261        JMP LBY
00256   1043        TAD 060
00257   3071        DCA TEMP
00260   2117        ISZ CARRY
00261   1103   LBY, TAD NAM3
00262   0050        AND 07700
00263   1071        TAD TEMP
00264   3103        DCA NAM3
00265   1117        TAD CARRY
00266   7650        SNA CLA
00267   5650        JMP I RENAME
00270   1103        TAD NAM3
00271   4335        JMS PBSW
00272   4325        JMS INC
00273   7640        SZA CLA
00274   5300        JMP MBY
00275   1043        TAD 060
00276   3071        DCA TEMP
00277   2117        ISZ CARRY
00300   1071   MBY, TAD TEMP
00301   4335        JMS PBSW
00302   3071        DCA TEMP
00303   1103        TAD NAM3
00304   0044        AND 077
00305   1071        TAD TEMP
00306   3103        DCA NAM3
00307   1117        TAD CARRY
00310   7650        SNA CLA
00311   5650        JMP I RENAME
00312   1102        TAD NAM2
00313   4325        JMS INC
00314   7640        SZA CLA
00315   5320        JMP HBY
00316   1043        TAD 060
00317   3071        DCA TEMP
00320   1102   HBY, TAD NAM2
00321   0050        AND 07700
00322   1071        TAD TEMP
00323   3102        DCA NAM2
00324   5650        JMP I RENAME
00325   0000   INC, 0
00326   0044        AND 077
00327   7001        IAC
00330   3071        DCA TEMP
00331   3117        DCA CARRY
00332   1071        TAD TEMP
00333   1063        TAD M72
00334   5725        JMP I INC
                    / THIS SUBROUTINE SIMULATES THE
                    / PDP8E 'BSW' INSTRUCTION.
                    / IT WAS WRITTEN BY A. JERRAM.

00335   0000   PBSW, 0
00336   7100        CLL
00337   3150        DCA SAVE1
00340   1150        TAD SAVE1
00341   0050        AND 07700
00342   1150        TAD SAVE1
00343   7006        RTL
00344   7006        RTL
00345   7006        RTL
00346   5735        JMP I PBSW
00347   0000   ZCHRO, 0
00350   6041        TSF
00351   5350        JMP .-1
00352   6046        TLS
00353   7300        CLA CLL
00354   5747        JMP I ZCHRO
00377   2000
        0400   *400
                    / THIS SUBROUTINE USES THE USR
                    / TO STORE THE DATA ON THE
                    / RK05 DISK.
00400   0000   DSK, 0
```

```
00401   7300            CLA CLL
00402   1076            TAD DEVNME      / GET DEVICE NAME FROM CONSTANT
00403   3224            DCA FARG1       / AREA AND PREPARE TO FETCH THE
00404   1077            TAD DEVNME+1    / DEVICE HANDLER.
00405   3225            DCA FARG2
00406   1075            TAD HANADR      / GET THE LOCATION AT WHICH THE
00407   3226            DCA FARG3       / HANDLER MAY BE PLACED.
00410   1100            TAD NAMEP       / POINTS TO THE FILENAME.
00411   3247            DCA EARG1
00412   3250            DCA EARG2       / CLEAR 2ND. ARG.
00413   1100            TAD NAMEP
00414   3336            DCA CARG1
00415   1110            TAD NUMBLK      / GET THE FILE LENGTH.
00416   3337            DCA CARG2       / ( IN BLOCKS ).
00417   7300            CLA CLL
00420   6201            CDF+0
00421   6212            CIF+10
00422   4420            JMS I USR       / JUMP TO USR.
00423   0001            1               / DENOTES "FETCH" FUNCTION.
00424   0000    FARG1,  0
00425   0000    FARG2,  0
00426   0000    FARG3,  0
00427   7402            HLT             / ERROR IN GETTING HANDLER.
00430   7300            CLA CLL
00431   1225            TAD FARG2       / NOW THE DEVICE NUMBER.
00432   0042            AND 017         / MASK OFF UPPER BITS.
00433   3106            DCA CPYNUM
00434   1226            TAD FARG3       / ENTRY POINT OF HANDLER.
00435   3107            DCA CPYNTY
00436   1110            TAD NUMBLK      / CALCULATE VALUE IN AC
00437   0046            AND 0377        / ON ENTRY TO USR IN THE
00440   7106            CLL RTL         / "ENTER" MODE. SEE OS8
00441   7006            RTL             / SOFTWARE SUPPORT MANUAL
00442   1106            TAD CPYNUM      / PAGE 2-7.
00443   6201            CDF+0
00444   6212            CIF+10
00445   4420            JMS I USR
00446   0003            3               / DENOTES "ENTER" FUNCTION.
00447   0000    EARG1,  0
00450   0000    EARG2,  0
00451   7402            HLT             / ERROR RETURN.
00452   7300            CLA CLL
00453   1247            TAD EARG1       / NOW THE FIRST EMPTY
00454   3111            DCA STBLK       / BLOCK ON THE DEVICE.
00455   1113            TAD CCBFCW      / CONTROL WORD FOR THE CCB AREA.
00456   3306            DCA CHARG1
00457   1112            TAD CCBARA      / LOCATION AT WHICH THE CCB
00460   3307            DCA CHARG2      / IS STORED IN CORE.
00461   1111            TAD STBLK       / FIRST M.T. BLOCK.
00462   3310            DCA CHARG3
00463   2111            ISZ STBLK       / ALLOW ONE BLOCK FOR THE CCBB.
00464   7000            NOP
00465   1114            TAD FCW1        / GET FIELD 1 FCW.
00466   3315            DCA HARG1
00467   3316            DCA HARG2       / FIELD 1 BUFFER STARTS AT 0.
00470   1111            TAD STBLK       / NEXT M.T. BLOCK AFTER CCB.
00471   3317            DCA HARG3
00472   1115            TAD FCW2        / GET FIELD 0 FCW.
00473   3324            DCA HARG4
00474   1105            TAD HK5         / START OF FIELD 0 BUFFER.
00475   3325            DCA HARG5
00476   1111            TAD STBLK       / ALLOW FOR FIELD 1 DATA.
00477   1041            TAD 016         / =14 DATA, 2 PROG.=16 (8 ).
00500   3111            DCA STBLK
00501   1111            TAD STBLK
00502   3326            DCA HARG6
00503   6201            CDF+0
00504   6202            CIF+0
00505   4507            JMS I CPYNTY    / SAVE CCB.
00506   0000    CHARG1, 0
00507   0000    CHARG2, 0
00510   0000    CHARG3, 0
00511   7402            HLT
```

```
00512   6201            CDF+0
00513   6202            CIF+0
00514   4507            JMS I CPYNTY    / SAVE FIELD 1 DATA AND PROG.
00515   0000   HARG1,   0
00516   0000   HARG2,   0
00517   0000   HARG3,   0
00520   7402            HLT
00521   6201            CDF+0
00522   6202            CIF+0
00523   4507            JMS I CPYNTY    / SAVE FIELD 0 DATA.
00524   0000   HARG4,   0
00525   0000   HARG5,   0
00526   0000   HARG6,   0
00527   7402            HLT
00530   7300            CLA CLL
00531   1106            TAD CPYNUM
00532   6201            CDF+0
00533   6212            CIF+10
00534   4420            JMS I USR
00535   0004            4
00536   0000   CARG1,   0
00537   0000   CARG2,   0
00540   7402            HLT
00541   5600            JMP I DSK
                                / THIS SUBROUTINE INCREMENTS ALL THE
                                / DATA POINTERS AND SETS THE LINK
                                / IF ALL THE SAMPLES HAVE BEEN TAKEN.
00542   0000   INCR1,   0
00543   7300            CLA CLL
00544   2130            ISZ ZEROP
00545   2131            ISZ ONEP
00546   2132            ISZ TWOP
00547   2133            ISZ THREEP
00550   2134            ISZ FOURP
00551   2135            ISZ FIVEP
00552   1133            TAD THREEP
00553   1067            TAD NOSAMS
00554   7200            CLA
00555   5742            JMP I INCR1
00556   0000   MAINC,   0
00557   7301            CLA CLL IAC
00560   1065            TAD MADD
00561   3065            DCA MADD
00562   1056            TAD M6
00563   1065            TAD MADD
00564   7200            CLA
00565   5756            JMP I MAINC
00566   0000   GETWRD,  0
00567   4546            JMS I IGETBY
00570   3070            DCA SVE
00571   4546            JMS I IGETBY
00572   7106            CLL RTL
00573   7106            CLL RTL
00574   7106            CLL RTL
00575   1070            TAD SVE
00576   5766            JMP I GETWRD
        0600   *600             / THIS SUBROUTINE RETURNS THE CURRENT
                                / POINTER FOR THE CHANNEL REQUESTED BY
                                / THE AC CONTENTS. IT ALSO SETS THE
                                / DATA FIELD.
00600   0000   POIN1,   0
00601   7041            CIA
00602   6201            CDF+0
00603   7450            SNA
00604   5237            JMP ZERO
00605   7001            IAC
00606   7450            SNA
00607   5235            JMP ONE
00610   7001            IAC
00611   7450            SNA
00612   5233            JMP TWO
00613   6211            CDF+10
00614   7001            IAC
```

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00615    7450        SNA
00616    5231        JMP  THREE
00617    7001        IAC
00620    7450        SNA
00621    5227        JMP  FOUR
00622    7001        IAC
00623    7440        SZA
00624    7402        HLT
00625    1135        TAD  FIVEP
00626    5600        JMP  I  POIN1
00627    1134  FOUR,  TAD  FOURP
00630    5600        JMP  I  POIN1
00631    1133  THREE,  TAD  THREEP
00632    5600        JMP  I  POIN1
00633    1132  TWO,   TAD  TWOP
00634    5600        JMP  I  POIN1
00635    1131  ONE,   TAD  ONEP
00636    5600        JMP  I  POIN1
00637    1130  ZERO,  TAD  ZEROP
00640    5600        JMP  I  POIN1
00641    0000  RSTIN,  0
00642    7300        CLA  CLL
00643    1122        TAD  P0
00644    3130        DCA  ZEROP
00645    1123        TAD  P1
00646    3131        DCA  ONEP
00647    1124        TAD  P2
00650    3132        DCA  TWOP
00651    1125        TAD  P3
00652    3133        DCA  THREEP
00653    1126        TAD  P4
00654    3134        DCA  FOURP
00655    1127        TAD  P5
00656    3135        DCA  FIVEP
00657    5641        JMP  I  RSTIN
00660    0000  NUMPNT,  0
00661    7300        CLA  CLL
00662    1035        TAD  CR
00663    4536        JMS  I  ICHRO
00664    1037        TAD  LF
00665    4536        JMS  I  ICHRO
00666    1102        TAD  NAM2
00667    0044        AND  077
00670    4536        JMS  I  ICHRO
00671    1103        TAD  NAM3
00672    7012        RTR
00673    7012        RTR
00674    7012        RTR
00675    0044        AND  077
00676    4536        JMS  I  ICHRO
00677    1103        TAD  NAM3
00700    0044        AND  077
00701    4536        JMS  I  ICHRO
00702    5660        JMP  I  NUMPNT
00703    0000  GETBY,  0
00704    7300        CLA  CLL
00705    6621  WAIT,   SBR
00706    5325        JMP  CNTRLC
00707    6631        RUD
00710    0044        AND  077
00711    6641        SKERR    / TEST FOR ERRORS.
00712    5703        JMP  I  GETBY
00713    7300        CLA  CLL
00714    1152        TAD  ZSPCE
00715    4536        JMS  I  ICHRO
00716    1027        TAD  ZT
00717    4536        JMS  I  ICHRO
00720    1031        TAD  ZX
00721    4536        JMS  I  ICHRO
00722    1033        TAD  ZE
00723    4536        JMS  I  ICHRO
00724    5777'       JMP  TRL
00725    6031  CNTRLC,  KSF
```

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00726    5305              JMP WAIT
00727    6036              KRB
00730    0045              AND 0177
00731    1034              TAD MCNC
00732    7640              SZA CLA
00733    5305              JMP WAIT
00734    1035              TAD UPARRO
00735    4536              JMS I ICHRO
00736    1032              TAD ZC
00737    4536              JMS I ICHRO
00740    6201              CDF+0
00741    5421              JMP I MONST
00777    0211
         1000     *1000

                           / CORE CONTROL BLOCK
01000    7776              7776     / 2 SEGMENTS
01001    6213              6213     / STARTING FIELD
01002    6000              6000     / STARTING ADDRESS
01003    1400              1400     / JOB STATUS WORD
01004    0000              0000     / CORE ORIGIN
01005    3410              3410     / 34 PAGES, FIELD 1
01006    1400              1400     / CORE ORIGIN
01007    3000              3000     / 30 PAGES, FIELD 0
         2000     *2000    / CHARACTER INPUT ROUTINE
                           / HANDLES ^U,^C,^C,^J &RUBOUT.
02000    0000     FNME,    0
02001    7300              CLA CLL
02002    1153              TAD NOPER
02003    3777              DCA GNME         / RESET JMS TO NOP
02004    6046              TLS
02005    7300     START,   CLA CLL
02006    1360              TAD PSTRG
02007    4776              JMS PRINT        / PRINT PROMPT
02010    7300              CLA CLL
02011    3357              DCA FLAG         / CLEAR RUBOUT FLAG
02012    1155              TAD PPTR         / GET START OF BUFFER
02013    3154              DCA PTR          / AND SAVE IN PTR
02014    4775     GTCR,    JMS ZCHRI        / GET A CHARACTER
02015    3073              DCA TEMP3
02016    1073              TAD TEMP3
02017    1355              TAD MCRET        / = C.R. ?
02020    7650              SNA CLA
02021    5305              JMP OK5
02022    1073              TAD TEMP3
02023    1352              TAD MRBOUT       / WAS IT A RUBOUT ?
02024    7650              SNA CLA          / SKIP IF NOT
02025    5330              JMP ROUT         / JUMP TO RUBOUT IF WAS
02026    1357              TAD FLAG
02027    7650              SNA CLA          / WAS RUBOUT FLAG SET ?
02030    5234              JMP NOFLG        / NO SO JUMP OVER NEXT BIT.
02031    1356              TAD SLSH
02032    4536              JMS I ICHRO
02033    3357              DCA FLAG         / AND CLEAR THE FLAG
02034    1073     NOFLG,   TAD TEMP3
02035    1353              TAD MCNTU        / WAS IT A ^U ?
02036    7640              SZA CLA
02037    5245              JMP NOCU         / NO SO JUMP OVER NEXT BIT.
02040    1035              TAD UPARRO       / YES SO ECH ^
02041    4536              JMS I ICHRO
02042    1030              TAD ZU
02043    4536              JMS I ICHRO      / AND "U"
02044    5205              JMP START        / AND JUMP BACK.
02045    1073     NOCU,    TAD TEMP3
02046    1354              TAD MCNTJ
02047    7650              SNA CLA          / WAS IT A ^J ?
02050    5313              JMP LFEED
02051    1073              TAD TEMP3        / NO SO TEST FOR ^C
02052    1034              TAD MCNC
02053    7640              SZA CLA
02054    5263              JMP NOCC         / NO SO JUMP OVER NEXT BIT.
02055    1035              TAD UPARRO       / YES SO ECHO "^"
02056    4536              JMS I ICHRO
02057    1032              TAD ZC           / AND "C"
```

