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TITLE	OLFFT1 AND FETCHFFT
AUTHOR	R. Cooper, P. V. Pocock, W. J. Warren
COMPANY	Burden Neurological Institute Stapleton, Bristol, England
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ON-LINE FREQUENCY ANALYSIS OF NEUROPHYSIOLOGICAL DATA

USING A PDP 12 COMPUTER

Comprising:-

OLFFT1 - **A program for the transformation of one to four channels of data into their power spectra.**

FETCHFFT - **A program for displaying and plotting spectra stored by OLFFT1.**

Ray Cooper

P. V. Pocock

W. J. Warren

Burden Neurological Institute

Stapleton

Bristol

England.

Minimum hardware requirements:

PDP 12 with 8K memory
KW 12A real time clock
A/D converters

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ON-LINE FREQUENCY ANALYSIS OF NEUROPHYSIOLOGICAL DATA.

Introduction

The electroencephalogram (EEG) is a series of waveform traces of the electrical activity of the brain. The frequency range of this polyrhythmic activity is from DC to about 60 Hz and the amplitude about 50 uv although the output of the EEG amplifiers is usually about 1 volt.

It is often valuable to observe the presence or otherwise of specific rhythms in the EEG and therefore to separate the waveforms into their constituent frequency components. This can be achieved by the Fourier Transform, the power spectra thus produced being histograms of the relative proportion of activity of different frequencies.

In practise it is often valuable for this frequency analysis to be done 'on-line', that is, during the collection of the data. One reason for this is that in some instances only the power spectra are needed and can be stored in less space than the original data. A second reason is that immediate information about the rhythmic activity can assist the experimenter to direct the course of the experiment.

Even using a modern computer, the ordinary Fourier Transform takes far too long but the development of the Fast Fourier Transform (FFT) by Cooley and Tukey makes 'on-line' analysis possible. The advantages of speed of the FFT are counterbalanced by the large amount of memory core it requires. This limits the number of channels to four for an 8K core.

OLFFT1 program

OLFFT1 is a DIAL program developed to transform up to four channels of EEG (or any other continuous) data 'on-line' and store the resultant power spectra on DEC magnetic tape. The FFT sub-routine is based on a program written by C. Molnar of Washington University. OLFFT1 is written for a PDP 12 with 8K memory and KW12 'real-time' clock.

A second program, FETCHFFT, was developed to retrieve the stored spectra for further inspection and analysis.

Basic Operation (see Fig. 1 and 2)

Four channels of the EEG recorder are linked directly to the analogue/digital converters of the computer and any number of these four can be selected for analysis. Although the input waveforms are continuous the analysis is performed on sections of record which can be consecutive. The program hence has two modes of operation, continuous (Fig.1) and non-continuous (Fig.2). These sections of the input signal are of 2 or 4 seconds duration and referred to as epochs.

A KW12 clock is used to sample analogue lines 10 through 13 at such a rate that 256 points of data are collected (on each channel) in 2 or 4 seconds as selected in an input question and answer routine (Fig.3).

The incoming data samples are stored (in location A, referred to in Figs.1 and 2 and p.6) according to a bit reversal table and interleaved with zeros for the imaginary values thus making 512 "data" points for each channel. After an initial period of 2 or 4 seconds according to the epoch selected the incoming data are diverted to different memory locations (referred to as B in Figs.1 and 2 and p.6) and the Fast Fourier Transform proceeds on the data already collected, taking each channel in turn. The sine and cosine components so acquired are squared and stored as double precision (22 bits) numbers in memory core. After the second set of data (2 or 4 seconds later) has been collected the incoming data are now diverted back to the first memory locations (A) and the FFT is done on the second set of data. These new squared values are added to the previous values to give a summated power spectra over two sets of data (total of 4 or 8 seconds of time). An option on the input of the program (Fig.3) permits a choice of the number of pairs of sets (maximum 4) of data to be summated. If 2 pairs have been chosen the procedure outlined above will be repeated once more making a total analysis time of 8 or 16 seconds.

Figures 1 and 2 show the operational sequence in the case of a 2 second epoch and 2 pairs for each mode.

The spectra so formed are composed of 128 components representing the DC level, the fundamental (that wave whose period is the length of the epoch (2 or 4 seconds)) and 126 harmonics (waves whose frequencies are 2, 3, 4 etc. times that of the fundamental). The mean level of the analogue input signal appearing as the first (0 Hz) component of the spectrum, can often be so large that it swamps other components. This results in a reduction of the information obtained and is overcome in the program by subtracting the mean (DC) value of each epoch from the data before analysis.

The choice of epoch determines the discrimination required between the frequencies. For a 2 second epoch, the frequency range is 0 - $63\frac{1}{2}$ Hz in $\frac{1}{2}$ Hz intervals; for a 4 second epoch the range is 0 - $31\frac{3}{4}$ in $\frac{1}{4}$ Hz intervals. The minimum possible epoch length is determined by the time taken for the transformation. For one channel this is 0.4 seconds; in the continuous mode four channels must be completed during one epoch making the minimum epoch length 1.6 seconds. For convenience 2 or 4 seconds epochs have been chosen. The number of pairs of sets of spectra summated is limited to 4 by the double precision word used for the power spectra.

Storage of power spectra

If sense switch 5 is set to ONE the power spectra will be transferred to magnetic tape on Unit 1 immediately after the last set of data has been transformed (Fig.1). This is done using the buffered tape system and the collection and analysis of new data continues without interruption. This process of collection, transformation and storage will proceed until the tape is full (1600 octal blocks), when the tape rewinds and can be changed to start again at block 0, or until SNS 5 is set to ZERO when the program goes into a display routine at the end of the current data collection and analysis (Fig.2). The last set of power spectra is then displayed on the scope and can be stored on magnetic tape (unit 1) by typing W. The number of the first block of each set stored is typed on the teletype (Fig.3).

