Audiological testing using the cortical electroencephalogram and its microprocessor implementation

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Adrian Stuart Poulton

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Engineering in Medicine Laboratory

Department of Electrical Engineering

Imperial College of Science and Technology

London SW7

ABSTRACT

A microprocessor-based system designed for use in audiological experiments has been built and employed for clinical trials and further investigations into the character of evoked EEG potentials.

If the phase spectra of a number of responses to consecutive suprathreshold stimuli are taken, and certain harmonics are examined, aggregation of the phases may be observed. It was proposed to investigate whether this effect could be explained on an additive hypothesis, or whether a different hypothesis involving some synchronization of neural activity in the cortex should be postulated.

The microprocessor system could be used both to generate auditory stimuli, and also to collect, store, and analyze responses from the patient. Stimuli could be produced with a variety of waveforms, and with accurately controlled amplitude, frequency and phase.

Clinical trials on normal hearing subjects gave results which were comparable with results obtained by the visually-scored ensemble average method in common use. Further analysis of the results from two subjects led to the conclusion that the additive hypothesis is unlikely to be true.

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TO GARETH

CHAPTER 1
INTRODUCTION

1.1 Background.

The work described in this thesis concerns audiological testing by methods of electric response audiometry. Apparatus was required that utilized modern technological developments for implementing an objective test of auditory threshold. Some basic neurophysiological aspects of the mechanisms implied were to be further examined.

Thus, an instrument was required that would produce the various acoustic stimuli used in these tests. A further requirement was for a device that would implement the phase spectral analysis algorithm of Sayers, Beagley and Henshall (1974) and Ross (1978) which will be described later. It was found to be convenient to include both these functions in the same piece of equipment. The phase spectral approach implies either of two models for the generation of EEG responses and a choice between these is required.

The methods of audiometry for which the system was intended will be described briefly. Particular reference will then be made to the types of stimuli required for each test. It will be seen that the problem of generating stimuli is fairly complex, and a reasonably large amount of electronic circuitry is necessary. For this reason, the system was designed around a microprocessor.

1.2 Evoked cortical response audiometry

In this method of audiometry, auditory stimuli are presented to a subject, and the ensemble of post-stimulus EEG is examined. The method is widely used and has been described by several authors (Beagley, 1972: Davis, 1976: Goff, 1974: Hood, 1975: Roberts and Watson, 1974). No anaesthesia or sedation is required, and a complete threshold audiogram can be obtained by testing at any required frequency in the audiometric range, i.e. 0.25 to 8 kHz. It tests the integrity of the entire pathway from the ear to the cortex.

In this test one electrode ("active") is placed on the vertex, and another ("reference") is placed over the mastoid bone or ear lobe. An alternating electrical potential, the electro-encephalogram or EEG, is developed between these two electrodes. A third electrode, usually located on the forehead, is used as an earth electrode. The EEG normally has an amplitude in the order of 10^{-5} volts and appears superficially to be random, although in fact definite spectral components may be identified. In audiological testing, the changes in the EEG in response to acoustic stimuli, known as the auditory evoked cortical potentials, are examined.

The responses are usually below the level of the ongoing EEG, so it is necessary to use a number of stimuli and to perform some signal analysis such as coherent averaging on the ensemble of post-stimulus records in order to obtain reliable results. The normal response as seen in the ensemble post-stimulus mean EEG is characterized by: a vertex-positive peak 50 mS after the onset of the stimulus, a negative peak at 90-110 mS, a positive peak at 180mS, and a negative peak at 250mS. This may be abbreviated as P_{50}-N_{90}-P_{180}-N_{250} (Davis, 1976), although the designation P_1,N_1,P_2,N_2 is also used.

The type of stimulus most commonly used in this test is the sinusoidal tone burst, modulated by an envelope in order to reduce transients at the beginning and end of the burst (e.g. a trapezium). A wide range of frequencies must be covered. The tone burst is typically 50-100 mS long, with 10 mS rise and fall times. The stimulus repetition rate must not be too short, or else previous responses will not have decayed when a stimulus begins. On the other hand, a very long inter-stimulus interval would prolong the test unnecessarily. A repetition rate in the order of 0.8 Hz is used in practice. A typical trial would consist of 64 stimuli.