```
02060  4536           JMS I ICHRO
02061  6203           CDF CIF+0        / ENSURE I/F AND D/F = 0
02062  5421           JMP I MONST
02063  1073  NOCC,    TAD TEMP3
02064  1062           TAD M60          / NOW CHECK FOR NUMBER 0-9 OR
02065  7510           SPA              / LETTER A-Z (UPPER CASE).
02066  5214           JMP GTCR
02067  1060           TAD M12
02070  7510           SPA
02071  5300           JMP OK           / WAS A NUMBER
02072  1057           TAD M7
02073  7510           SPA
02074  5214           JMP GTCR         / CODE WAS 72-100 OCTAL SO ERROR.
02075  1061           TAD M32
02076  7500           SMA
02077  5214           JMP GTCR         / CODE WAS > 132 (Z) SO ERROR.
02100  7300  OK,      CLA CLL
02101  1073           TAD TEMP3
02102  3554           DCA I PTR
02103  1073           TAD TEMP3
02104  4536           JMS I ICHRO      / ECHO TO TTY.
02105  2154  OK5,     ISZ PTR          / INCREMENT POINTER.
02106  1073           TAD TEMP3
02107  1355           TAD MCRET        / TEST FOR RETURN.
02110  7440           SZA
02111  5214           JMP GTCR
02112  5774'          JMP TSTNME
02113  4773' LFEED,   JMS CRLF         / PRINT RETURN AND LINEFEED.
02114  1155           TAD PPTR         / SET TEMP3 POINTER=START
02115  3156           DCA TPTR
02116  1154  NXCH,    TAD PTR
02117  7041           CIA
02120  1156           TAD TPTR
02121  7700           SMA CLA
02122  5214           JMP GTCR         / JUMP BACK IF FINISHED
02123  1556           TAD I TPTR       / GET CURRENT CHAR.
02124  4536           JMS I ICHRO
02125  7300           CLA CLL
02126  2156           ISZ TPTR         / INCREMENT POINTER.
02127  5316           JMP NXCH
02130  1357  ROUT,    TAD FLAG         / GET FLAG
02131  7440           SZA
02132  5337           JMP FLSET
02133  7001           IAC
02134  3357           DCA FLAG         / SET FLAG
02135  1356           TAD SLSH         / AND PRINT "/"
02136  4536           JMS I ICHRO
02137  7340  FLSET,   CLA CLL CMA      / SET AC=-1
02140  1154           TAD PTR          / DEC POINTER.
02141  3154           DCA PTR
02142  1155           TAD PPTR
02143  7041           CIA
02144  1154           TAD PTR
02145  7710           SPA CLA          / BACK TO START OF BUFFER.
02146  5205           JMP START        / YES SO BACK TO START.
02147  1554           TAD I PTR        / GET CHAR.
02150  4536           JMS I ICHRO      / AND ECHO IT.
02151  5214           JMP GTCR
02152  7601  MRBOUT,  -177
02153  7753  MCNTU,   -25
02154  7766  MCNTJ,   -12
02155  7763  MCRET,   -15
02156  0057  SLSH,    57
02157  0000  FLAG,    0
02160  3500  PSTRG,   STRING
02173  2200
02174  2224
02175  2206
02176  2214
02177  0206
       2200  PAGE
02200  0000  CRLF,    0
02201  1036           TAD CR
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```
02202  4536          JMS I ICHRO
02203  1037          TAD LF
02204  4536          JMS I ICHRO
02205  5600          JMP I CRLF
02206  0000  ZCHRI,  0
02207  6031          KSF
02210  5207          JMP .-1
02211  6036          KRB
02212  0045          AND 0177
02213  5606          JMP I ZCHRI
02214  0000  PRINT,  0
02215  3072          DCA TEMP2
02216  1472          TAD I TEMP2
02217  7450          SNA
02220  5614          JMP I PRINT
02221  4536          JMS I ICHRO
02222  2072          ISZ TEMP2
02223  5216          JMP PRINT+2
02224  7300  TSTNME, CLA CLL          / TEST THE FILENAME IS VALID.
02225  1155          TAD PPTR          / CHECK THE LENGTH FIRST.
02226  7041          CIA
02227  1154          TAD PTR
02230  1057          TAD M7
02231  7640          SZA CLA
02232  5265          JMP ERMESS
02233  1555          TAD I PPTR        / IS THE FIRST CHARACTER ALPHA.
02234  1064          TAD M101
02235  7710          SPA CLA
02236  5265          JMP ERMESS
02237  1100          TAD NAMEP
02240  3156          DCA TPTR          / NAME LOOKS OK SO PACK INTO
02241  1155          TAD PPTR          / 6 BIT OCTAL.
02242  3154          DCA PTR
02243  1554  NXCHRP, TAD I PTR
02244  0044          AND 077
02245  7106          CLL RTL
02246  7006          RTL
02247  7006          RTL
02250  3071          DCA TEMP
02251  2154          ISZ PTR
02252  1554          TAD I PTR
02253  0044          AND 077
02254  1071          TAD TEMP
02255  3556          DCA I TPTR
02256  2154          ISZ PTR
02257  2156          ISZ TPTR
02260  1154          TAD PTR
02261  1157          TAD LIMIT
02262  7710          SPA CLA
02263  5243          JMP NXCHRP
02264  5777'         JMP GNME
02265  7300  ERMESS, CLA CLL
02266  1271          TAD PSTRIN
02267  4214          JMS PRINT
02270  5776'         JMP START
02271  3632  PSTRIN, STRIN2
02376  2005
02377  0206
       3600          *3600
03600  0212  STRING, 212
03601  0215          215
03602  0320          "P
03603  0314          "L
03604  0305          "E
03605  0301          "A
03606  0323          "S
03607  0305          "E
03610  0240          "
03611  0324          "T
03612  0331          "Y
03613  0320          "P
03614  0305          "E
03615  0240          "
```

```
03616   0306              "F
03617   0311              "I
03620   0314              "L
03621   0305              "E
03622   0316              "N
03623   0301              "A
03624   0315              "M
03625   0305              "E
03626   0212              212
03627   0215              215
03630   0276              ">
03631   0000              0
03632   0212      STRIN2, 212
03633   0215              215
03634   0311              "I
03635   0316              "N
03636   0326              "V
03637   0301              "A
03640   0314              "L
03641   0311              "I
03642   0304              "D
03643   0240              "
03644   0316              "N
03645   0301              "A
03646   0315              "M
03647   0305              "E
03650   0212              212
03651   0215              215
C3652   0000              0
        0001      FIELD 1          / THIS IS STORED AT THE SAME TIME
        6000      *6000            / AS THE DATA. IT ENABLES THE USER TO
16000   7300              CLA CLL  / EXAMINE (ON AN X-Y DISPLAY)OR TRANSFER
16001   6026              PLS      / THE DATA TO THE SERIAL LINE OUTPUT
16002   6046              TLS      / BY USING THE OS8 'RUN DEV:FILENAME'
16003   1350              TAD STUS / COMMAND. ONCE RUNNING THE USER MAY TYPE
16004   6634              LSTAT    / THE FOLLOWING COMMANNDS;
                                   / "D 0","D 1", ETC TO DISPLAY THE DATA.
                                   / "H NNN" TO SET THE BATCH NUMBER TO NNN.
                                   / "P" TO TRANSFER THE DATA TO THE SERIAL
                                   /        LINE.
16005   7300      NXCMD,  CLA CLL
16006   6211              CDF+10
16007   4777'             JMS PCRLF
16010   4776'             JMS GETCHR
16011   3356              DCA CMND
16012   1356              TAD CMND
16013   1357              TAD MH
16014   7650              SNA CLA
16015   5233              JMP HDR
16016   1356              TAD CMND
16017   1360              TAD MP
16020   7650              SNA CLA
16021   5775'             JMP PUNCH
16022   1356              TAD CMND
16023   1361              TAD MD
16024   7650              SNA CLA
16025   5774'             JMP DISP
16026   1362      ERROR,  TAD SPCE
16027   4773'             JMS CHROUT
16030   1363              TAD QMK
16031   4773'             JMS CHROUT
16032   5205              JMP NXCMD
16033   1362      HDR,    TAD SPCE
16034   4773'             JMS CHROUT
16035   1365              TAD BUFF
16036   3366              DCA BUFFP
16037   4776'     GET,    JMS GETCHR
16040   3355              DCA TMPSTR
16041   1355              TAD TMPSTR
16042   1352              TAD M260
16043   7710              SPA CLA
16044   5256              JMP ENDCHK
16045   1355              TAD TMPSTR
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16046   1353            TAD M272
16047   7700            SMA CLA
16050   5226            JMP ERROR
16051   1355            TAD TMPSTR
16052   1352            TAD M260
16053   3766            DCA I BUFFP
16054   2366            ISZ BUFFP
16055   5237            JMP GET
16056   1355   ENDCHK,  TAD TMPSTR
16057   1354            TAD MCR
16060   7640            SZA CLA
16061   5226            JMP ERROR
16062   3364            DCA BATNO
16063   1366            TAD BUFFP
16064   7041            CIA
16065   1365            TAD BUFF
16066   7650            SNA CLA
16067   5314            JMP ENDHDR
16070   4324            JMS BUFDEC
16071   3364            DCA BATNO
16072   1366            TAD BUFFP
16073   7041            CIA
16074   1365            TAD BUFF
16075   7650            SNA CLA
16076   5314            JMP ENDHDR
16077   4324            JMS BUFDEC
16100   4332            JMS TENS
16101   1364            TAD BATNO
16102   3364            DCA BATNO
16103   1366            TAD BUFFP
16104   7041            CIA
16105   1365            TAD BUFF
16106   7650            SNA CLA
16107   5314            JMP ENDHDR
16110   4324            JMS BUFDEC
16111   4341            JMS HUNS
16112   1364            TAD BATNO
16113   3364            DCA BATNO
16114   7300   ENDHDR,  CLA  CLL
16115   1364            TAD BATNO
16116   7510            SPA
16117   5226            JMP ERROR
16120   1351            TAD PM193
16121   7710            SPA CLA
16122   5205            JMP NXCMD
16123   5226            JMP ERROR
16124   0000   BUFDEC,  0
16125   7340            CLA CLL CMA
16126   1366            TAD BUFFP
16127   3366            DCA BUFFP
16130   1766            TAD I BUFFP
16131   5724            JMP I BUFDEC
16132   0000   TENS,    0
16133   7041            CIA
16134   3371            DCA T1
16135   1370            TAD KTEN
16136   2371            ISZ T1
16137   5335            JMP .-2
16140   5732            JMP I TENS
16141   0000   HUNS,    0
16142   7041            CIA
16143   3371            DCA T1
16144   1367            TAD KHUN
16145   2371            ISZ T1
16146   5344            JMP .-2
16147   5741            JMP I HUNS
                        / CONSTANTS
16150   0017   STUS,    17
16151   7477   PM193,   7477
16152   7520   M260,    -260
16153   7506   M272,    -272
16154   7563   MCR,     7563
16155   0000   TMPSTR,  0
```

```
16156   0000   CMND,    0
16157   7470   MH,      7470
16160   7460   MP,      7460
16161   7474   MD,      7474
16162   0240   SPCE,    240
16163   0277   QMK,     277
16164   0000   BATNO,   0
16165   7000   BUFF,    7000
16166   0000   BUFFP,   0
16167   0144   KHUN,    144
16170   0012   KTEN,    12
16171   0000   T1,      0
16173   6317
16174   6254
16175   6200
16176   6600
16177   6325
        6200   *6200
16200   4777'  PUNCH,   JMS LLDR
16201   4777'           JMS LLDR
16202   3352            DCA CHNO
16203   1776'  STRT,    TAD P0377
16204   4333            JMS UAOUT
16205   1776'           TAD P0377
16206   4333            JMS UAOUT
16207   1775'           TAD BATNO
16210   4774'           JMS WRDOUT
16211   7300            CLA CLL
16212   3355            DCA CKSM
16213   1353            TAD MCNT
16214   3351            DCA CNTR
16215   1352            TAD CHNO
16216   4773'           JMS POINT
16217   3345            DCA CPTR
16220   6214            RDF
16221   3354            DCA DFLD
16222   1354   GDAT,    TAD DFLD
16223   7650            SNA CLA
16224   6201            CDF+0
16225   1745            TAD I CPTR
16226   6211            CDF+10
16227   4774'           JMS WRDOUT
16230   2345            ISZ CPTR
16231   7000            NOP
16232   2351            ISZ CNTR
16233   5222            JMP GDAT
16234   1346            TAD P0300
16235   4333            JMS UAOUT
16236   1355            TAD CKSM
16237   4333            JMS UAOUT
16240   2352            ISZ CHNO
16241   1352            TAD CHNO
16242   1350            TAD PM6
16243   7700            SMA CLA
16244   5251            JMP FIN
16245   2775'           ISZ BATNO
16246   7000            NOP
16247   4777'           JMS LLDR
16250   5203            JMP STRT
16251   4777'  FIN,     JMS LLDR
16252   4777'           JMS LLDR
16253   5772'           JMP NXCMD
16254   7300   DISP,    CLA CLL / DISPLAY SLECTED CHANNEL.
16255   1771'           TAD SPCE
16256   4317            JMS CHROUT
16257   4770'           JMS GETNO
16260   3343            DCA CHAN
16261   3344            DCA PXDIS
16262   1343            TAD CHAN
16263   4773'           JMS POINT
16264   3345            DCA CPTR
16265   7330   NXLOC,   CLA CLL CML RAR
16266   1745            TAD I CPTR
```