After each set of power spectra has been written on unit 1 the blocks are checked. If the check fails the blocks are written and checked again. If this second check fails a question mark is typed next to the block number and no further attempts are made to write the blocks.

The spectra stored are in the form of double precision words, each channel having 128 frequency components occupying 256 points or 1 block of magnetic tape. Thus a maximum of 4 blocks is used each time storage is performed. If 4 seconds epoch, 4 pairs and 4 channels are chosen the analysis time for each set of spectra is 32 seconds. Each tape contains 1600 (octal) or 896 (decimal) blocks and as 1 block is used for each channel (4 blocks per 32 secs) the total continuous analysis time is about 2 hours if storage commences at block 0. The time to fill one tape is proportionately longer for fewer channels.

Plotting and examination of the stored spectra can be done using the program FETCHFFT.

Display (non-continuous mode only, SNS 5 = 0)

If SNS 5 is set to ZERO and the required number of pairs of epochs have been collected and transformed, the power spectra are displayed on the scope. The channels displayed are selected by sense switches 0 through 3 and can be moved on the scope by knobs 0 through 3. Thus SNS 0 on a ONE with SNS 1, 2 and 3 on ZERO will display channel 1 which can be moved by knob 0. A cursor is also displayed to identify the frequencies and can be moved using knob 4 (Fig.4).

The displayed spectra can be scaled by bits 8, 9, 10 and 11 of the right switches. For example, if the RSW are set to 0002 the amplitude of the spectra are divided by 4 (scaled twice). This scaling does not affect the storage of data on magnetic tape.

Whilst in display the spectra can be stored by typing W. Typing C will cancel the current display and start a collection of new data. Key C can be used at any time during collection of data to cancel the current set and restart the sampling.

Alternatively, when in display sense line 1 (SXL1) can be used to start sampling data (same as C) and SXL 2 can be used to store data (same as W). Whilst sampling data SXL 0 can be used to cancel the present set and restart collection (same as C).

Display Scale Factor

The spectral power amplitudes can vary enormously between channels and from time to time and for optimum display a separate scale factor has been used for each channel. These scale factors are displayed on the scope (Fig.3) and must be taken into account when comparing the amplitudes of the spectra of different channels. A large scale factor (say 8) means that the biggest spectral component in that channel was large and all the components had to be scaled right 8 in order to reduce them from double to single precision numbers suitable for display. Thus one channel, scale factor 4, can be compared directly with another channel, scale factor 5, if the amplitude of display on the first channel (SF4) is considered to be half the size of that displayed.

An alternative method of considering the scale factor is from the size of the input data. If two inputs of similar frequency content but one twice the amplitude of the other, are transformed to power spectra the scale factor on the larger amplitude data will be 2 greater than the other, say 6 compared with 4. This scale increase of 2 is because the final display is that of power - an amplitude factor of 2 (scale 1) in the data becoming an amplitude factor of 4 (scale 2) in the power spectra.

The scale factors have been chosen such that an input sin wave of 1 volt peak to peak will give a scale factor 9. Peak to peak values should not exceed this value. Scale factors of 10 (T) and 11 (E) can be displayed with extra large input signals.

Relays

When the FFT is continuous (SNS 5 ONE) the relays 3 and 4 will alternate with each set of epochs. Relay 2 is switched on for a short time at the beginning of each epoch and can be used as a trigger for external events that are to be synchronised to each epoch (2 or 4 seconds).

Aliasing

When using this program the analogue inputs to the PDP 12 should have a bandwidth restricted to that covered by the frequency spectra 0-64 Hz or 0-32 Hz. Unless this is done activity at a higher frequency than that covered by the range can appear in the spectrum. For example, 50 Hz interference from the electricity supply could appear at (2x32)-50 = 14 Hz in the 0-32 Hz band. This effect is known as aliasing and is due to the sampling of the data - it is not caused by the frequency analysis (see Measurement and analysis of random data, Bendat & Piersol, Wiley & Son; or Spectral analysis and its applications, Jenkins & Watts).

The best solution is to use analogue filters on the input to the PDP 12. Whilst a simple filter might be adequate in most situations steep cut-off filters (e.g. Butterworths, Bessel or Tchebyscheff) are preferable.

Use of program

Mount a tape on unit 1 for the storage of the power spectra and set switches to WRITE ENABLED and REMOTE. The program OLFFT1 is loaded through DIAL and starts with a teletype question and answer routine in which administrative details such as name, date, etc. are typed in. The storage start block number (unit 1), the epoch (2 or 4 seconds), the number of pairs of epochs to be summated (1 to 4) and number of channels (1 to 4) are then selected.

The RUBOUT key can be used during the questionnaire to correct errors.

At the end of the questionnaire the tape on unit 1 will position itself at the start block. ~~(If the program halts check that the switches on unit 1 are correct)~~.

The program then goes into a display routine in which the channels (showing no spectral lines) can be selected by SNS 0, 1, 2 or 3. Data collection can be commenced by typing C or by using SXL 1.

If SNS 5 is set to ONE then the collection, transformation and storage of power spectra on unit 1 will be continuous and can be interrupted by setting SNS 5 to ZERO.

If SNS 5 is set to ZERO the program re-enters the display after the collection and transformation of the specified number of pairs of epochs of data. Whilst in display type W or use SXL 2 to store on unit 1 the displayed spectra. To prevent storing the same data twice the W key and SXL 2 are made inoperative after being used once and are only activated after new data is collected.

The amplitude of the displayed spectra can be scaled by the rightmost 4 bits of the Right Switches. These settings do not affect the storage of spectra.

If the tape on unit 1 becomes full a message is typed out and the user should change the tape. Type C to recommence collecting data. New spectra will be stored starting at block number 0.

Control D will return user to DIAL.

Summary

After entering display following the questionnaire type C or use SXL 1 to start sampling data.

SNS 5 ONE - collection, transformation and storage will be continuous.