1.3 Brain stem electric response audiometry (BSER)

These responses are recorded with a similar set of electrodes to those for cortical responses, but occur on a much shorter time scale (1 to 12 mS after the start of the stimulus). They are also lower in voltage, so that the summing of 1000 or 2000 responses is required. The subject is often sedated. The responses are thought to originate in the brain stem, and so contain information about the integrity of the cochlea and cochlear nerve and the auditory tracts of the brainstem. The major response is a vertex-positive peak at 6mS.

A very short stimulus is needed for this test. Short tone pips and rectangular pulses have been used. There is a compromise between precision in time and precision in frequency, as these two are related by a reciprocal law similar to Heisenberg's uncertainty principle. The best theoretical solution is the elementary signal or 'logon' described by Gabor (1946,1947).

The inter-stimulus interval may be much shorter than that used for the cortical response, because the BSER soon decays. Davis (1976) suggests that 30mS is the minimum. This allows a large number of responses to be collected in a reasonable time.

1.4 Electrocochleography (ECochG)

In this technique a response is derived directly from the cochlea and the auditory nerve. It is strictly monaural, so that the opposite ear does not need to be masked, and the stimuli may be produced by a loudspeaker. It is an invasive procedure, requiring hospital conditions and the participation of an otologist (Beagley, 1973: Davis, 1976: Simmons and Glattke, 1975, Portmann, 1977)

A fine needle electrode is used, insulated with varnish except at the tip. It pierces the tympanic membrane and rests on the promontory in front of the round window of the vestibule. A local anaesthetic is given for adults, but a general anaesthetic is necessary for children.

The electrocochleogram may be characterized by three main components: the cochlear microphonic (CM), an a.c. response which closely follows the stimulus; the summating potential (SP) which is a shift in the d.c. level during the course of the stimulus; and the compound action potential (AP) which is a transient phenomenon produced by the conduction