```
16267   7110            CLL RAR
16270   7110            CLL RAR
16271   6066            DUTY
16272   7300            CLA CLL
16273   1344            TAD PXDIS
16274   6056            OUTX
16275   2345            ISZ CPTR
16276   7300            CLA CLL
16277   2344            ISZ PXDIS
16300   1344            TAD PXDIS
16301   1347            TAD PM2000
16302   7710            SPA CLA
16303   5265            JMP NXLOC
16304   6031            KSF
16305   5261            JMP DISP+5
16306   5772'           JMP NXCMD
16307   0000    CHRIN,  0
16310   7300            CLA CLL
16311   6031            KSF
16312   5311            JMP .-1
16313   6036            KRB
16314   0767'           AND P0177
16315   1766'           TAD P0200
16316   5707            JMP I CHRIN
16317   0000    CHROUT, 0
16320   6041            TSF
16321   5320            JMP .-1
16322   6046            TLS
16323   7300            CLA CLL
16324   5717            JMP I CHROUT
16325   0000    PCRLF,  0
16326   1341            TAD PCR
16327   4317            JMS CHROUT
16330   1342            TAD PLF
16331   4317            JMS CHROUT
16332   5725            JMP I PCRLF
16333   0000    UAOUT,  0
16334   6624            STR
16335   5334            JMP .-1
16336   6644            OUT
16337   7300            CLA CLL
16340   5733            JMP I UAOUT
16341   0215    PCR,    215
16342   0212    PLF,    212


16343   0000    CHAN,   0
16344   0000    PXDIS,  0
16345   0000    CPTR,   0
16346   0300    P0300,  300
16347   6000    PM2000, 6000
16350   7772    PM6,    7772
16351   0000    CNTR,   0
16352   0000    CHND,   0
16353   6000    MCNT,   6000
16354   0000    DFLD,   0
16355   0000    CKSM,   0
16366   6557
16367   6556
16370   6532
16371   6162
16372   6005
16373   6471
16374   6411
16375   6164
16376   6560
16377   6400
        6400    *6400
16400   0000    LLDR,   0
16401   7300            CLA CLL
16402   1362            TAD KLD
16403   3346            DCA T2
16404   4777'           JMS UAOUT
```

```
16405    2346              ISZ  T2
16406    5204              JMP  .-2
16407    5600              JMP  I LLDR
16410    0100    PO100,    100
16411    0000    WRDOUT,   0
16412    3347              DCA  T3
16413    7300              CLA  CLL
16414    1347              TAD  T3
16415    0361              AND  PO7700
16416    7012              RTR
16417    7012              RTR
16420    7012              RTR
16421    1210              TAD  PO100
16422    4245              JMS  EPTY
16423    3346              DCA  T2
16424    1346              TAD  T2
16425    1776'             TAD  CKSM
16426    0360              AND  PO377
16427    3776'             DCA  CKSM
16430    1346              TAD  T2
16431    4777'             JMS  UAOUT
16432    1347              TAD  T3
16433    0355              AND  PO77
16434    4245              JMS  EPTY
16435    3346              DCA  T2
16436    1346              TAD  T2
16437    1776'             TAD  CKSM
16440    0360              AND  PO377
16441    3776'             DCA  CKSM
16442    1346              TAD  T2
16443    4777'             JMS  UAOUT
16444    5611              JMP  I WRDOUT
16445    0000    EPTY,     0
16446    0356              AND  PO177
16447    3351              DCA  T6
16450    1354              TAD  PM7
16451    3352              DCA  T7
16452    3353              DCA  BITS
16453    1351              TAD  T6
16454    7010              RAR
16455    7430              SZL
16456    2353              ISZ  BITS
16457    2352              ISZ  T7
16460    5254              JMP  .-4
16461    7300              CLA  CLL
16462    1353              TAD  BITS
16463    7010              RAR
16464    7200              CLA
16465    1351              TAD  T6
16466    7430              SZL
16467    1357              TAD  PO200
16470    5645              JMP  I EPTY
16471    0000    POINT,    0
16472    7041              CIA
16473    6201              CDF+0
16474    7450              SNA
16475    5330              JMP  DZ
16476    7001              IAC
16477    7450              SNA
16500    5326              JMP  DD
16501    7001              IAC
16502    7450              SNA
16503    5324              JMP  DTW
16504    6211              CDF+10
16505    7001              IAC
16506    7450              SNA
16507    5322              JMP  DTH
16510    7001              IAC
16511    7450              SNA
16512    5320              JMP  DF
16513    7001              IAC
16514    7440              SZA
16515    7402              HLT
```

A11-17

```
16516   1363            TAD FIP
16517   5671            JMP I POINT
16520   1364    DF,     TAD FOP
16521   5671            JMP I POINT
16522   1365    DTH,    TAD THP
16523   5671            JMP I POINT
16524   1366    DTW,    TAD TWP
16525   5671            JMP I POINT
16526   1357    DO,     TAD OP
16527   5671            JMP I POINT
16530   1370    DZ,     TAD ZP
16531   5671            JMP I POINT
16532   0000    GETNO,  0
16533   4775'           JMS GETCHR
16534   1774'           TAD M260
16535   3350            DCA T4
16536   1350            TAD T4
16537   7510            SPA
16540   5773'           JMP ERROR
16541   1772'           TAD PM6
16542   7700            SMA CLA
16543   5773'           JMP ERROR
16544   1350            TAD T4
16545   5732            JMP I GETNO
16546   0000    T2,     0
16547   0000    T3,     0
16550   0000    T4,     0
16551   0000    T6,     0
16552   0000    T7,     0
16553   0000    BITS,   0
16554   7771    PM7,    7771
16555   0077    P077,   77
16556   0177    P0177,  177
16557   0200    P0200,  200
16560   0377    P0377,  377
16561   7700    P07700, 7700
16562   7730    KLD,    7730
16563   4000    FIP,    4000
16564   2000    FOP,    2000
16565   0000    THP,    0
16566   5400    TWP,    5400
16567   3400    OP,     3400
16570   1400    ZP,     1400
16572   6350
16573   6026
16574   6152
16575   6600
16576   6355
16577   6333
        6600    *16600
16600   0000    GETCHR, 0
16601   4777'           JMS CHRIN
16602   3222            DCA SAVE
16603   1222            TAD SAVE
16604   1223            TAD MCC
16605   7650            SNA CLA
16606   5213            JMP EXIT
16607   1222            TAD SAVE
16610   4776'           JMS CHROUT
16611   1222            TAD SAVE
16612   5600            JMP I GETCHR
16613   1224    EXIT,   TAD UPARR
16614   4776'           JMS CHROUT
16615   1225            TAD CHC
16616   4776'           JMS CHROUT
16617   6203            CDF CIF+0
16620   5621            JMP I .+1
16621   7600            7600
16622   0000    SAVE,   0
16623   7575    MCC,    7575
16624   0336    UPARR,  336
16625   0303    CHC,    303
16776   6317
```

$

Symbol	Addr	Symbol	Addr	Symbol	Addr	Symbol	Addr
ACMLTR	0074	FLAG	2157	MCRET	2155	PCR	6341
BATNO	6164	FLSET	2137	MD	6161	PCRLF	6325
BITS	6553	FNME	2000	MH	6157	PLF	6342
BUFDEC	6124	FOP	6564	MONST	0021	PM193	6151
BUFF	6165	FOUR	0627	MP	6160	PM2000	6347
BUFFP	6166	FOURP	0134	MRBOUT	2152	PM6	6350
CARG1	0536	GDAT	6222	M1	0051	PM7	6554
CARG2	0537	GET	6037	M101	0064	PNTR	0116
CARRY	0117	GETBY	0703	M12	0060	POINT	6471
CCBARA	0112	GETCHR	6600	M2	0052	POIN1	0600
CCBFCW	0113	GETNO	6532	M260	6152	PO100	6410
CHAN	6343	GETWRD	0566	M272	6153	PO177	6556
CHARG1	0506	GNME	0206	M3	0053	PO200	6557
CHARG2	0507	GTCR	2014	M32	0061	PO300	6346
CHARG3	0510	HANADR	0075	M4	0054	PO377	6560
CHC	6625	HARG1	0515	M5	0055	PO77	6555
CHNO	6352	HARG2	0516	M6	0056	PO7700	6561
CHRIN	6307	HARG3	0517	M60	0062	PPTR	0155
CHROUT	6317	HARG4	0524	M7	0057	PRINT	2214
CKSM	6355	HARG5	0525	M72	0063	PSTRG	2160
CMND	6156	HARG6	0526	NAMEP	0100	PSTRIN	2271
CNTR	6351	HBY	0320	NAM1	0101	PTR	0154
CNTRLC	0725	HDR	6033	NAM2	0102	PUNCH	6200
CPTR	6345	HK5	0105	NAM3	0103	PXDIS	6344
CPYNTY	0107	HUNS	6141	NAM4	0104	P0	0122
CPYNUM	0106	ICHRO	0136	NEXT	0216	P1	0123
CR	0036	IDSK	0141	NOCC	2063	P2	0124
CRLF	2200	IGETBY	0146	NOCU	2045	P3	0125
CURPNT	0066	IGTWRD	0145	NOFLG	2034	P4	0126
DEVNME	0076	IINCR	0142	NOPER	0153	P5	0127
DF	6520	IMAINC	0143	NOSAMS	0067	QMK	6163
DFLD	6354	INC	0325	NUMBLK	0110	RENAME	0250
DISNUM	0121	INCR1	0542	NUMPNT	0660	ROUT	2130
DISP	6254	INPRT	0137	NXCH	2116	RSTIN	0641
DO	6526	IPOIN1	0144	NXCHRP	2243	RUD	6631
DSK	0400	IRENME	0140	NXCMD	6005	SAVE	6622
DTH	6522	IRSTIN	0147	NXLOC	6265	SAVE1	0150
DTW	6524	KHUN	6167	OK	2100	SAVE3	0151
DZ	6530	KLD	6562	OK5	2105	SDR	6621
EARG1	0447	KTEN	6170	ONE	0635	SKERR	6641
EARG2	0450	LBY	0261	ONEP	0131	SLSH	2156
ENDCHK	6056	LF	0037	OP	6567	SPCE	6162
ENDHDR	6114	LFEED	2113	OUT	6644	START	2005
EPTY	6445	LIMIT	0157	OUTX	6056	STATUS	0022
ERMESS	2265	LLDR	6400	OUTY	6066	STBLK	0111
ERROR	6026	LSTAT	6634	O16	0041	STCODE	0025
EXIT	6513	MADD	0065	O17	0042	STR	6624
FARG1	0424	MAINC	0556	O177	0045	STRING	3600
FARG2	0425	MBY	0300	O377	0046	STRIN2	3632
FARG3	0426	MCC	6623	O4000	0047	STRT	6203
FCW1	0114	MCNC	0034	O50	0043	STUS	6150
FCW2	0115	MCNT	6353	O7	0040	SVE	0070
FIN	6251	MCNTJ	2154	O77	0044	TEMP	0071
FIP	6563	MCNTU	2153	O7700	0050	TEMP2	0072
FIVEP	0135	MCR	6154	PBSW	0335	TEMP3	0073

Symbol	Addr
TENS	6132
THP	6565
THREE	0631
THREEP	0133
TMPST	0023
TMPSTR	6155
TPTR	0156
TRIALS	0024
TRILIM	0026
TRL	0211
TSTNME	2224
TWO	0633

```
TWOP    0132
TWP     6566
T1      6171
T2      6546
T3      6547
T4      6550
T6      6551
T7      6552
UAOUT   6333
UPARR   6624
UPARRO  0035
USR     0020
WAIT    0705
WRDOUT  6411
XDIS    0120
ZC      0032
ZCHRI   2206
ZCHRO   0347
ZE      0033
ZERO    0637
ZEROP   0130
ZP      6570
ZSPCE   0152
ZT      0027
ZU      0030
ZX      0031
```

ERRORS DETECTED: 0
LINKS GENERATED: 52

FORTRAN Programmes used in the Analysis of the CNV Data

The listings of the three major analysis programmes
are given in this appendix together with their associated
subroutines. These programmes perform (i) The Pre- and
Post- Stimulus (Broadband) Energy Test as described in
section 2.2.3.1; (ii) The tests described in sections
2.2.2.1 (The Rayleigh Test of Circular Variance), 2.2.2.2
(The Modified Rayleigh Test), 2.2.2.3 (The Hodges-Ajne
Test) and 2.2.3.3 (The Nearest and Furthest Mean Amplitude
Test); (iii) All the tests in (ii) and in addition the test
described in section 2.2.3.2 (The Pre- and Post- Stimulus
Mean Amplitude differences test). All the CNV data were
tested using programme (i). The one second ISI CNV's were
tested using Programme (iii) whilst the four second ISI
CNV's could only be tested using Programme (ii) because of
the limited amount of pre-stimulus information available.

Programmes similar to (i) and (iii) were used in the
analysis of the auditory responses.

The programmes listed in this appendix and in append-
ices 8.7 and 8.8 use a number library subroutines and
functions specific to the Prime 750/550 system installed
at Plymouth Polytechnic.

Brief details of these are as follows:-

1.) Input and Output

a) On the Prime computer system the FORTRAN input / output unit numbers are as follows:-

unit 1 = Input / output from / to the users terminal.

unit 5 = Input / output from / to PRIMOS file unit 1.

unit 6 = Input / output from / to PRIMOS file unit 2.

Thus READ(1,*)A,I would perform a READ operation from the users terminal. The '*' infers free format whereby any numbers separated by spaces or commas are assigned to the elements of the variable list.

2) Applications Library and Operating System Subroutines.

The following routines are part of the PRIMOS applications library.

CLOS$A[†]   Closes a file by its PRIMOS file unit number.

EXST$A   Tests whether the file specified exists or not.

FILL$A   Fills an array with a specified ASCII character.

MSUB$A	Copies a string of characters into another string.
NLEN$A	Returns the number of non-blank characters in a string array.
OPEN$A[†]	Opens a file for reading or writing on a specified PRIMOS file unit.
TREE$A	Tests a string of characters to establish whether they constitute a valid file treename. The file need not exist.
YSNO$A	Prompts the user with a specified string and requests a YES or NO answer. Returns a logical .TRUE. or .FALSE. according to the users reply.
†	May be treated as Functions or Subroutines.

The following routines are part of the PRIMOS operating system.

EXIT	Returns from FORTRAN to PRIMOS.
TNOUA	Transfers a character string to the users terminal without appending a 'newline' sequence.
TODEC	Writes the argument as a decimal number on the users terminal.

T1IN   Obtains a single character from the users terminal.

3)   Graphics subroutines

The following subroutines form part of the GINO graphics package. For further details see the GINOGRAF and GINO-F manuals or contact The GINO-F Support Team, C.A.D. Centre, Madingley Road, Cambridge, CB3 0HB.

ARCTO2	DEVEND
BROKEN	DEVSPE
CC81	LINTO2
CC906	MOVTO2
CHAANG	PENSEL
CHAARR	PICCLE
CHAFLO	S5660
CHAINT	SYMBOL
CHAHAR	T4010
CHAHOL	
CHAMOD	UNITS
CHASIZ	WINDO2
CURSOR	WINDOW

The following subroutine is part of the GINOGRAF graphics package.

GRAF