SNS 5 ZERO - the spectra are displayed after transformation.

SNS 0, 1, 2 and 3 select channels which are moved by knobs 0,1,2 and 3.

Rightmost 4 bits of Right Switches can be used to scale display.

Type W or use SXL 2 to store displayed spectra.

Type C or use SXL 1 to restart data collection.

When not in display, that is when collecting data, type C or use SXL 0 to cancel the current set and start collecting new data.

Control D for DIAL.

Figures

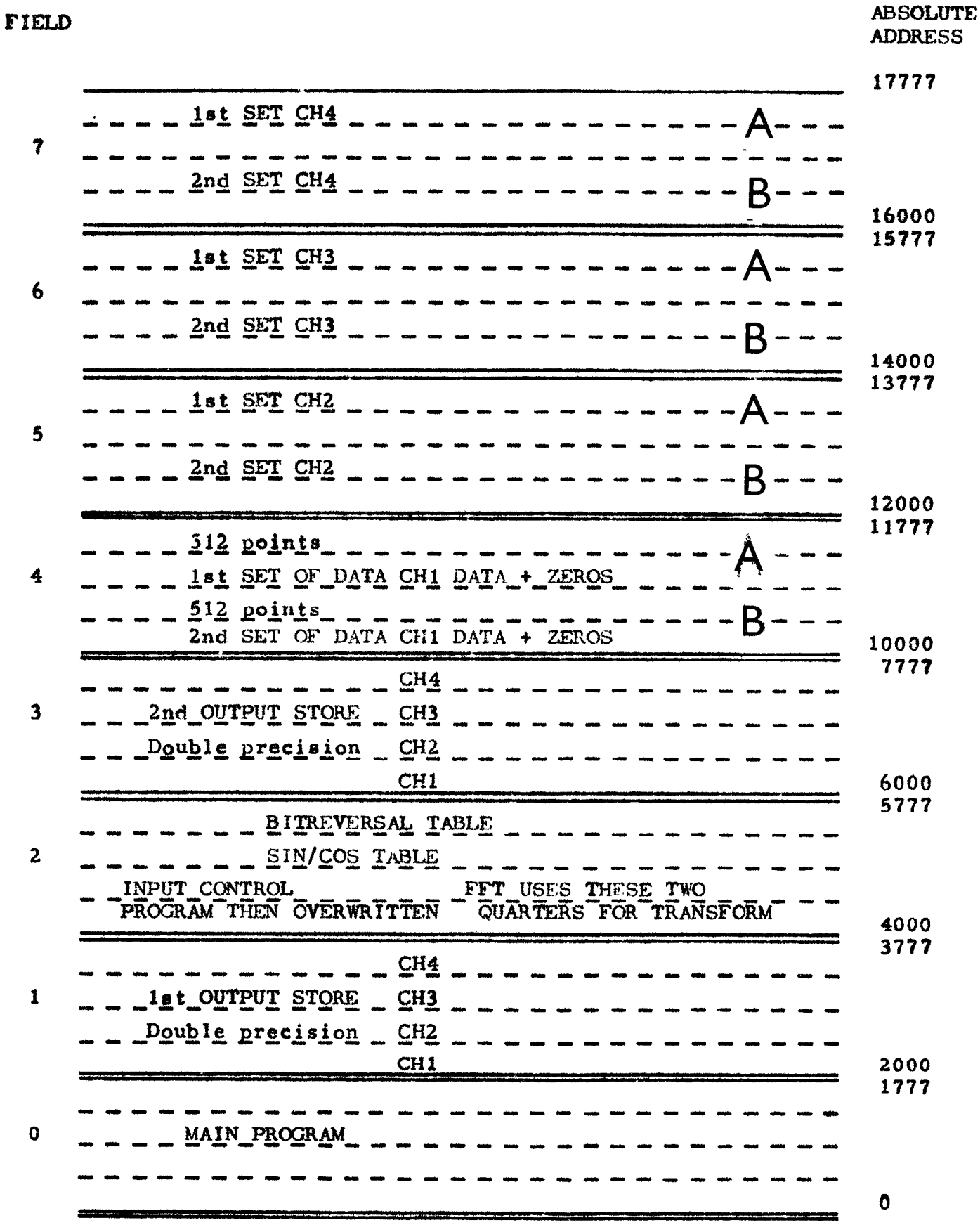
Figures 1 and 2 give a diagrammatic representation of the operational use of OLFFT1 in its two modes.

Figure 3 shows a teletype question and answer routine at the initialization of OLFFT1 and also shows a few storage block numbers typed (block 204 failing the write check; see 'Storage of Power Spectra').

Figure 4 shows a scope display of 4 channels. (RSW = 4).

OLFFT1

MEMORY FIELDS AND ADDRESSES



FETCHFFT program

Basic Operation

This is a program for retrieving power spectra stored on tape by OLFFT1 program for further inspection and analysis including plotting. Its operational use has been made as similar to that of OLFFT1 as possible and requires 5K of memory on the PDP 12 and an incremental plotter (Complot DP-1-M2 or Calcomp 565, step size 0.01 in.)

After entering the program through a teletype question and answer routine (Fig.5) 1-4 selected consecutive blocks (i.e. 1-4 spectra) are retrieved and the program enters immediately into display. The choice of continuing onto the next set, retrieving the previous set, plotting the present set, plotting continuously, typing amplitudes or restarting is then left to the operator.

The program will retrieve data from a 1600 block tape.

Display

The display is exactly similar to that of OLFFT1 viz. histograms with a range of frequency 0-63.5 Hz for a 2 sec. epoch, 0-31.75 Hz for a 4 sec. epoch, the channels displayed according to SNS 0, 1, 2 and 3 and moveable by knobs 0, 1, 2 and 3 respectively. (SNS 3 is not operable when only 3 channels selected on input, etc.). The scale factor for each channel, as described in OLFFT1 (which see) is also displayed, as is the cursor for identifying frequencies (moveable on knob 4). Also, as in OLFFT1, the display of the spectra can be scaled by the last 4 bits of the right switches (see Fig.4).