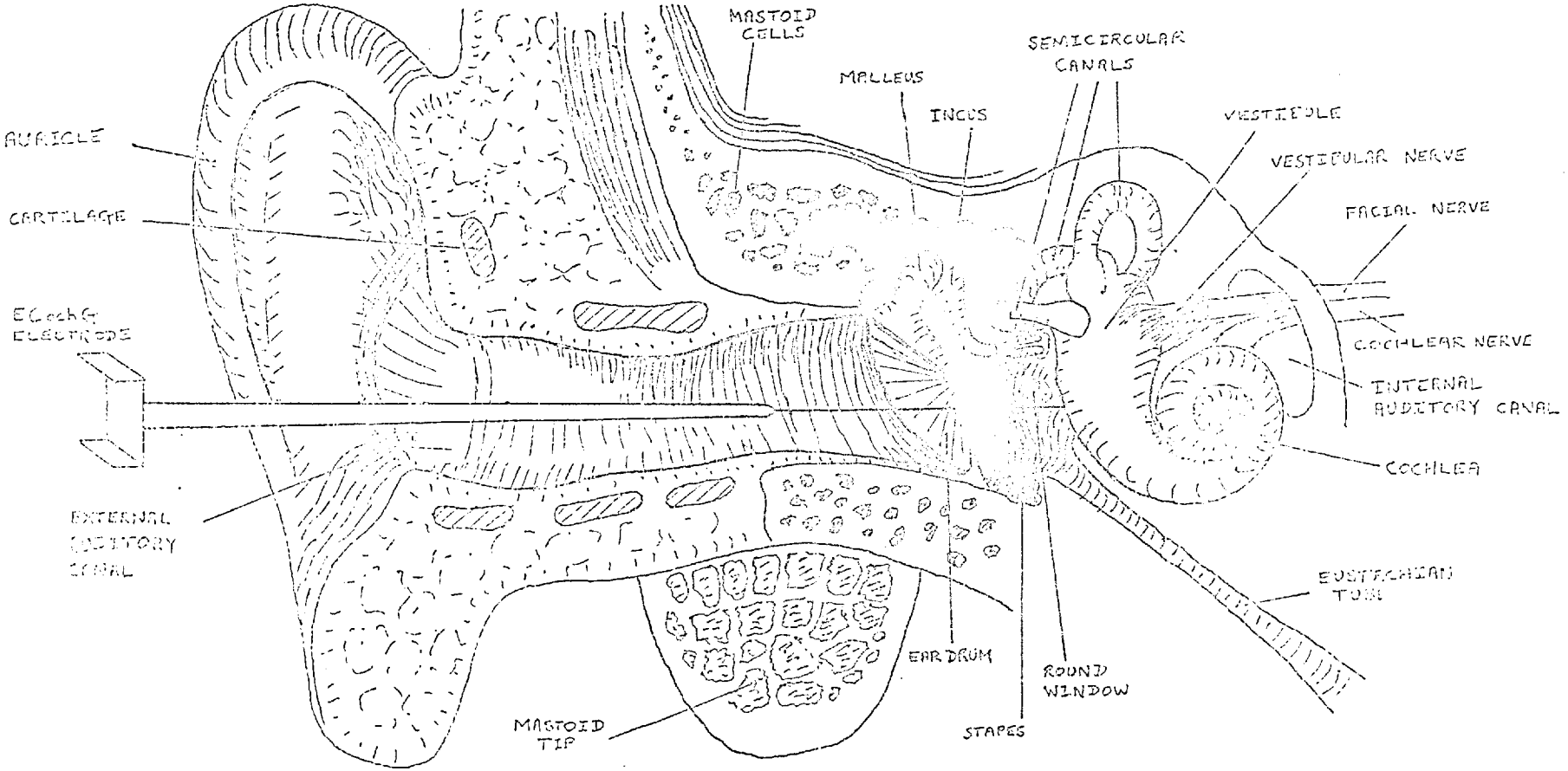


Figure 1.1 Section through human ear showing placement of transtympanic electrode for ECochG.

mechanism of the axons of the auditory nerve. The CM and SP are thought to be generated in the organ of Corti, in the basal turn of the cochlea.

The reliability of ECochG is very high, and it provides direct information about the cochlea. It is often used in combination with BSER to provide information about the eighth cranial nerve and the entire brain stem.

The electrocochleogram is an even earlier response than the BSER (0-5 mS), so a stimulus such as a short tone burst, click, or logon is used. It is often desirable, in clinical practice, to remove the CM from the response. This can be done quite simply, as the CM is inverted when the stimulus is inverted, while the SP and AP are always the same polarity. If the stimulus is alternated in polarity at each presentation, and the coherent average of the responses is taken, then the CM will average to zero. This, then, is a further necessary feature of a stimulus generator.

The CM can however be separated non-destructively from the AP by passing the electrical responses to stimuli of one polarity into one half of a split memory (memory A) and those in response to stimuli of the opposite polarity into memory B.

By adding (A+B) the AP is displayed, and by subtracting (A-B) the CM can be inspected, and neither potential is destroyed.

1.5 Description of equipment

The apparatus at the Department of Electrophysiology at the Royal National Throat, Nose and Ear Hospital for performing these tests included a signal averaging computer (Medelec) and an FM tape recorder (Store-4, Racal) for recording data for later off-line analysis. The signal averager performs coherent averaging of the physiological signals, displaying the result on a c.r.t. and also providing a hard copy by means of a u.v. recorder. It also provides an amplified EEG signal at a convenient level for the analogue input of the microprocessor system. Acoustic stimuli are produced either by headphones or by a loudspeaker driven by a 50W amplifier, placed 50cm from the ear to be tested.

The electrodes used for cortical and brain-stem measurements are of the silver/ silver chloride type (Binnie, 1974: Kapp, 1970). Before use, the electrodes are checked with an EEG impedance meter at a frequency of 16Hz to ensure that the contact impedance is sufficiently low.