```
C          BROADBAND POWER ANALYSIS OF PRE- AND POST-STIMULUS CNV'S
C          ----------------------------------------------------------
C
C
C          INPUT FILES: DATA
C          OUTPUT FILES: RESULTS>ENG.CNV......
$INSERT SYSCOM>A$KEYS
      REAL DATA(1024),SSPRS1(32),SSS1(32),MUPR,MUS1
      DIMENSION TRDAT(1024)
      INTEGER*2 FNAME(20),CHANAN,BATNRS(32),BLINE,DEL
      INTEGER*2 SSR,EP1,EP2
      INTEGER BATNO,CHNO,RESNAM(20),RESLEN,ODEV
      LOGICAL FILE
      COMMON ODEV
      DATA ODEV/99/
      FILE=.TRUE.
      N=1024
      ICHAR='  '
      DEL=125
C
C                GET THE DETAILS OF THE SECTIONS TO BE
C                           ANALYSED.
C
    1 WRITE(1,2)
    2 FORMAT('LENGTH OF SECTION 1')
      READ(1,*,ERR=1)NL1
    3 WRITE(1,4)
    4 FORMAT('LENGTH OF SECTION 2')
      READ(1,*,ERR=3)NL2
    5 WRITE(1,6)
    6 FORMAT('START OF SECTION 1')
      READ(1,*,ERR=5)EP1
    7 WRITE(1,8)
    8 FORMAT('START OF SECTION 2')
      READ(1,*,ERR=7)EP2
C
C                ONE SECOND STIMULUS POINTS
C
      IS1=407
      IS2=532
    9 WRITE(1,10)
   10 FORMAT('ONE OR FOUR SECOND PARADIGM')
      READ(1,*,ERR=9)IPARA
   11 WRITE(1,12)
   12 FORMAT('PERFORM BASELINE CORRECTIONS')
      READ(1,*,ERR=11)BLINE
      IF(BLINE .LT. 0 .OR. BLINE .GT. 1)GO TO 11
      IF(BLINE .EQ. 1)ICHAR='B'
      IF(IPARA .EQ. 1)GO TO 14
      IS1=219
      IS2=719
      IF(IPARA .NE. 4)GO TO 9
   14 IF(.NOT. YSNO$A('STORE RESULTS IN A FILE',23,A$DYES))
     +      FILE=.FALSE.
C
C                PREPARE THE FILENAME FOR THE RESULTS
C
      CALL FILL$A(RESNAM,40,' ')
      ENCODE(19,15,RESNAM)ICHAR
   15 FORMAT('P03400>RESULTS>ENG',A1)
      RESLEN=NLEN$A(RESNAM,40)
C
C                GET THE FILENAME OF THE DATA TO BE PROCESSED.
C
   18 CALL GETNAM(FNAME)
      NL=NLEN$A(FNAME,40)
C
C                TEST FOR A VALID NAME.
C
      IF (.NOT. TREE$A(FNAME,NL,NT,NTL))GO TO 18
C
C                ADD THE NAME OF THE DATA INPUT FILE
C                TO THE RESULTS FILENAME TO GIVE A UNIQUE
C                FILENAME.
C
      I9=MSUB$A(FNAME,NL,NT,NT+NTL-1,RESNAM,40,RESLEN+1,RESLEN+NTL)
      RESLEN=NLEN$A(RESNAM,40)
C
C                GET THE NUMBER OF THE CHANNEL TO BE ANALYSED.
```

```
C
   20 WRITE(1,30)
   30 FORMAT('CHANNEL 4 OR 5')
      READ(1,*,ERR=20)CHNO
      IF(CHNO .NE. 4 .AND. CHNO .NE. 5)GO TO 20
      CHANAN=CHNO-3
C
C                    ECORR=1 IF DATA IS TO BE CORRECTED FOR EYE MOVEMENTS.
C                         =0 IF NOT.
C
      ECORR=1
C
C                    IFILT=1 IF DATA IS TO BE FILTERED.
C                         =0 IF NOT.
C
      IFILT=1
C
C                    GET THE NUMBERS OF THE BATCHES TO BE ANALYSED.
C
      CALL BATNOS(BATNRS,MBAT)
C
C                    NOW THE ITERATIVE BIT
C
      DO 240 IC=1,MBAT
      BATNO=BATNRS(IC)
   54 WRITE(1,55)BATNO
   55 FORMAT('PROCESSING BATCH ',I4)
C
C                    GET THE CORRECTED OR UNCORRECTED DATA.
C
      CALL EYECOR(FNAME,BATNO,CHANAN,DATA,SF1,SF2,SAMRAT,ECORR)
      IF(BLINE .EQ. 1)CALL BASLNE(DATA,N,1,IS1,IS2+DEL,N)
C
C                    APPLY FILTER IF REQUIRED.
C
      IF(IFILT .EQ. 1)CALL FILTER(N,DATA)
C
C                    SSR=SUBSAMPLING RATE
C
      SSR=1
C
C                    EP1=START OF PRE-S1 DATA
C
      N1=NL1*SSR
      N2=SSR
C
C                    REMOVE PRE-STIMULUS DATA AT REQUIRED POINTS
C                    AND PERFORM ANALYSIS. STORE RESULTS IN ARRAY
C                    SSPRS1.
C
      L1=0
      DO 135 I=1,N1,N2
      L1=L1+1
  135 TRDAT(L1)=DATA(I+EP1-1)
      CALL SSQRE(NL1,TRDAT,SSPRS1(IC))
C
C                    NOW THE SAME FOR POST-STIMULUS AND PUT THE
C                    RESULTS INTO ARRAY SSS1.
C
      N1=NL2*SSR
      L1=0
      DO 200 I=1,N1,N2
      L1=L1+1
  200 TRDAT(L1)=DATA(I+EP2-1)
      CALL SSQRE(NL2,TRDAT,SSS1(IC))
  240 CONTINUE
C
C                    CALCULATE MEAN AND ST. DEV. FOR PRE-STIM. DATA.
C
      CALL STDMN(MBAT,SSPRS1,MUPR,SIGPR)
      WRITE(1,510)MUPR,SIGPR
  510 FORMAT('MEAN OF PRE-S1 ',E16.8,'   STANDARD DEV.',E16.8)
C
C                    CALCULATE MEAN AND ST. DEV. FOR POST-STIM. DATA.
C
      CALL STDMN(MBAT,SSS1,MUS1,SIGS1)
      WRITE(1,520)MUS1,SIGS1
  520 FORMAT('MEAN OF S1 ',E16.8,'   STANDARD DEV. ',E16.8)
      IF(.NOT. FILE)GO TO 560
      IF(.NOT. EXST$A(RESNAM,RESLEN))GO TO 550
```

```
      WRITE(1,540)RESNAM
 540  FORMAT('OVERWRITE EXISTING FILE :      ',20A2)
      IF(.NOT. YSNO$A('YES OR NO ',10,A$DNO))FILE=.FALSE.
      IF(.NOT. FILE)GO TO 560
 550  IF(.NOT. OPEN$A(2,RESNAM,RESLEN,2))GO TO 2900
 560  DO 600 IC=1,MBAT
      DIFF=SSS1(IC)-SSPRS1(IC)
      WRITE(1,730)BATNRS(IC),SSPRS1(IC),SSS1(IC),DIFF
      IF(FILE)WRITE(6,735)BATNRS(IC),SSPRS1(IC),SSS1(IC),DIFF
 600  CONTINUE
 730  FORMAT('BATCH ',I3,'  PRE S1 ',E16.8,5X,'  POST S1 ',
     *E16.8,'   DIFFERENCE ',E16.8)
 735  FORMAT(I3,3(E16.8,2X))
      IF(FILE)CALL CLOS$A(2)
1900  CALL CLOS$A(1)
      CALL EXIT
2900  WRITE(1,2901)RESNAM
2901  FORMAT('CANT OPEN RESULTS FILE :   ',20A2)
      STOP
      END
```

```
C                 PHASOR DIAGRAM ANALYSIS OF CNV
C                 ------------------------------
C
C
C                     INPUT FILES: DATA
C                     OUTPUT FILES: NONE
C
$INSERT SYSCOM>A$KEYS
C
        REAL DATA(1024)
        COMPLEX TDATA(512),S1(6,32)     /* 6 HARMONICS, 32 TRIALS
        DIMENSION TRDAT(512),ANGLE(32),RAD(32)
        INTEGER*2 FNAME(20),CHANAN,BATNRS(32),SSR,BLINE
        INTEGER*2 TDLEN,BATNO
        INTEGER*2 LAB1(40),EP1,ODEV,DEL
        COMMON ODEV
        DATA ODEV / 99 /
        PI=3.14159265
        WRITE(1,1)
    1 FORMAT('CNV PHASOR DIAGRAM ANALYSIS')
C
C                     FIND OUT WHICH GRAPHICAL OUTPUT
C                     DEVICE IS TO BE USED.
C
        WRITE(1,2)
    2 FORMAT('WHICH OUTPUT DEVICE FOR GRAPHIC DATA')
    3 WRITE(1,5)
    5 FORMAT('TEKTRONIX(0), CALCOMP(1) OR SIGMA(2)')
        READ(1,*,ERR=3)IDEV
    6 WRITE(1,7)
    7 FORMAT('CNV PARADIGM 1 OR 4 SECONDS')
        READ(1,*,ERR=6)IPARA
        IF(IPARA .EQ. 1 .OR. IPARA .EQ. 4)GO TO 10
        GO TO 6
   10 N=1024
C
C                     THESE PARAMETERS ARE GOVERNED
C                     BY THE CNV PARADIGM
C                     EP1 IS THE START OF THE POST- S1 DATA.
C                     NP IS THE LENGTH OF THE POST- S1 DATA.
C                     IS1 IS THE S1 STIMULUS POINT
C                     IS2 IS THE S2 STIMULUS POINT
C                     DEL IS A DELAY FROM S2 TO ALLOW THE AEP & CNV TO SETTLE.
C                     ALL VALUES ARE IN TERMS OF 'SAMPLE NUMBER' 1  N  1024
C
        NP=64
        TDLEN=64
        DEL=125
C
C                     FOR ONE SECOND CNV'S
C
        EP1=472
        IS1=407
        IS2=532
        IF(IPARA .EQ. 1)GO TO 20
        NP=400
        TDLEN=512
C
C                     FOR FOUR SECOND CNV'S
C
        EP1=295
        IS1=219
        IS2=719
C
C                     GET THE NAME OF THE INPUT DATA FILE.
C
   20 CALL GETNAM(FNAME)
        LGTDLN=IFIX(ALOG10(FLOAT(TDLEN))/ALOG10(2.) + 0.5)
        ITL=TDLEN/2 + 1
        CHANAN=4
C                     STUDY CHANNEL 4 I.E. VERTEX
C
        CHANAN=CHANAN-3
   25 WRITE(1,30)
   30 FORMAT('PERFORM EYE MOVEMENT CORRECTIONS')
        READ(1,*,ERR=25)ECORR
   31 WRITE(1,35)
   35 FORMAT('PERFORM BASELINE CORRECTIONS')
        READ(1,*,ERR=31)BLINE
   38 WRITE(1,40)
```

```
   40 FORMAT('FILTER')
      READ(1,*,ERR=38)IFILT
C
C                   ALLOW VARIABLE SCALE FACTORS SO AS TO GET
C                   ALL THE POINTS ON THE PHASOR DIAGRAM.
C
   45 WRITE(1,50)
   50 FORMAT('MULTIPLICATION FACTOR')
      READ(1,*,ERR=45)SF
      SF=SF*1.5E6
C
C                   FIND OUT WHICH BATCHES ARE TO BE ANALYSED.
C
      CALL BATNOS(BATNRS,MBAT)
      SSR=1
      N1=NP*SSR
      CALL FILLSA(LAB1,40,' ')
      ENCODE(57,52,LAB1)TDLEN,NP,SSR,EP1,BLINE
   52 FORMAT(I3,' PT FFT,',I3,' DATA PTS, SSR= ',I2,', POST =',I3,
     +4X,'B. LINE=',I2)
C
C                   NOW THE ITERATIVE BIT
C
      DO 640 IC=1,MBAT
      BATNO=BATNRS(IC)
   54 WRITE(1,55)BATNO
   55 FORMAT('PROCESSING BATCH ',I4)
      CALL EYECOR(FNAME,BATNO,CHANAN,DATA,SF1,SF2,SAMRAT,ECORR)
      IF(BLINE .EQ. 1)CALL BASLNE(DATA,N,1,IS1,IS2+DEL,N)
      IF(IFILT .EQ. 1)CALL FILTER(N,DATA)
      ISTRT=EP1-1
C
C                   EXTRACT DATA TO BE ANALYSED AND PUT
C                   INTO TRDAT.
C
      L1=0
      DO 135 I=1,N1,SSR
      L1=L1+1
  135 TRDAT(L1)=DATA(I+ISTRT)
C
C                   TAPER THE DATA.
C
      CALL TAPER2(TRDAT,NP)
      DO 136 I=1,TDLEN
      TDATA(I)=CMPLX(0.,0.)
  136 IF(I .LE. NP)TDATA(I)=CMPLX(TRDAT(I),0.)
C
C                   CALL FFT SUBROUTINE
C
  151 CALL NLOGN(LGTDLN,TDATA,-1.)
      DO 160 IHAR=1,6      /* STUDY HARMONICS 1-6
C
C                   NOT INTERESTED IN DC TERM
C                   I.E. TDATA(1)
C
  160 S1(IHAR,IC)=TDATA(IHAR+1)*2./FLOAT(NP)
  640 CONTINUE
      CALL PHASR1(S1,MBAT,SF,SAMRAT,FNAME,LAB1,IDEV)
      CALL PHASR1(S1,MBAT,SF,SAMRAT,FNAME,LAB1,-1)
      IF(IDEV .EQ. 0 .OR. IDEV .EQ. 2)CALL T1IN(IXYZ)
      DO 1650 IHAR=1,6
      DO 1630 K=1,MBAT
      ANGLE(K)=ATAN2(AIMAG(S1(IHAR,K)),REAL(S1(IHAR,K)))
      RAD(K)=CABS(S1(IHAR,K))
 1630 CONTINUE
C
C                   NOW DO THE STATISTICAL TESTS.
C
      WRITE(1,1635)IHAR
 1635 FORMAT(20X,'ANGULAR STATISTICS FOR POST-STIMULUS CNV HARMONIC',
     +I3,//)
      CALL RSTAT1(RAD,MBAT)
      CALL ASTAT1(ANGLE,MBAT)
      CALL ASTAT2(ANGLE,MBAT)
      CALL VSTAT1(ANGLE,RAD,MBAT)
      CALL VSTAT3(ANGLE,RAD,MBAT)
      CALL VSTAT2(ANGLE,RAD,MBAT)
      WRITE(1,1640)
 1640 FORMAT(////)
 1650 CONTINUE
```