In addition, however, the block number of the first spectrum of the set of 4 is displayed in the top right.

A further important addition is that the data can be displayed in logarithmic form (i.e. in dBs). This is operative on SNS 4. In this case the scale factors are not displayed and the horizontal scale has been shifted up (according to the number of pairs making up the spectra) so that ~~it is~~ true <u>average</u> log spectra are displayed. Bits 0, 1 and 2 can be used to scale the logarithmic display.

Preceding and subsequent sets of spectra can be retrieved for display by using the teletype, B and F.

If SNS 5 is set to ZERO, the display waits for operator action (see <u>Use</u>).

If SNS 5 is set to ONE the program automatically plots the displayed spectra and continues to plot the next 1-4 consecutive spectra, and so on until all the specified blocks (according to the entry questionnaire) have been plotted.

Plotting

The 1-4 channels are plotted in a row across the paper separated by short gaps. Horizontal axes are drawn for each channel and are graduated in intervals of 10 harmonics, i.e. 5 Hz intervals for a 2 sec. epoch, and 2.5 Hz intervals for a 4 sec. epoch. (Fig.6).

The plot of the spectra corresponds precisely with the display in terms of number, size, resolution and standard or logarithmic version (see Fig.7). Only the channels displayed will be plotted but gaps will be left for those omitted so that corresponding channels are always plotted underneath each other.

The amplitude of the display also determines the size of the plot and the resolution of the plot is identical to that of the display, i.e. an amplitude that can just be detected on the displayed spectrum will also just be discernible on the plotted spectrum. Because the D.C. was removed from the analogue input to the OLFFT1 program, the zero harmonic is omitted from the plot of each channel.

Underneath the plot-out of each channel are written 3 parameters associated with that channel:-

S.F. - this is the Scale Factor as displayed

M.A. - this is the Maximum Amplitude that occurs in that spectrum and although the units are arbitrary this allows a comparison of spectra remembering that the scale factor (SF) must also be taken into account (see OLFFT1).

D.F. - this is the Dominant Frequency (in Hz) and is the frequency which has the maximum amplitude (M.A.) in that spectrum.

Note:- This writing does not appear on the logarithmic version. At the commencement of the plot of each set, a short horizontal line is drawn to separate sets and then the block number of the first spectrum of that set is written. The paper then automatically moves up the appropriate distance for the plot which follows.

Note also that M.A. and D.F. do not appear when the components of a spectrum are all zero.

If SNS 5 is set to ZERO the program returns to display at the completion of each set.

If SNS 5 is set to ONE the program automatically continues to retrieve and plot the next set until all specified blocks have been plotted (or SNS 5 set to ZERO).

An appropriate message is output on the teletype on completion of all specified blocks.

Amplitude type-out

The absolute amplitude of the components of any specified frequency can be typed out. In display, typing "A" will initiate a question and answer routine in which the frequency has to be typed as a decimal number with 2 figures (leading zeros if necessary) before the decimal point (typed automatically) and one figure after for a 2 second epoch and two figures after (the last figure being typed automatically) for a 4 second epoch. The teletype will then output the block number (i.e. that displayed on the scope) and the absolute (7 figure) amplitude of that specified frequency component for each channel (Fig.5).

If SNS 5 is set to ZERO, the program returns to display.

If SNS 5 is set to ONE, the program will type out these amplitudes continuously for subsequent blocks until all specified (in the input questionnaire) blocks have been completed.

Use of Program

The tape of stored spectra must be mounted on unit 1 and the switches set to REMOTE. The program FETCHFFT is loaded through DIAL and automatically commences with a teletype question and answer routine, asking for the number of channels, the first and last blocks to be retrieved, the number of pairs used in forming each spectrum and the epoch. (Leading zeros are not necessary and each answer must be concluded with EOL. RUBOUT will repeat the current question, allowing for correction of errors).

The plotter pen is then automatically positioned, but it must previously have been set manually near to the left hand side of the plotter.

The program then retrieves the first specified set of spectra. If SNS 5 is set to ONE the program enters the plotting routine (after flashing a display) and continues retrieving and plotting consecutive blocks until it has either completed the set containing the last specified block or SNS 5 is set to ZERO, in which case it completes plotting the current set and returns to display.

If SNS 5 is set to ZERO the program displays the current set and waits for operator action:-

Type F (forward) to retrieve and display the next set of spectra
" B (back) " " " " " previous set of spectra
" P to plot the present displayed spectra and return to display on completion
" A to type amplitudes of specified frequency components
" CTRL R to restart the program
" CTRL D to return to DIAL

These last two are operative at any time.

Figures

Figure 5 shows a teletype question and answer routine at the initialisation of FETCHFFT and also shows the use of the amplitude type-out facility.

Figure 6 shows a plot of 4 spectra in both the standard (RSW=3) and corresponding logarithmic form.

Figure 7 demonstrates a comparison of the three facilities of FETCHFFT. (a) is a single channel scope display of block 210 (RSW=2); (b) shows the corresponding plot with particular frequencies marked (by hand) and (c) shows an example of a series of amplitude type-outs relating to that spectrum (block 210).

Acknowledgments.

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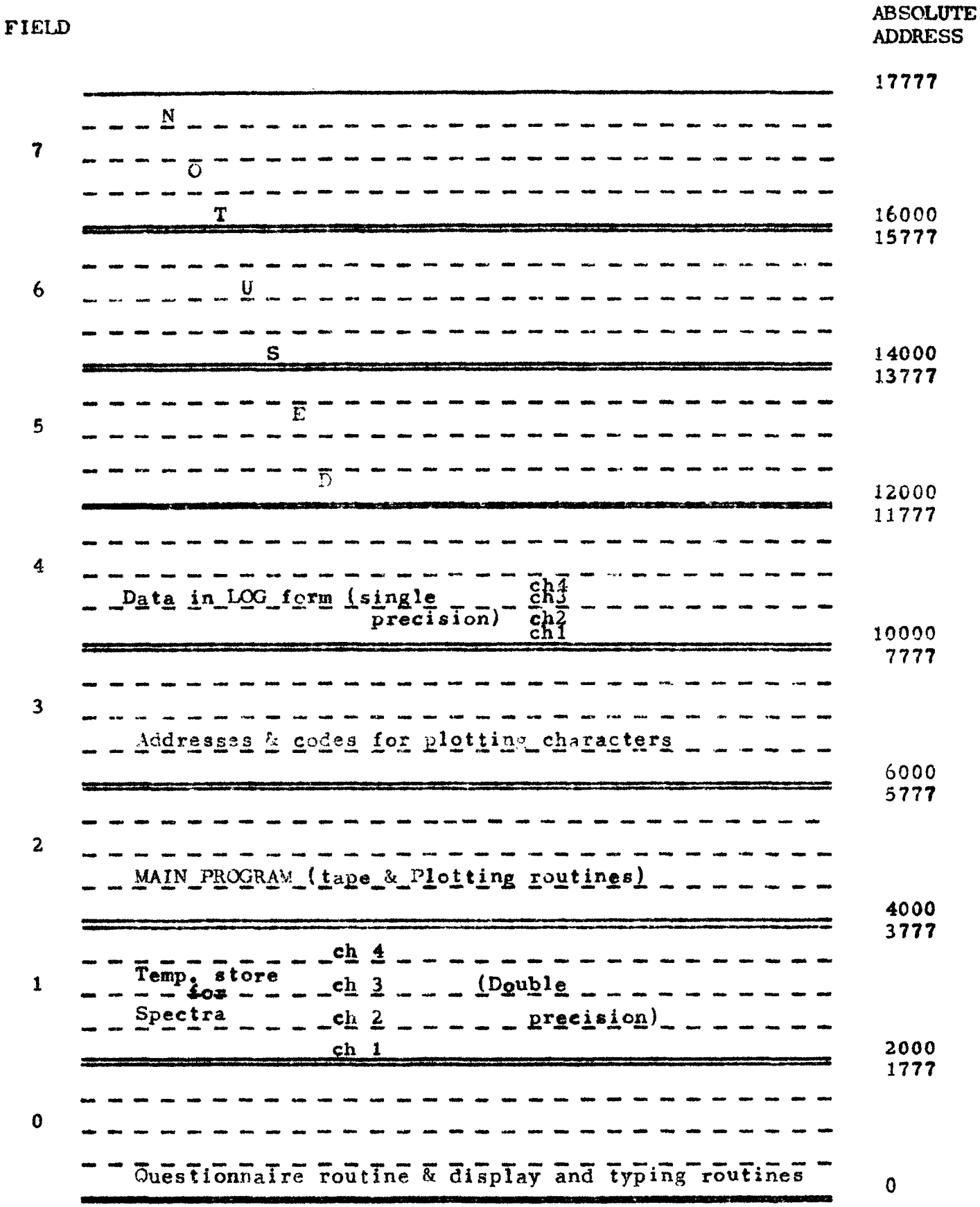
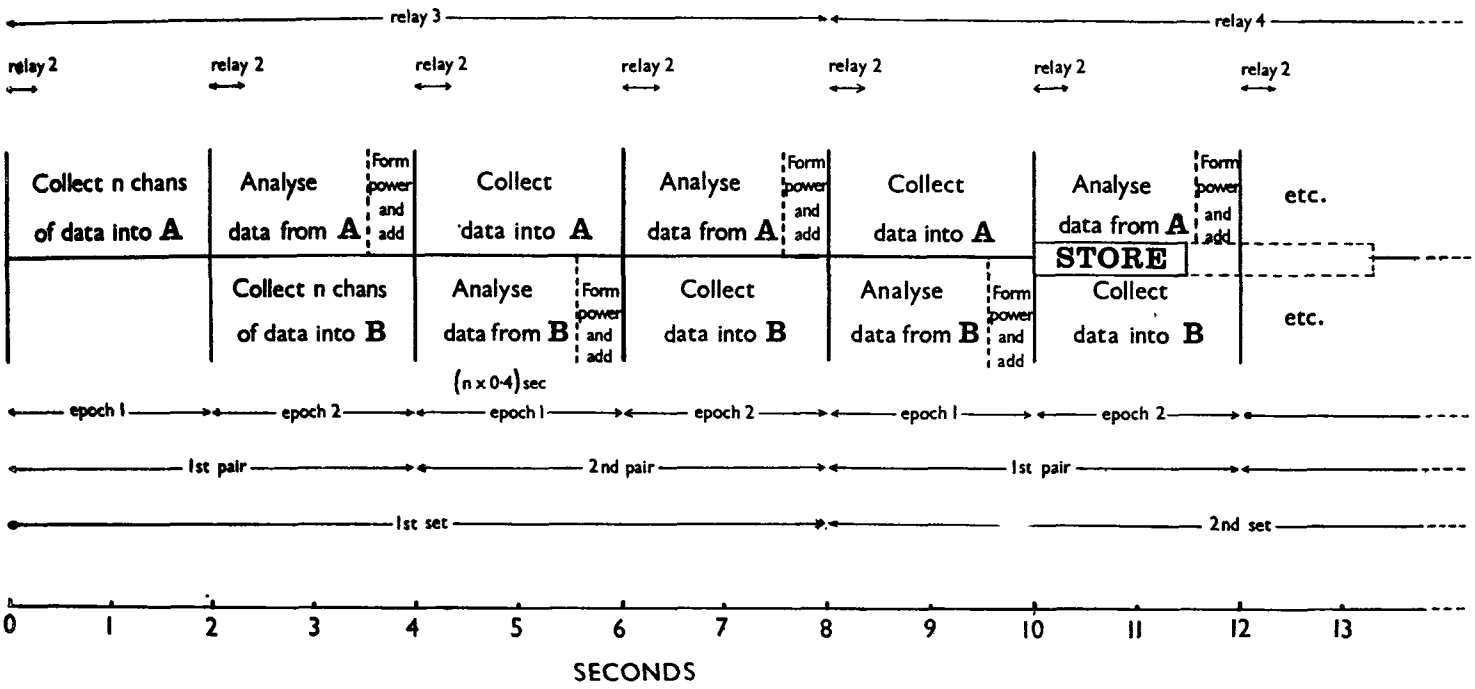
FETCHFFT

MEMORY FIELDS AND ADDRESSES.