```
1900 CALL CLOSSA(1)
     CALL EXIT
     END
```

```
C               PHASOR DIAGRAM ANALYSIS OF 1 SECOND ISI CNV
C                     (PRE- AND POST-STIMULUS)
C               ----------------------------------------------
C
C
C
C               INPUT FILES: DATA
C               OUTPUT FILES: NONE
C
$INSERT SYSCOM>A$KEYS
C
        REAL DATA(1024)
        COMPLEX TDATA(64),PRES1(6,32),S1(6,32)   /* 6 HARS., 32 TRIALS
        DIMENSION TRDAT(64),ANGLE(32),RAD(32),RADDIF(6,32)
        INTEGER*2 FNAME(20),CHANAN,BATNRS(32),SSR,DEL,BLINE
        INTEGER*2 TDLEN,BATNO
        INTEGER*2 LAB1(40),PRES,POSS,ODEV
        COMMON ODEV
        DATA ODEV / 99 /
        PI=3.14159265
        N=1024
    4   WRITE(1,5)
    5   FORMAT('TEKTRONIX(0) OR CALCOMP(1)')
        READ(1,*,ERR=4)IDEV
        CALL GETNAM(FNAME)
        CHANAN=4
   28   WRITE(1,30)
   30   FORMAT('PERFORM EYE MOVEMENT CORRECTIONS')
        READ(1,*,ERR=28)ECORR
   32   WRITE(1,35)
   35   FORMAT('PERFORM BASELINE CORRECTIONS')
        READ(1,*,ERR=32)BLINE
   40   WRITE(1,45)
   45   FORMAT('FILTER')
        READ(1,*,ERR=40)IFILT
   48   WRITE(1,50)
   50   FORMAT('MULTIPLICATION FACTOR')
        READ(1,*,ERR=48)SF
        SF=SF*1.5E6
        CALL BATNOS(BATNRS,MBAT)
        TDLEN=64
        ITL=TDLEN/2 + 1
        LGTDLN=6
        NP=64
        SSR=1
        N1=NP*SSR
C
C               THESE PARAMETERS ARE GOVERNED
C               BY THE CNV PARADIGM
C               IS1 IS THE S1 STIMULUS
C               IS2 IS THE S2 STIMULUS
C               PRES IS THE START OF THE PRE. STIM. DATA TO BE ANALYSED.
C               POSS IS THE START OF THE POST STIM. DATA TO BE ANALYSED.
C               ALL VALUES ARE IN TERMS OF 'SAMPLE NUMBER' 1  N  1024
C
        PRES=1
        POSS=472
        IS1=407
        IS2=532
        DEL=125
        CALL FILL$A(LAB1,80,' ')
        ENCODE(71,52,LAB1)TDLEN,NP,SSR,PRES,POSS,CHANAN,BLINE
   52   FORMAT(I3,' PT,FFT,',I3,' DATA PTS, SSR= ',I2,' PRE =',I3,
       +', POST =',I3,' CH',I2,4X,' B. LINE=',I2)
C
C               NOW THE ITERATIVE BIT
C
        DO 640 IC=1,MBAT
        BATNO=BATNRS(IC)
   54   WRITE(1,55)BATNO
   55   FORMAT('PROCESSING BATCH ',I4)
        CALL EYECOR(FNAME,BATNO,CHANAN-3,DATA,SF1,SF2,SAMRAT,ECORR)
        IF(BLINE .EQ. 1)CALL BASLNE(DATA,N,1,IS1,IS2+DEL,N)
        IF(IFILT .EQ. 1)CALL FILTER(N,DATA)
C
C               PRE STIMULUS
        ISTRT=PRES-1
        L1=0
        DO 135 I=1,N1,SSR
        L1=L1+1
```

```
  135 TRDAT(L1)=DATA(I+ISTRT)
      CALL TAPER2(TRDAT,NP)
      DO 136 I=1,TDLEN
      TDATA(I)=CMPLX(0.,0.)
  136 IF(I .LE. NP)TDATA(I)=CMPLX(TRDAT(I),0.)
  151 CALL NLOGN(LGTDLN,TDATA,-1.)
      DO 160 IHAR=1,6      /* STUDY HARMONICS 1-6
  160 PRES1(IHAR,IC)=TDATA(IHAR+1)*2./FLOAT(NP)
C
C                       POST STIMULUS
      ISTRT=POSS-1
      L1=0
      DO 200 I=1,N1,SSR
      L1=L1+1
  200 TRDAT(L1)=DATA(I+ISTRT)
      CALL TAPER2(TRDAT,NP)
      DO 220 I=1,TDLEN
      TDATA(I)=CMPLX(0.,0.)
  220 IF(I .LE. NP)TDATA(I)=CMPLX(TRDAT(I),0.)
      CALL NLOGN(LGTDLN,TDATA,-1.)
      DO 230 IHAR=1,6
  230 S1(IHAR,IC)=TDATA(IHAR+1)*2./FLOAT(NP)
  640 CONTINUE
      CALL PHASOR(PRES1,S1,MBAT,SF,SAMRAT,FNAME,LAB1,IDEV)
      CALL PHASOR(PRES1,S1,MBAT,SF,SAMRAT,FNAME,LAB1,-1)
      IF(IDEV .EQ. 0)CALL T1IN(IXYZ)
      DO 1650 IHAR=1,6
      DO 1600 K=1,MBAT
      ANGLE(K)=ATAN2(AIMAG(PRES1(IHAR,K)),REAL(PRES1(IHAR,K)))
      RAD(K)=CABS(PRES1(IHAR,K))
 1600 CONTINUE
      WRITE(1,1610)IHAR
 1610 FORMAT(20X,'ANGULAR STATISTICS FOR PRE-STIMULUS HARMONIC ',I3)
      CALL RSTAT1(RAD,MBAT)
      CALL ASTAT1(ANGLE,MBAT)
      CALL ASTAT2(ANGLE,MBAT)
      CALL VSTAT1(ANGLE,RAD,MBAT)
      CALL VSTAT3(ANGLE,RAD,MBAT)
      CALL VSTAT2(ANGLE,RAD,MBAT)
      WRITE(1,1620)
 1620 FORMAT(/////)
      DO 1630 K=1,MBAT
      ANGLE(K)=ATAN2(AIMAG(S1(IHAR,K)),REAL(S1(IHAR,K)))
      RAD(K)=CABS(S1(IHAR,K))
      RADDIF(IHAR,K)=CABS(S1(IHAR,K))-CABS(PRES1(IHAR,K))
 1630 CONTINUE
      WRITE(1,1635)IHAR
 1635 FORMAT(20X,'ANGULAR STATISTICS FOR POST-STIMULUS HARMONIC ',I3)
      CALL RSTAT1(RAD,MBAT)
      CALL ASTAT1(ANGLE,MBAT)
      CALL ASTAT2(ANGLE,MBAT)
      CALL VSTAT1(ANGLE,RAD,MBAT)
      CALL VSTAT3(ANGLE,RAD,MBAT)
      CALL VSTAT2(ANGLE,RAD,MBAT)
      WRITE(1,1640)
 1640 FORMAT(/////)
 1650 CONTINUE
 1900 CALL CLOS$A(1)
      WRITE(1,2200)
 2200 FORMAT(//,'RESULTS OF A PAIRED T-TEST ON THE PRE-POST RADIUS '
     'LENGTHS',///)
      MBAT1=MBAT-1
      DO 3000 IHAR=1,6
      SUM=0.
      DO 2000 I=1,MBAT
 2000 SUM=SUM+RADDIF(IHAR,I)
      RMEAN=SUM/FLOAT(MBAT)
      SUMSQ=0.
      DO 2100 I=1,MBAT
 2100 SUMSQ=SUMSQ+(RADDIF(IHAR,I)-RMEAN)*(RADDIF(IHAR,I)-RMEAN)
      STDEV=SQRT(SUMSQ/FLOAT(MBAT1))
      TSTAT=RMEAN/(STDEV/SQRT(FLOAT(MBAT)))
      WRITE(1,2210)IHAR,RMEAN,STDEV,TSTAT,MBAT1
 2210 FORMAT('HARMONIC= ',I2,5X,'MEAN= ',E14.8,5X,
     &'ST. DEV= ',E14.8,5X,'T= ',F8.4,5X,'WITH',5X,I3,' DF')
 3000 CONTINUE
      CALL EXIT
      END
```

```
      SUBROUTINE ASTAT1(ANGLE,N)
C
C     THIS SUBROUTINE CALCULATES SUMMARY STATISTICS FOR THE N ANGULAR
C     VALUES (RADIANS) STORED IN ARRAY 'ANGLE'.
C
C     MEAN DIRECTION .... THETA=ATAN(S/C)
C
C          WHERE   C = AVERAGE COSINE VALUE
C                  S = AVERAGE SINE VALUE
C
C     CIRCULAR VARIANCE .... VO=1-SQRT(C*C+S*S)
C
C          VO HAS A VALUE 1 FOR COMPLETE UNIFORMITY ON THE CIRCLE
C                         0 FOR A SET OF IDENTICAL ANGLES
C..................................................................
C
C
C
C     WRITTEN BY TERRY JOHNSON. DEPT. OF MATHS. STATS. & COMPUTING
C     PLYMOUTH POLYTECHNIC.
C
      DIMENSION ANGLE(N)
      DATA PI/3.1415926536/
      C=0
      S=0
      DO 1 I=1,N
      C=C+COS(ANGLE(I))
    1 S=S+SIN(ANGLE(I))
      C=C/N
      S=S/N
      THETA=ATAN2(S,C)
      VO=1-SQRT(C*C+S*S)
      WRITE(1,100) THETA
      THETA=THETA*180/PI
      WRITE(1,102) THETA
      WRITE(1,101) VO
  100 FORMAT(/'MEAN DIRECTION',13X,'= ',F10.5,'  RADIANS')
  101 FORMAT('CIRCULAR VARIANCE',10X,'= ',F10.5)
  102 FORMAT(27X,'= ',F10.5,'   DEGREES')
      RETURN
      END

      SUBROUTINE ASTAT2(ANGLE,N)
C
C     THIS SUBROUTINE TESTS THE N ANGULAR VALUES IN ARRAY 'ANGLE'
C     FOR UNIFORMITY OF DISTRIBUTION ON THE CIRCLE USING THE
C     HODGES-AJNE TEST. THE TEST STATISTIC IS M WHERE M IS THE
C     MINIMUM NUMBER OF OBSERVATIONS FOUND IN ANY SEMI-CIRCLE.
C
C..................................................................
C
C     WRITTEN BY TERRY JOHNSON. DEPT. OF MATHS. STATS. & COMPUTING
C     PLYMOUTH POLYTECHNIC.
C
      DIMENSION ANGLE(N)
      DOUBLE PRECISION S
      DATA PI/3.1415926536/
      M=N
      DO 1 I=1,N
      NR=0
      IF(ANGLE(I).GT.0.0) GO TO 3
      AMIN=ANGLE(I)
      AMAX=AMIN+PI
      DO 2 J=1,N
      IF(ANGLE(J).GT.AMIN.AND.ANGLE(J).LE.AMAX) NR=NR+1
    2 CONTINUE
      GO TO 5
    3 AMAX=ANGLE(I)
      AMIN=AMAX-PI
      DO 4 J=1,N
      IF(ANGLE(J).GE.AMIN.AND.ANGLE(J).LT.AMAX) NR=NR+1
    4 CONTINUE
    5 IF(NR.LT.M) M=NR
      IF(N-NR.LT.M) M=N-NR
    1 CONTINUE
      WRITE(1,100) M
C
C     FOR M LESS THAN (N/3) EXACT SIGNIFICANCE IS GIVEN BY
C
C                        N    (1-N)
C          S = (N-2*M). C .2
```

```
      IF(M.GT.N/3) RETURN
      S=(N-2*M)/(2.0**(N-1))
      IF(M.EQ.0) GO TO 7
      DO 6 I=1,M
    6 S=S*(N+1-I)/I
    7 WRITE(1,101) S
  100 FORMAT(/'HODGES-AJNE TEST STATISTIC = ',I4)
  101 FORMAT('LEVEL OF SIGNIFICANCE     = ',F10.5)
      RETURN
      END

      SUBROUTINE BASLNE(DATA,N,NP1,NP2,NP3,NP4)
C
C            CORRECT THE BASELINE OF A SECTION OF EEG
C            BY AVERAGING BETWEEN NP1&NP2 AND ALSO
C            BETWEEN NP3&NP4. CALCULATE THE DIFFERENCE
C            BETWEEN THE AVERAGES AND SUBTRACT THE
C            APPROPRIATE FRACTION FROM THE DATA.
C            FINALLY ADJUST THE SECTIONS NP1-NP2 AND
C            NP3-NP4 TO HAVE A ZERO MEAN.
C
      INTEGER*2 N,NP1,NP2,NP3,NP4,Z1,Z2
      DIMENSION DATA(N)
      CALL SECTAV(NP1,NP2,DATA,SAV1)
      CALL SECTAV(NP3,NP4,DATA,SAV2)
      GRAD=(SAV2-SAV1)/(FLOAT(NP3-NP2))
      DO 70 I=1,NP2
   70 DATA(I)=DATA(I)-SAV1
      Z1=NP2+1
      DO 72 I=Z1,NP3
   72 DATA(I)=DATA(I)-SAV1-GRAD*(I-NP2)
      Z2=NP3+1
      DO 74 I=Z2,N
   74 DATA(I)=DATA(I)-SAV2
      RETURN
      END

      SUBROUTINE BATNOS(BATS,MAX)
C
C            GET A SEQUENCE OF BATCH NUMBERS
C            FROM THE USER.
C
      INTEGER*2 BATS(32)
      LOGICAL YSNOSA
   10 WRITE(1,20)
   20 FORMAT('HOW MANY BATCHES TO BE PROCESSED')
      READ(1,*,ERR=10)MAX
      IF(MAX .GT. 32 .OR. MAX .LT. 1)GO TO 10
      IF(MAX .EQ. 32)GO TO 100
      ITBAT=0
      I=1
   40 CALL TNOUA('BATCH',5)
      CALL TODEC(ITBAT)
      IF(.NOT. YSNOSA(' TO BE INCLUDED ',16,1))GO TO 50
      BATS(I)=ITBAT
      I=I+1
   50 ITBAT=ITBAT+6
      IF(I .LE. MAX)GO TO 40
      RETURN
  100 DO 120 I=1,MAX
      BATS(I)=(I-1)*6
  120 CONTINUE
      RETURN
      END