Epoch = 2 seconds
Nō of pairs = 2
n = 1, 2, 3 or 4 channels

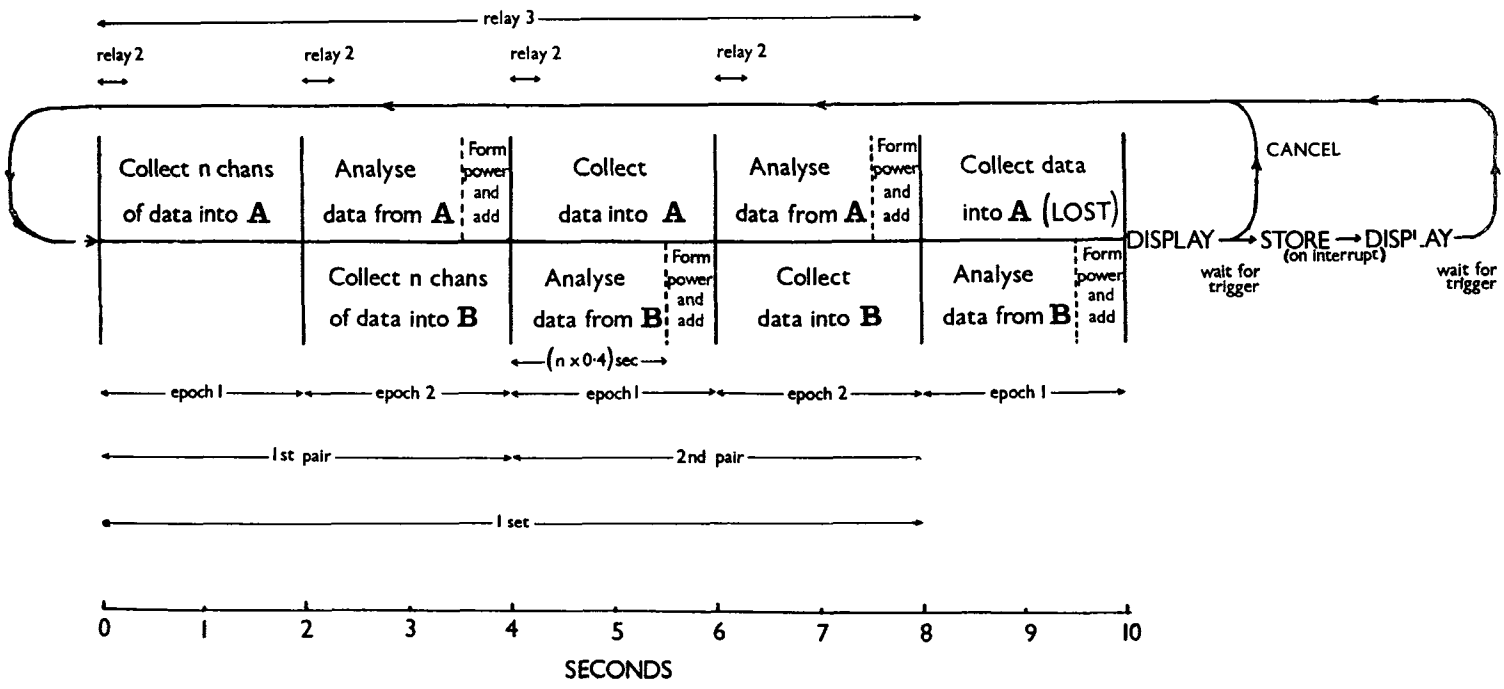
Continuous mode (SNS 5 = 1)



1.

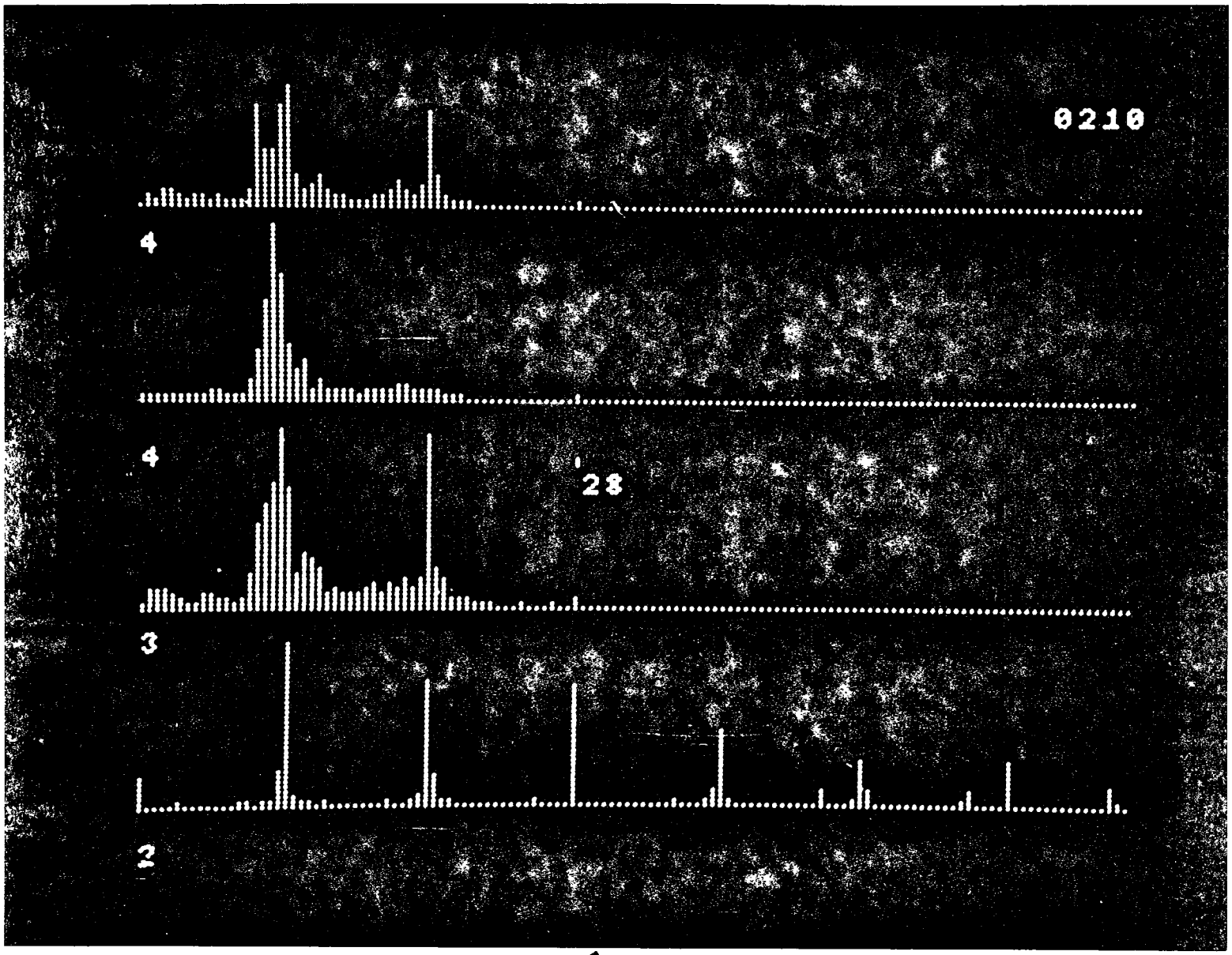
Epoch = 2 seconds
Nō of pairs = 2
n = 1, 2, 3 or 4 channels

Non-continuous mode (SNS 5 = 0)



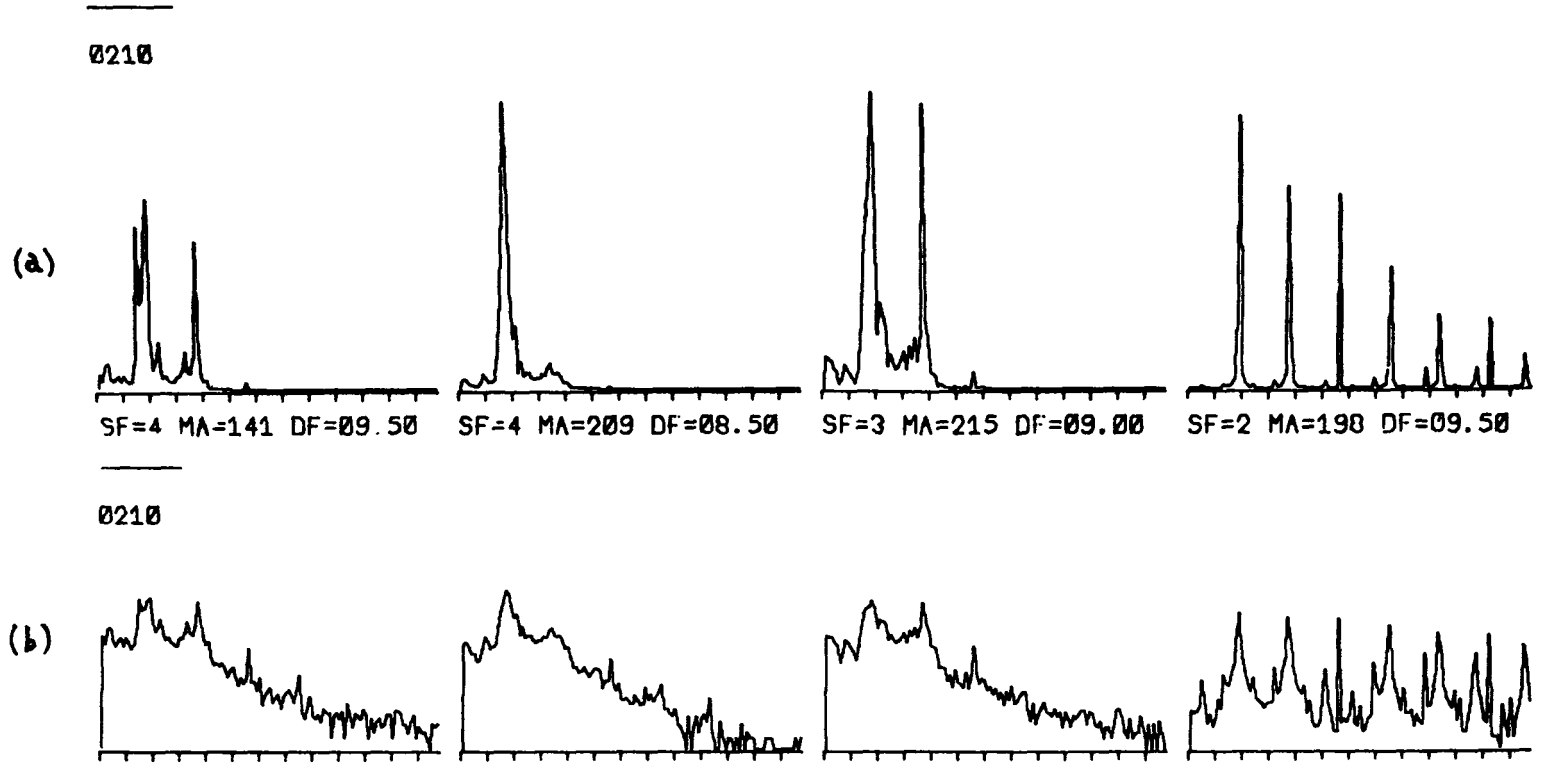
2.

```
OLFFT1


NAME..... POCOCK,P.V.
DATE..... 10/8/71
TAPE NO... E142
START POWER STORE AT BLOCK NO..... 170
EPOCH LENGTH, 2 SEC OR 4 SEC..... 2
NO OF PAIRS TO BE AVERAGED, 1-4... 4
NO OF CHANNELS, 1-4.. 4
CHANNEL 1... L.FRONTAL
CHANNEL 2... R.FRONTAL
CHANNEL 3... VERTEX
CHANNEL 4... MONITOR
SET UNIT 1 TO REMOTE & WRITE ENABLED::EOL TO START
SET UNIT 1 TO REMOTE & WRITE ENABLED: EOL TO START


 170
 174
 200
 204 ?
 210
```