      SUBROUTINE DATIN(IBATNO,IDATA,RNAME,SF1,SF2,SAMRAT,CSE)
C
C            THIS SUBROUTINE READS DATA FROM A DATA FILE
C            SPECIFIED BY ARGUMENT RNAME.
C            THE BATCH SPECIFIED IS READ INTO IDATA.
C            THE PROGRAM ALSO RETURNS THE SCALE FACTORS
C            SF1, SF2, AND THE SAMPLE RATE. (SAMRAT)
C            SETTING CSE = -1 CLOSES ANY OPEN FILE AND
C            RETURNS.
C
      LOGICAL CLOSSA,OPENSA
      INTEGER*2 IDATA(1024),ONAME(20),RNAME(20),TITLE(36),NME(6)
      INTEGER*2 RWKEY,NLEN,NLEN2,PRIMNO,NBAT,IBATNO,IAA1(4)
```

```fortran
      LOGICAL NEOPEN,CSE
      DATA NEOPEN /.FALSE./
      RWKEY=1
      PRIMNO=1
      NLEN=40
      NLEN2=NLEN/2
      IF(NEOPEN)GO TO 1300
      IF(CSE)RETURN
  900 IF(.NOT. OPEN$A(RWKEY,RNAME,NLEN,PRIMNO))GO TO 1700
      DO 1000 IC=1,NLEN2
 1000 ONAME(IC)=RNAME(IC)
      NEOPEN=.TRUE.
      READ(5,3000,END=1800,ERR=1900)NME,SF1,SF2
      READ(5,3010,END=1800,ERR=1900)MAXBAT
      READ(5,3020,END=1800,ERR=1900)TITLE
      DO 234 IL=1,4
  234 IAA1(IL)=TITLE(IL+20)
      DECODE (8,236,IAA1)SAMRAT
  236 FORMAT(F8.4)
 1100 READ(5,END=1800,ERR=1900)NBAT
      READ(5,END=1800,ERR=1900)(IDATA(I),I=1,1024)
      IF(NBAT .NE. IBATNO)GO TO 1100
      NBAT=NBAT+1
      RETURN
 1200 IF(.NOT. CLOS$A(PRIMNO))GO TO 1600
      NEOPEN=.FALSE.
      RETURN
 1300 IF(CSE)GO TO 1200
      DO 1400 IC=1,NLEN2
 1400 IF(ONAME(IC) .NE. RNAME(IC))GO TO 1500
      IF(IBATNO .GE. NBAT)GO TO 1100
 1500 IF(CLOS$A(PRIMNO))GO TO 900
 1600 WRITE(1,1610)ONAME
 1610 FORMAT('*** CAN NOT CLOSE FILE ',20A2,' ***')
      STOP 1
 1700 WRITE(1,1710)RNAME
 1710 FORMAT('*** CAN NOT OPEN FILE ',20A2,' ***')
      STOP 2
 1800 WRITE(1,1810)RNAME
 1810 FORMAT('*** END OF FILE ',20A2,' ***')
      STOP 3
 1900 WRITE(1,1910)IBATNO,RNAME
 1910 FORMAT('*** ERROR TRYING TO READ BATCH ',I5,' FROM FILE ',
     +20A2,' ***')
      STOP 4
 3000 FORMAT(6A2,2F8.6)
 3010 FORMAT(I4)
 3020 FORMAT(36A2)
      END


      SUBROUTINE EYECOR(FNAME,BATNO,ICHAN,COR1,SF1,SF2,SAMRAT,ECORR)
C              THIS PROGRAM IS INTENDED TO MINIMISE THE AMOUNT OF
C              E.O.G POWER IN THE E.E.G. IT USES THE MODIFIED
C              QUILTER TECHNIQUE. HORIZONTAL AND VERTICAL COMPONENTS
C              OF BOTH EYES ARE TAKEN INTO CONSIDERATION.
C              THE PROGRAM REMOVES ANY D.C OFFSET ON ANY OF
C              THE INPUT DATA CHANNELS.
      REAL VL(1024),VR(1024),HL(1024),HR(1024),E1(1024),COR1(1024)
      DIMENSION X1(4,5),RM1(4),RHS(4)
      INTEGER*2 BATNO,INP(1024),FNAME(20)
      LOGICAL CSE
      DATA CSE /.FALSE./
      N=1024
C              THE DATA IS ASSUMED TO BE IN THE FOLLOWING
C              ORDER ; VL , VR , HL , HR , M1 , M2
C              M1 OR M2 ARE THE CHANNELS TO BE CORRECTED BY THE
C              MODIFIED QUILTER TECHNIQUE.
C              SF1 FOR EOG DATA. SF2 FOR EEG DATA.
C              CHECK THAT THE BATCH NUMBER IS VALID.
      IF (BATNO .LT. 0 .OR. BATNO .GT. 191)GO TO 2999
      IF(FLOAT(BATNO/6) .NE. FLOAT(BATNO)/6.)GO TO 2999
      L=BATNO
C              READ THE DATA AND CONVERT TO REAL FORMAT.
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 22 I=1,N
   22 VL(I)=FLOAT(INP(I))*SF1*1.E-06
      L=L+1
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 24 I=1,N
   24 VR(I)=FLOAT(INP(I))*SF1*1.E-06
```

```
      L=L+1
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 26 I=1,N
   26 HL(I)=FLOAT(INP(I))*SF1*1.E-06
      L=L+1
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 28 I=1,N
   28 HR(I)=FLOAT(INP(I))*SF1*1.E-06
      L=L+1
C
C                   CHECK WHICH CHANNEL
C                   IS TO BE CORRECTED.
C                   IF CHANNEL 5 INCREMENT L.
C
      IF(ICHAN .GE. 2)L=L+1
      CALL DATIN(L,INP,FNAME,SF1,SF2,SAMRAT,CSE)
      DO 30 I=1,N
   30 E1(I)=FLOAT(INP(I))*SF2*1.E-06
C                   SUBTRACT THE MEAN OF EACH DATA BATCH FROM THE DATA.
      CALL SMEAN(N,E1,E1AV)
      IF(ECORR .NE. 1.)GO TO 1000
      CALL SMEAN(N,VL,VLM)
      CALL SMEAN(N,VR,VRM)
      CALL SMEAN(N,HL,HLM)
      CALL SMEAN(N,HR,HRM)
C                   FORM THE CORRELATION SUMS OF PRODUCTS.
      A=0.
      B=0.
      C=0.
      D=0.
      E=0.
      F=0.
      G=0.
      P=0.
      Q=0.
      R=0.
      S=0.
      T=0.
      U=0.
      V=0.
      DO 100 I=1,N
      A=A+VL(I)*VL(I)
      B=B+VL(I)*VR(I)
      C=C+VL(I)*HL(I)
      D=D+VL(I)*HR(I)
      E=E+VR(I)*VR(I)
      F=F+VR(I)*HL(I)
      G=G+VR(I)*HR(I)
      P=P+HL(I)*HL(I)
      Q=Q+HL(I)*HR(I)
      R=R+HR(I)*HR(I)
      S=S+E1(I)*VL(I)
      T=T+E1(I)*VR(I)
      U=U+E1(I)*HL(I)
      V=V+E1(I)*HR(I)
  100 CONTINUE
      X1(1,1)=A
      X1(1,2)=B
      X1(1,3)=C
      X1(1,4)=D
      X1(2,2)=E
      X1(2,3)=F
      X1(2,4)=G
      X1(3,3)=P
      X1(3,4)=Q
      X1(4,4)=R
      RHS(1)=S
      RHS(2)=T
      RHS(3)=U
      RHS(4)=V
C            SET UP SYMMETRICAL MATRIX.
      X1(2,1)=X1(1,2)
      X1(3,1)=X1(1,3)
      X1(4,1)=X1(1,4)
      X1(3,2)=X1(2,3)
      X1(4,2)=X1(2,4)
      X1(4,3)=X1(3,4)
C            SOLVE THE SIMULTANEOUS EQUATIONS BY THE
C            GAUSS PIVOTAL METHOD.
      CALL GAUSS(4,X1,RHS,RM1)
```

```
C                       APPLY THE CORRECTIONS TO THE DATA.
        DO 220 I=1,N
        COR1(I)=E1(I) - (RM1(1)*VL(I) + RM1(2)*VR(I) + RM1(3)*HL(I)
       1+ RM1(4)*HR(I))
  220 CONTINUE
        RETURN
 1000 DO 1010 I=1,N
 1010 COR1(I)=E1(I)
        RETURN
 2999 WRITE(1,4000)BATNO
 4000 FORMAT(///,' BATCH NUMBER INCORRECT',I6)
        STOP 8
        END

        SUBROUTINE FILTER(NPTS,XT)
C
C                       DIGITAL FILTER THE DATA.
C
        DIMENSION XT(NPTS),DATOUT(1024),H(128)
        REAL H
        LOGICAL GOTEM,OPEN$A,CLOS$A
        INTEGER*2 WTFILE(20),NLEN$A
        DATA GOTEM / .FALSE. /
        IF(GOTEM)GO TO 60
    4 WRITE(1,5)
    5 FORMAT('NAME OF FILTER CO-EFFICIENT FILE')
        READ(1,8,ERR=4)WTFILE
    8 FORMAT(20A2)
        NLEN=NLEN$A(WTFILE,40)
        IF(.NOT. OPEN$A(1,WTFILE,NLEN,2))GO TO 100
        READ(6,10)
   10 FORMAT(/)
        READ(6,15)ICASE
   15 FORMAT(6X,I2)
C                       CASE 1 = ODD LENGTH, SYMMETRICAL
C                       CASE 2 = EVEN LENGTH, SYMMETRICAL
C                       CASE 3 = ODD LENGTH, ANTI-SYMMETRICAL
C                       CASE 4 = EVEN LENGTH, ANTI-SYMMETRICAL
        ISGN=1
        IF(ICASE .EQ. 3 .OR. ICASE .EQ. 4)ISGN=-1
        READ(6,20)N
   20 FORMAT(16X,I4)
        N2=(N+1)/2
        DO 50 I=1,N2
        READ(6,40)H(I)
   40 FORMAT(9X,E15.8)
   50 H(N+1-I)=H(I)*FLOAT(ISGN)
        GOTEM=.TRUE.
        IF(.NOT. CLOS$A(2))GO TO 110
   60 DO 80 I=1,NPTS
        STORE=0.
        IF(N .LT. I)GO TO 70
        STORE=XT(I)
        GO TO 80
   70 DO 75 K=1,N
   75 STORE=STORE + XT(I-K+1)*H(K)
   80 DATOUT(I)=STORE
        DO 85 I=1,NPTS
   85 XT(I)=DATOUT(I)
        RETURN
  100 WRITE(1,105)WTFILE
  105 FORMAT('CANT OPEN FILE',10A2)
        STOP
  110 WRITE(1,115)WTFILE
  115 FORMAT('CANT CLOSE FILE',10A2)
        STOP
        END

        SUBROUTINE GAUSS(K,B,RHS,X)
C                       A SUBROUTINE TO SOLVE SIMULTANEOUS
C                       EQUATIONS BY THE GAUSS PIVOTAL METHOD
        DIMENSION A(7,8),X(K),B(K,K),RHS(K)
        INTEGER*2 Z2,Z3,Z4,Z5,Z6,Z7
C
C                       AUGMENT INPUT MATRICES
C                       AND SAVE INPUT DATA.
C
        DO 12 I=1,K
        DO 10 J=1,K
   10 A(I,J)=B(I,J)
```

```
   12 A(I,K+1)=RHS(I)
      Z2=K-1
      DO 35 I=1,Z2
      L=I
      DO 15 J=I,K
   15 IF(ABS(A(L,I)) .LT. ABS(A(J,I)))L=J
      IF(ABS(A(L,I)) .EQ. 0.)GO TO 60
      IF(L .EQ. 1)GO TO 21
      Z3=K+1
      DO 20 N=I,Z3
      SAVE=A(I,N)
      A(I,N)=A(L,N)
   20 A(L,N)=SAVE
C                        PIVOTAL REDUCTION
   21 Z4=I+1
      DO 35 M=Z4,K
      D=A(M,I)/A(I,I)
      Z5=I+1
      Z6=K+1
      DO 35 J=Z5,Z6
   35 A(M,J)=A(M,J)-D*A(I,J)
C                        BACK SUBSTITUTION
      DO 50 L=1,K
      J=K+1-L
      IF(J .EQ. K)GO TO 45
      Y=A(J,K+1)
      Z7=K-1
      DO 40 M=J,Z7
   40 Y=Y-A(J,M+1)*X(M+1)
      X(J)= Y/A(J,J)
      IF(J .NE. K)GO TO 50
   45 X(J)=A(J,K+1)/A(J,J)
   50 CONTINUE
      RETURN
   60 WRITE(1,65)
   65 FORMAT('   ERROR MESSAGE ZERO COLUMN FOUND')
      STOP
      END

      SUBROUTINE GETNAM(NAME)
C
C              GET A VALID FILENAME FROM THE USER.
C
      INTEGER*2 NAME(20),TBUFF(20),NLEN$A
      LOGICAL EXST$A
      DATA TBUFF /'NONAMEGIVEN                    '/
    6 WRITE(1,8)
    8 FORMAT('GIVE NAME OF FILE TO BE PROCESSED')
      READ(1,10)NAME
   10 FORMAT(20A2)
      IF(NAME(1) .EQ. '  ')GO TO 100
      DO 20 I=1,20
   20 TBUFF(I)=NAME(I)
      GO TO 130
  100 DO 120 I=1,20
  120 NAME(I)=TBUFF(I)
  130 IF(EXST$A(NAME,NLEN$A(NAME,40)))RETURN
      WRITE(1,140)NAME
  140 FORMAT('INVALID OR NON-EXISTANT FILE : ',20A2)
      GO TO 6
      END