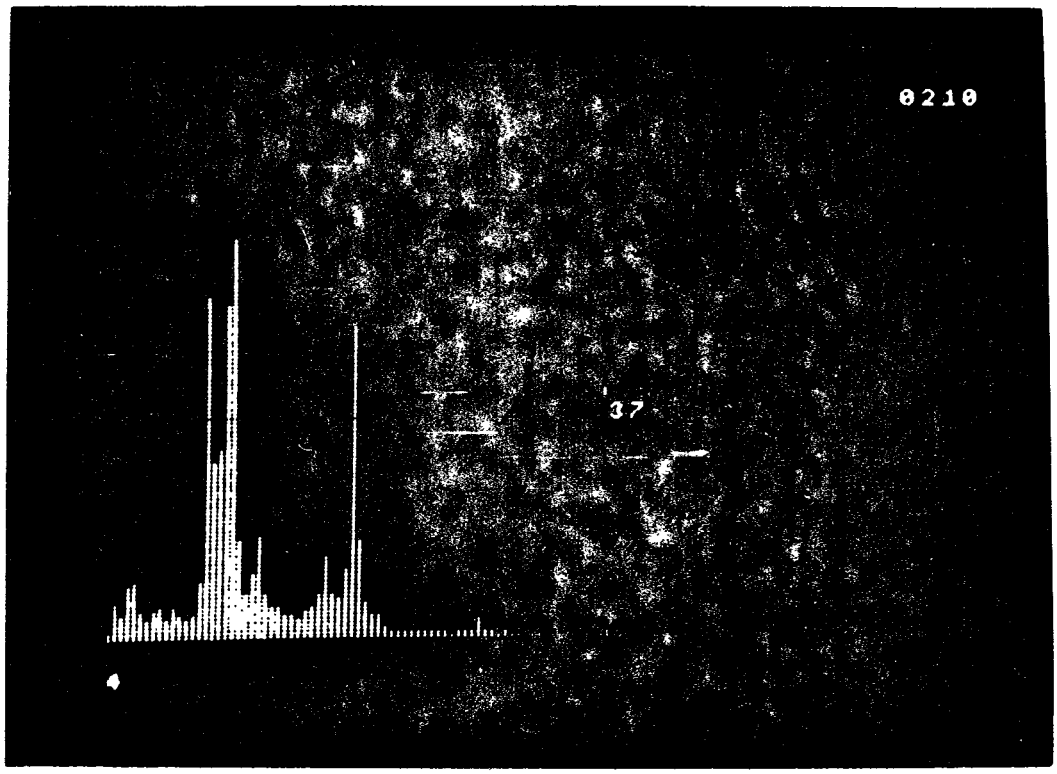
4.

```
FETCHFFT


NO OF CHANS..4
RETRIEVE 4 BLOCKS AT A TIME STARTING AT BN..... 170
UNTIL THE LAST 4 BLOCKS COMMENCING AT BN..... 210
NO OF PAIRS..4
EPOCH.....2
EOL TO START


AMP OF FREQ 10.5 HZ
0170    0008860    0013542    0007212    0000350
0174    0007292    0006600    0007244    0000044
0200    0014104    0005032    0014200    0000172
0204    0027196    0010764    0020806    0001586
0210    0003936    0011910    0008130    0000296


ALL DONE.
CTRL R TO RESTART
CTRL D TO RETURN TO DIAL
```

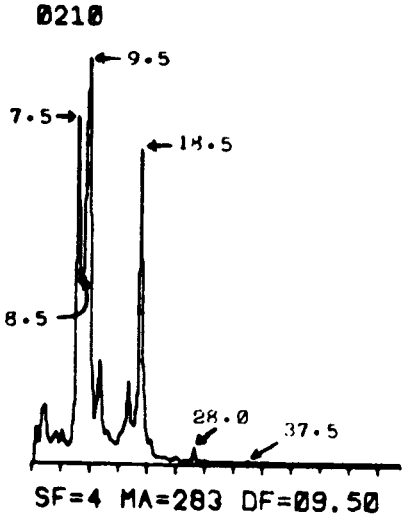

0210
(a)
SF=4 MA=141 DF=09.50
SF=4 MA=209 DF=08.50
SF=3 MA=215 DF=09.00
SF=2 MA=190 DF=09.50
0210
(b)

6.

(a)



(b)



(c)

```
AMP OF FREQ 07.5 HZ
0210     0031094
AMP OF FREQ 08.5 HZ
0210     0017176
AMP OF FREQ 09.5 HZ
0210     0036282
AMP OF FREQ 18.5 HZ
0210     0028258
AMP OF FREQ 28.0 HZ
0210     0001358
AMP OF FREQ 37.5 HZ
0210     0000232
```