      SUBROUTINE NLOGN(N,X,SIGN)
C              THIS PROGRAM PERFORMS THE FFT.
C              N=BASE  2 LOG OF NO. OF POINTS.
C              X= COMPLEX ARRAY OF DATA FOR TRANSFORMATION.
C              SIGN= -1. FOR FFT.
C              SIGN= +1. FOR IFFT.
C              TRANSFORMED DATA IS RETURNED IN X.
C
C              WRITTEN BY E. A. ROBINSON.
C
      DIMENSION M(12)
      COMPLEX WK,HOLD,Q,X(2048)
      LX=2**N
      DO 1 I=1,N
    1 M(I)=2**(N-I)
      DO 4 L=1,N
      NBLOCK=2**(L-1)
      LBLOCK=LX/NBLOCK
```

```
      LBHALF=LBLOCK/2
      K=0
      DO 4 IBLOCK=1,NBLOCK
      FK=K
      FLX=LX
      V=SIGN*6.283185308*FK/FLX
      WK=CMPLX(COS(V),SIN(V))
      ISTART=LBLOCK*(IBLOCK-1)
      DO 2 I=1,LBHALF
      J=ISTART+I
      JH=J+LBHALF
      Q=X(JH)*WK
      X(JH)=X(J)-Q
      X(J)=X(J)+Q
    2 CONTINUE
      DO 3 I=2,N
      II=I
      IF(K.LT.M(I))GO TO 4
    3 K=K-M(I)
    4 K=K+M(II)
      K=0
      DO 7 J=1,LX
      IF(K.LT.J)GO TO 5
      HOLD=X(J)
      X(J)=X(K+1)
      X(K+1)=HOLD
    5 DO 6 I=1,N
      II=I
      IF(K.LT.M(I))GO TO 7
    6 K=K-M(I)
    7 K=K+M(II)
      IF(SIGN.LT.0.)RETURN
      DO 8 I=1,LX
    8 X(I)=X(I)/FLX
      RETURN
      END

      SUBROUTINE PHASOR(PRE,POST,NMAX,SF,SAMRAT,FNAME,ILAB1,DEVICE)
C
C                 PRE- AND POST-STIMULUS PHASOR DIAGRAMS.
C
      COMPLEX PRE(6,64),POST(6,64)
      INTEGER*2 DEVICE,ODEV,ILAB1(40),FNAME(20)
      COMMON ODEV
C                 TEST FOR A VALID DEVICE CODE
C                 CURRENTLY 0=TEKTRONIX
C                           1=CALCOMP 536 VIA 906
C                           2=SIGMA 5670 COLOUR.
      IF(DEVICE .GT. 3)GO TO 999
C
C                 SKIP THE INITIALISATION IF THIS
C                 DEVICE ALREADY BEEN INITIALISED
C
      IF(DEVICE .EQ. ODEV)GO TO 50
      IF(DEVICE .LT. 0)GO TO 600
C
C                 DE-ASSIGN CURRENT DEVICE IF
C                 DIFFERENT DEVICE REQUESTED.
C
      IF(ODEV .NE. 99)CALL DEVEND
C
C                 ASSIGN REQUESTED DEVICE
C
      IF(DEVICE .EQ. 0)CALL T4010
      IF(DEVICE .EQ. 1)CALL CC906
      IF(DEVICE .EQ. 2)CALL S5660
      IF(DEVICE .EQ. 3)CALL CC81
      IBAUD=1200
      CALL DEVSPE(IBAUD)
      IF(DEVICE .EQ. 0)CALL UNITS(1.0)
      IF(DEVICE .EQ. 1)CALL UNITS(1.0)
      IF(DEVICE .EQ. 2)CALL UNITS(1.5)
      IF(DEVICE .EQ. 3)CALL UNITS(0.75)
      ODEV=DEVICE
   50 CALL CHAHAR(1,0)
      XS=46.
      YS=70.
      XD=100.
      CRAD=40.
      CALL WINDO2(0.,250.,0.,200.)
```

```
            CALL WINDOW(1)
            DO 400 IHAR=1,6
            CALL TITLE(FNAME,ILAB1,DEVICE)
C
C                   PRE STIM CIRCLE DIAGRAM OUTLINE.
C
            IF(DEVICE .EQ. 2)CALL PENSEL(6,0.,0)        /* RED
            CALL MOVTO2(XS,YS)
            CALL SYMBOL(7)
            CALL MOVTO2(XS-CRAD,YS)
            CALL ARCTO2(XS,YS,XS-CRAD,YS,0)
C
C                   POST STIM CIRCLE DIAGRAM OUTLINE.
C
            IF(DEVICE .EQ. 2)CALL PENSEL(5,0.,0)        /* BLUE
            CALL MOVTO2(XS+XD,YS)
            CALL SYMBOL(7)
            CALL MOVTO2(XS+XD-CRAD,YS)
            CALL ARCTO2(XS+XD,YS,XS+XD-CRAD,YS,0)
            IF(DEVICE .EQ. 2)CALL PENSEL(7,0.,0)        /* WHITE
            CALL MOVTO2(XS-15.,135.)
            CALL CHAHOL('PRE STIM.*.')
            CALL MOVTO2(XS+XD-15.,135.)
            CALL CHAHOL('POST STIM.*.')
            CALL MOVTO2(XS+XD/2-15.,125.)
            CALL CHAHOL('HARMONIC *.')
            CALL CHAINT(IHAR,2)
C
C                       DRAW PRE STIMULUS DIAGRAM
C                       RADSM=SUM OF RADII.
C                       RADMN=AVERAGE RADII.
C                       RADSTD=STANDARD DEVIATION OF RADII.
C
            RADSM=0.
            RADSMS=0.
            IF(DEVICE .EQ. 2)CALL PENSEL(3,0.,0)        /* GREEN
            DO 250 NTR=1,NMAX
            X=REAL(PRE(IHAR,NTR))
            Y=AIMAG(PRE(IHAR,NTR))
C
C                   CALCULATE SUMS AND SUMS OF SQUARES.
C
            RAD=CABS(PRE(IHAR,NTR))
            RADSM=RADSM+RAD
            RADSMS=RADSMS+RAD*RAD
C
C                   CALCULATE ANGLE.
C
            PHI=ATAN2(Y,X)
            X1=CRAD*COS(PHI)
            Y1=CRAD*SIN(PHI)
C
C                   PUT TRIANGLE ON CIRCLE AT CORRECT ANGLE.
C
            CALL MOVTO2(X1+XS,Y1+YS)
            CALL SYMBOL(1)
C
C                   PUT CROSS AT END OF PHASOR.
C
            CALL MOVTO2(SF*X+XS,SF*Y+YS)
        250 CALL SYMBOL(3)
            IF(DEVICE .EQ. 2)CALL PENSEL(7,0.,0)        /* WHITE
C
C                   CALCULATE STATISTICS.
C
            RADMN=RADSM/FLOAT(NMAX)
            RADSTD=SQRT((RADSMS-RADSM*RADSM/FLOAT(NMAX))/FLOAT(NMAX-1))
C
C                   PUT RESULTS ON GRAPH.
C
            CALL MOVTO2(10.,10.)
            CALL CHAHOL('AV. RAD= *.')
            CALL MOVTO2(40.,10.)
            CALL CHAFLO(RADMN,10)
            CALL MOVTO2(10.,4.)
            CALL CHAHOL('ST. DEV= *.')
            CALL MOVTO2(40.,4.)
            CALL CHAFLO(RADSTD,10)
C
C                   DRAW POST STIMULUS DIAGRAM
```

```
C
      RADSM=0.
      RADSMS=0.
      IF(DEVICE .EQ. 2)CALL PENSEL(2,0.,0)        /* YELLOW
      DO 300 NTR=1,NMAX
      X=REAL(POST(IHAR,NTR))
      Y=AIMAG(POST(IHAR,NTR))
      RAD=CABS(POST(IHAR,NTR))
      RADSM=RADSM+RAD
      RADSMS=RADSMS+RAD*RAD
      PHI=ATAN2(Y,X)
      X1=CRAD*COS(PHI)
      Y1=CRAD*SIN(PHI)
      CALL MOVTO2(X1+XS+XD,Y1+YS)
      CALL SYMBOL(1)
      CALL MOVTO2(SF*X+XS+XD,SF*Y+YS)
  300 CALL SYMBOL(4)
      IF(DEVICE .EQ. 2)CALL PENSEL(7,0.,0)        /* WHITE
      RADMN=RADSM/FLOAT(NMAX)
      RADSTD=SQRT((RADSMS-RADSM*RADSM/FLOAT(NMAX))/FLOAT(NMAX-1))
      CALL MOVTO2(108.,10.)
      CALL CHAHOL('AV. RAD= *.')
      CALL MOVTO2(138.,10.)
      CALL CHAFLO(RADMN,10)
      CALL MOVTO2(108.,4.)
      CALL CHAHOL('ST. DEV= *.')
      CALL MOVTO2(138.,4.)
      CALL CHAFLO(RADSTD,10)
      CALL MOVTO2(0.,180.)
      CALL CHAMOD
      IF(DEVICE .EQ. 0 .OR. DEVICE .EQ. 2)CALL T1IN(IXYZ)
  400 CONTINUE
      ODEV=DEVICE
      RETURN
  600 ODEV=99
      CALL DEVEND
      RETURN
  999 WRITE(1,1000)DEVICE
 1000 FORMAT('INVALID PLOTTING DEVICE CODE',I5)
      STOP 1
      END

      SUBROUTINE PHASR1(DATA,NMAX,SF,SAMRAT,FNAME,ILAB1,DEVICE)
C
C              SINGLE PHASOR DIAGRAM
C
      COMPLEX DATA(6,32)
      INTEGER*2 DEVICE,ODEV,ILAB1(40),FNAME(20)
      COMMON ODEV
C              TEST FOR A VALID DEVICE CODE
C              CURRENTLY 0=TEKTRONIX
C                        1=CALCOMP 536 VIA 906
C                        2=SIGMA 5670 COLOUR.
      IF(DEVICE .GT. 2)GO TO 999
C
C              SKIP THE INITIALISATION IF THIS
C              DEVICE ALREADY BEEN INITIALISED
C
      IF(DEVICE .EQ. ODEV)GO TO 50
      IF(DEVICE .LT. 0)GO TO 600
C
C              DE-ASSIGN CURRENT DEVICE IF
C              DIFFERENT DEVICE REQUESTED.
C
      IF(ODEV .NE. 99)CALL DEVEND
C
C              ASSIGN REQUESTED DEVICE
C
      IF(DEVICE .EQ. 0)CALL T4010
      IF(DEVICE .EQ. 1)CALL CC906
      IF(DEVICE .EQ. 2)CALL S5660
      IBAUD=1200
      CALL DEVSPE(IBAUD)
      IF(DEVICE .EQ. 0)CALL UNITS(1.0)
      IF(DEVICE .EQ. 1)CALL UNITS(1.0)
      IF(DEVICE .EQ. 2)CALL UNITS(1.5)
      ODEV=DEVICE
   50 CALL CHAHAR(1,0)
      XS=100.
      YS=70.
```

```
      CRAD=50.
      CALL WINDO2(0.,250.,0.,200.)
      CALL WINDOW(1)
      DO 400 IHAR=1,6
      CALL TITLE(FNAME,ILAB1,DEVICE)
      CALL MOVTO2(XS,YS)
      CALL SYMBOL(7)
      CALL MOVTO2(XS-CRAD,YS)
      CALL ARCTO2(XS,YS,XS-CRAD,YS,0)
      CALL MOVTO2(XS-15.,145.)
      CALL CHAHOL('CNV DATA.*.')
      CALL MOVTO2(XS-15.,135.)
      CALL CHAHOL('HARMONIC *.')
      CALL CHAINT(IHAR,2)
C
C                 DRAW PHASOR DIAGRAM
C                 RADSM=SUM OF RADII.
C                 RADMN=AVERAGE RADII.
C                 RADSTD=STANDARD DEVIATION OF RADII.
C
      RADSM=0.
      RADSMS=0.
      DO 250 NTR=1,NMAX
      X=REAL(DATA(IHAR,NTR))
      Y=AIMAG(DATA(IHAR,NTR))
C
C           CALCULATE SUMS AND SUMS OF SQUARES.
C
      RAD=CABS(DATA(IHAR,NTR))
      RADSM=RADSM+RAD
      RADSMS=RADSMS+RAD*RAD
C
C           CALCULATE ANGLE.
C
      PHI=ATAN2(Y,X)
      X1=CRAD*COS(PHI)
      Y1=CRAD*SIN(PHI)
C
C            PUT TRIANGLE ON CIRCLE AT CORRECT ANGLE.
C
      CALL MOVTO2(X1+XS,Y1+YS)
      CALL SYMBOL(1)
C
C            PUT CROSS AT END OF PHASOR.
C
      CALL MOVTO2(SF*X+XS,SF*Y+YS)
  250 CALL SYMBOL(3)
C
C            CALCULATE STATISTICS.
C
      RADMN=RADSM/FLOAT(NMAX)
      RADSTD=SQRT((RADSMS-RADSM*RADSM/FLOAT(NMAX))/FLOAT(NMAX-1))
C
C            PUT RESULTS ON GRAPH.
C
      CALL MOVTO2(30.,10.)
      CALL CHAHOL('AV. RAD= *.')
      CALL MOVTO2(70.,10.)
      CALL CHAFLO(RADMN,10)
      CALL MOVTO2(30.,4.)
      CALL CHAHOL('ST. DEV= *.')
      CALL MOVTO2(70.,4.)
      CALL CHAFLO(RADSTD,10)
      CALL MOVTO2(0.,180.)
      CALL CHAMOD
      IF(DEVICE .EQ. 0)CALL T1IN(IXYZ)
  400 CONTINUE
      ODEV=DEVICE
      RETURN
  600 ODEV=99
      CALL DEVEND
      RETURN
  999 WRITE(1,1000)DEVICE
 1000 FORMAT('INVALID PLOTTING DEVICE CODE',I5)
      STOP 1
      END

      SUBROUTINE RSTAT1(RAD,N)
C
C                 CALCULATE MEAN AND SD OF RADIUS LENGTHS.
```

```fortran
C
      DIMENSION RAD(N)
      SUM=0.
      SUMSQ=0.
      DO 10 I=1,N
      SUM=SUM+RAD(I)
      SUMSQ=SUMSQ+RAD(I)*RAD(I)
   10 CONTINUE
      RADMN=SUM/FLOAT(N)
      RADSTD=SQRT((SUMSQ-SUM*SUM/FLOAT(N))/FLOAT(N-1))
      WRITE(1,20)RADMN,RADSTD
   20 FORMAT(/,'MEAN RADIUS LENGTH',9X,'= ',E11.4,
     +/,'STANDARD DEV. OF RADIUS',4X,'= ',E11.4)
      RETURN
      END

      SUBROUTINE SECTAV(N1,N2,A,AV)
C
C             FIND THE MEAN VALUE OF THE DATA
C             BETWEEN POINTS N1 AND N2.
C
      DIMENSION A(1024)
      AV=0.
      DO 10 I=N1,N2
   10 AV=AV+A(I)
      AV=AV/FLOAT(N2-N1)
      RETURN
      END

      SUBROUTINE SMEAN(NPTS,DATA,RMEAN)
C
C             REMOVE THE MEAN VALUE FROM THE DATA.
C
      DIMENSION DATA(NPTS)
      RMEAN=0.
      DO 20 I=1,NPTS
   20 RMEAN=RMEAN+DATA(I)
      RMEAN=RMEAN/NPTS
      DO 30 I=1,NPTS
   30 DATA(I)=DATA(I)-RMEAN
      RETURN
      END

      SUBROUTINE SSQRE(N,DATA,SUMSQ)
C
C             CALCULATE THE SUMS OF THE SQUARES
C             OF THE SIGNAL AND DIVIDE BY THE
C             NUMBER OF POINTS.
C
      DIMENSION DATA(N)
      SUMSQ=0.
      DO 200 I=1,N
  200 SUMSQ=SUMSQ + (DATA(I))*(DATA(I))
      SUMSQ=SUMSQ/FLOAT(N)
      RETURN
      END

      SUBROUTINE STDMN(N,DATA,MEAN,STDEV)
C
C             CALCULATE THE MEAN AND SD.
C
      REAL MEAN
      DIMENSION DATA(N)
      SUM=0.
      DO 100 I=1,N
  100 SUM=SUM + DATA(I)
      MEAN=SUM/FLOAT(N)
      SUM=0.
      DO 200 I=1,N
  200 SUM=SUM + (DATA(I) - MEAN)*(DATA(I) - MEAN)
      STDEV=SQRT(SUM/FLOAT(N-1))
      RETURN
      END

      SUBROUTINE TAPER2(X,N)
C
C     TAPERS ARRAY X AND SUBTRACTS MEAN
C
      DIMENSION X(N)
      DOUBLE PRECISION SUM1,SUM2,SUM3
```

```
C
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      DO 1 I=1,N
      W=WINDY(I,N)
      SUM1=SUM1+W
      SUM3=SUM3+W*W
   1  SUM2=SUM2+W*X(I)
      SUM2=SUM2/SUM1
      SUM3=SQRT(N/SUM3)
      DO 2 I=1,N
   2  X(I)=(X(I)-SUM2)*SUM3*WINDY(I,N)
      RETURN
      END

      FUNCTION WINDY(J,N1)
      PARAMETER (PI=3.1415926536)
      TL=0.125
      AN=FLOAT(N1)
      AN1=AN-1
C
C              TL IS THE TAPER LENGTH ( PER UNIT )
C
      NTL=IFIX(TL*AN + 0.5)
      WINDY=1.0
      AJ=J-0.5
      IF(J .GE. NTL .AND. J .LE. (N1-NTL))RETURN
      WINDY=(1. - COS(PI*AJ/(AN1*TL)))/2.
      IF(J .GT. (N1-NTL))
     +WINDY=(1. + COS(PI*(AJ+NTL-AN1)/(AN1*TL)))/2.
      RETURN
      END

      SUBROUTINE TITLE(FNAME,GENINF,DEVICE)
C
C              PUTS A TITLE AND FILENAME ON A GRAPH.
C
      INTEGER*2 FNAME(20),GENINF(40),ODEV,DEVICE,NLEN$A,GL
      COMMON ODEV
C
C              TEST FOR A VALID DEVICE CODE
C              CURRENTLY 0=TEKTRONIX
C                        1=CALCOMP 536 VIA 906
C                        2=SIGMA 5660 (5670)
C                        3=CALCOMP 81
C
      IF(DEVICE .GT. 3)GO TO 999
C
C              SKIP THE INITIALISATION IF THIS
C              DEVICE ALREADY BEEN INITIALISED
C
      IF(DEVICE .EQ. ODEV)GO TO 50
      IF(DEVICE .LT. 0)GO TO 200
C
C              DE-ASSIGN CURRENT DEVICE IF
C              DIFFERENT DEVICE REQUESTED.
C
      IF(ODEV .NE. 99)CALL DEVEND
C
C              ASSIGN REQUESTED DEVICE
C
      IF(DEVICE .EQ. 0)CALL T4010
      IF(DEVICE .EQ. 1)CALL CC906
      IF(DEVICE .EQ. 2)CALL S5660
      IF(DEVICE .EQ. 3)CALL CC81
      IBAUD=1200
      CALL DEVSPE(IBAUD)
      IF(DEVICE .EQ. 0)CALL UNITS(1.0)
      IF(DEVICE .EQ. 1)CALL UNITS(1.0)
      IF(DEVICE .EQ. 2)CALL UNITS(1.5)
      IF(DEVICE .EQ. 3)CALL UNITS(0.75)
   50 CALL PICCLE
      CALL WINDO2(0.,240.,0.,185.)
      CALL WINDOW(1)
      CALL MOVTO2(80.,180.)
      CALL CHAHAR(1,0)
      CALL CHAHOL('DATA FILE: *.')
      NL=IFIX(FLOAT(NLEN$A(FNAME,40))/2. + 0.5)
      CALL CHAARR(FNAME,NL,2)
```

```
        CALL MOVTO2(0.,174.)
        GL=IFIX(FLOAT(NLEN$A(GENINF,80))/2. + 0.5)
        CALL CHAARR(GENINF,GL,2)
        CALL MOVTO2(0.,170.)
        CALL CHAMOD
        ODEV=DEVICE
        RETURN
  200   ODEV=99
        CALL DEVEND
        RETURN
  999   WRITE(1,1000)DEVICE
 1000   FORMAT('INVALID PLOTTING DEVICE CODE ',I5)
        STOP 1
        END

        SUBROUTINE VSTAT1(ANGLE,RAD,N)
C
C  THIS SUBROUTINE CALCULATES SUMMARY STATISTICS FOR THE N VECTORS
C  WHOSE DIRECTIONS ARE STORED IN ARRAY 'ANGLE' AND WHOSE MAGNITUDES
C  ARE STORED IN ARRAY 'RAD'.
C
C  RESULTANT DIRECTION  ....  THETA=ATAN(S/C)
C
C            WHERE    S = WEIGHTED AVERAGE OF SINE VALUES
C                     C = WEIGHTED AVERAGE OF COSINE VALUES
C            AND THE WEIGHTING FACTORS ARE THE VECTOR MAGNITUDES.
C
C  DISPERSION FACTOR  ....  UO=1-SQRT(S*S+C*C)
C
C            UO HAS VALUE 1 FOR A ZERO MAGNITUDE RESULTANT VECTOR
C                         0 FOR A SET OF ALIGNED VECTORS
C
C
C
C
C  WRITTEN BY TERRY JOHNSON. DEPT. OF MATHS. STATS. & COMPUTING
C  PLYMOUTH POLYTECHNIC.
C
        DIMENSION ANGLE(N),RAD(N)
        DATA PI/3.1415926536/
        C=0
        S=0
        SUMRAD=0.0
        DO 1 I=1,N
        SUMRAD=SUMRAD+RAD(I)
        C=C+RAD(I)*COS(ANGLE(I))
    1   S=S+RAD(I)*SIN(ANGLE(I))
        C=C/SUMRAD
        S=S/SUMRAD
        THETA=ATAN2(S,C)
        UO=1-SQRT(S*S+C*C)
        WRITE(1,100) THETA
        THETA=THETA*180/PI
        WRITE(1,101) THETA
        WRITE(1,102) UO
  100   FORMAT(/'RESULTANT DIRECTION',8X,'= ',F10.5,'  RADIANS')
  101   FORMAT(27X,'= ',F10.5,'  DEGREES')
  102   FORMAT('DISPERSION FACTOR',10X,'= ',F10.5)
        RETURN
        END

        SUBROUTINE VSTAT2(ANGLE,RAD,N)
C
C  THIS SUBROUTINE EXAMINES THE N VECTORS WHOSE DIRECTIONS ARE STORED
C  IN ARRAY ANGLE AND WHOSE MAGNITUDES ARE STORED IN ARRAY RAD. THE
C  PROGRAM IDENTIFIES THE (N/2) VECTORS WHICH LIE IN THE SMALLEST ARC
C  AND COMPARES THE AVERAGE LENGTH OF THESE VECTORS WITH THE AVERAGE
C  LENGTH OF THE REMAINING VECTORS. COMPARISON IS MADE BY A T-TEST
C  WITH AN APPROXIMATE CORRECTION FOR (POSSIBLE) UNEQUAL VARIANCES.
C
C
C
C  WRITTEN BY TERRY JOHNSON. DEPT. OF MATHS. STATS. & COMPUTING
C  PLYMOUTH POLYTECHNIC.
C
        DIMENSION ANGLE(N),RAD(N),TEMP(100)
        DOUBLE PRECISION SUM11,SUM12,SUM21,SUM22
        DATA PI/3.1415926536/
C
C  STORES ANGLES IN A TEMPORARY ARRAY AND ARRANGES IN ASCENDING
C  ORDER USING A BUBBLE SORT.
```

```fortran
C
      DO 1 I=1,N
    1 TEMP(I)=ANGLE(I)
      DO 2 I=2,N
      MAX=1
      AMAX=TEMP(1)
      NMAX=N-I+2
      DO 3 J=2,NMAX
      IF(TEMP(J).LE.AMAX) GO TO 3
      AMAX=TEMP(J)
      MAX=J
    3 CONTINUE
      TEMP(MAX)=TEMP(NMAX)
    2 TEMP(NMAX)=AMAX
C
C     FIND THE (N/2) VALUES LYING IN THE SMALLEST ARC.
C
      N2=N/2
      DMIN=TEMP(N2)-TEMP(1)
      AMIN=TEMP(1)
      AMAX=TEMP(N2)
      DO 4 I=2,N
      IU=I+N2-1
      IF(IU .LE. N)UPPER=TEMP(IU)
      IF(IU .GT. N)UPPER=TEMP(IU-N)+2.*PI
      IF((UPPER-TEMP(I)) .GE. DMIN)GO TO 4
      DMIN=UPPER-TEMP(I)
      AMIN=TEMP(I)
      AMAX=UPPER
    4 CONTINUE
C
C     CALCULATES MEAN AND VARIANCE FOR BOTH SETS OF DATA
C
      SUM11=0.0
      SUM12=0.0
      SUM21=0.0
      SUM22=0.0
      N2=0
      N21=0
      CONST=0.
      IF(AMAX.GT.PI) CONST=2*PI
      DO 5 I=1,N
      A=ANGLE(I)
      IF(A .LT. 0.)A=A+CONST
      IF(A .LT. AMIN .OR. A .GT. AMAX)GO TO 6
      N2=N2+1
      SUM11=SUM11+RAD(I)
      SUM12=SUM12+RAD(I)*RAD(I)
      GO TO 5
    6 SUM21=SUM21+RAD(I)
      N21=N21+1
      SUM22=SUM22+RAD(I)*RAD(I)
    5 CONTINUE
      SUM11=SUM11/N2
      SUM21=SUM21/N21
      SUM12=(SUM12/N2-SUM11*SUM11)/(N2-1)
      SUM22=(SUM22/N21-SUM21*SUM21)/(N21-1)
C
C     CALCULATES T-STATISTIC AND OUTPUTS RESULTS
C
      TSTAT=SNGL((SUM11-SUM21)/DSQRT(SUM12+SUM22))
      DF=(SUM12+SUM22)*(SUM12+SUM22)
      DF=DF/(SUM12*SUM12/(N2+1)+SUM22*SUM22/(N21+1))-2
      SUM12=DSQRT(SUM12*N2)
      SUM22=DSQRT(SUM22*N21)
      WRITE(1,100)N2,SUM11,SUM12
      WRITE(1,101)N21,SUM21,SUM22
      WRITE(1,102)TSTAT,DF
  100 FORMAT(/'MEAN AND S.D. OF LENGTHS OF THE',I4,' CLOSEST '
     +'VECTORS   = ',E16.8,E16.8)
  101 FORMAT('MEAN AND S.D. OF LENGTHS OF THE',I4,' REMAINING '
     +'VECTORS =',E16.8,E16.8)
  102 FORMAT(/'T-STATISTIC =',F10.5,' WITH ',F6.1,
     +'   DEGREES OF FREEDOM')
      RETURN
      END

      SUBROUTINE VSTAT3(ANGLE,RAD,N)
C
C THIS SUBROUTINE CALCULATES A 'MODIFIED DISPERSION' STATISTIC FOR
```

```
C     'N' VECTORS WHOSE DIRECTIONS ARE STORED IN ARRAY 'ANGLE' AND WHOSE
C     MAGNITUDES ARE STORED IN ARRAY 'RAD'.
C
C     MODIFIED DISPERSION FACTOR ....   UM=1-SQRT(S*S+C*C)
C
C     WHERE    S= WEIGHTED AVERAGE OF SINE VALUES
C              C= WEIGHTED AVERAGE OF COSINE VALUES
C
C     AND THE WEIGHTING FACTORS ARE THE RANK ORDERS OF THE VECTORS
C
C     UM HAS VALUE 1 FOR A ZERO MAGINTUDE RESULTANT VECTOR
C                  0 FOR A SET OF ALIGNED VECTORS
C
C.....................................................................
C
C     WRITTEN BY TERRY JOHNSON. DEPT. OF MATHS. STATS. & COMPUTING
C     PLYMOUTH POLYTECHNIC.
C
      DIMENSION ANGLE(N),RAD(N),TEMPA(100),TEMPR(100)
      DO 1 I=1,N
      TEMPA(I)=ANGLE(I)
    1 TEMPR(I)=RAD(I)
      C=0.0
      S=0.0
      DO 2 I=2,N
      MAX=1
      AMAX=TEMPR(1)
      NMAX=N-I+2
      DO 3 J=2,NMAX
      IF (TEMPR(J).LE.AMAX) GO TO 3
      AMAX=TEMPR(J)
      MAX=J
    3 CONTINUE
      C=C+NMAX*COS(TEMPA(MAX))
      S=S+NMAX*SIN(TEMPA(MAX))
      TEMPR(MAX)=TEMPR(NMAX)
    2 TEMPA(MAX)=TEMPA(NMAX)
      C=C+COS(TEMPA(1))
      S=S+SIN(TEMPA(1))
      SUMN=N*(N+1)/2
      C=C/SUMN
      S=S/SUMN
      UM=1.0-SQRT(S*S+C*C)
      WRITE(1,100) UM
  100 FORMAT(/'MODIFIED DISPERSION FACTOR = ',F10.5)
      RETURN
      END
```