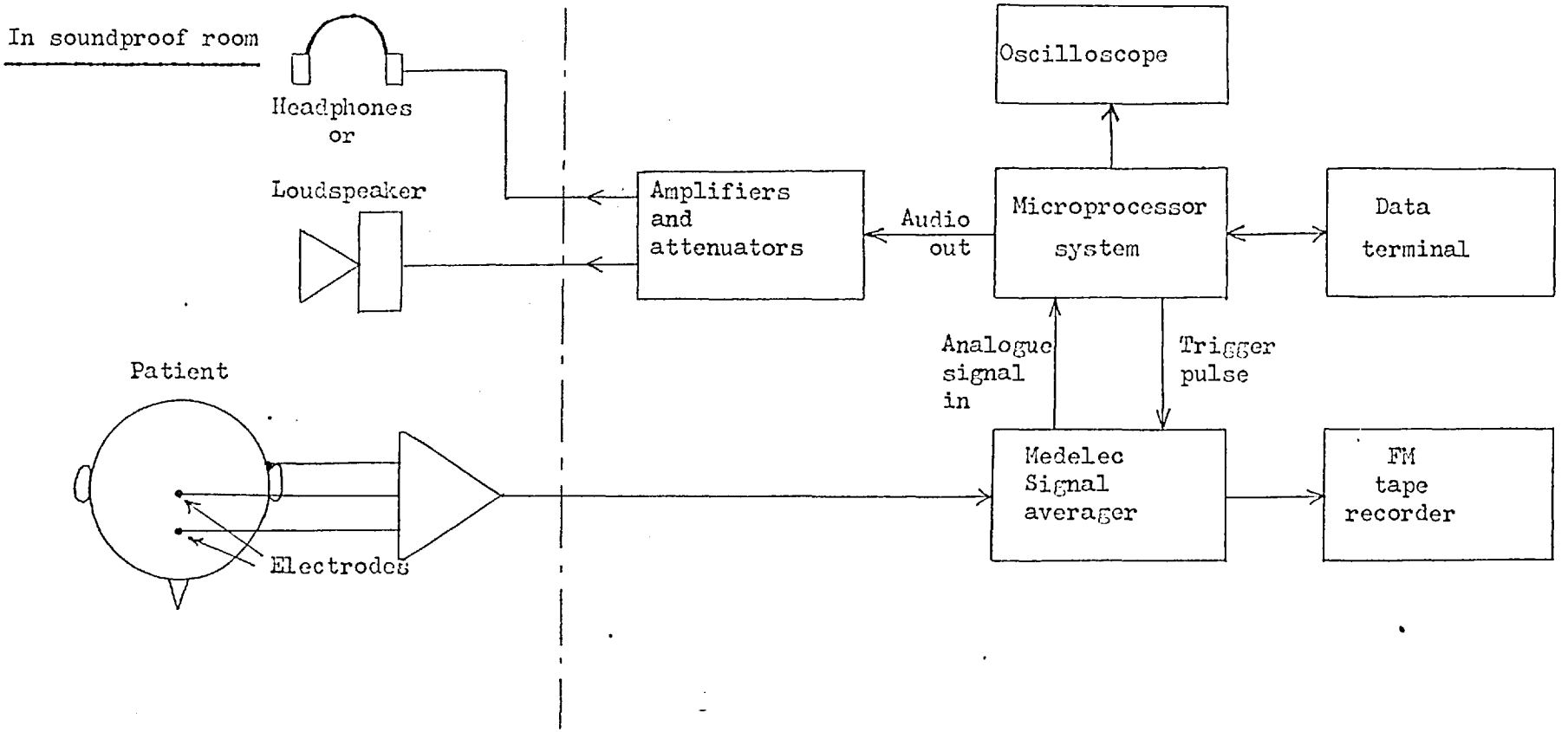


Figure 1.2 Complete system for ERA.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Methods of processing EEG signals

In this section various methods of processing evoked potentials will be reviewed. It will be noted that, although a technique may be justified by the results obtained by its use, it will generally embody certain underlying assumptions about the nature of the signal being analysed. These assumptions will also be embodied in models that may be proposed to explain the generation of the evoked potentials against a background of ongoing, or unstimulated, EEG. As the nature of the ongoing EEG has a bearing on the possible hypotheses, some techniques for analysing this signal will also be discussed.

2.2 Evoked potentials

The stimuli used in evoked cortical response work have, in the main, been tone bursts of various frequencies, or short transients such as unfiltered clicks. However, spoken words have also been used. Lowy (1966) presented spoken words at 3 to 4 second intervals to a subject, at 45dB above the subject's threshold. Although there was some variability across subjects and tests, there were implications that responses to different words could show reproducible qualitative differences; the results

were, however, not constant. Sharrard (1969) used evoked cortical responses to examine patients with language disorders. He presented spoken words from a tape recorder to the patient. The patient was also tested with the tape played backwards, so that the frequency components of the stimulus were the same, but the intelligibility was lost.

The early history of the analysis of electrophysiological signals has been described by Davis (1976). Many of the early experiments were performed with galvanometers, but later amplifiers and oscilloscopes were developed, so that signals could be recorded with much less distortion. The amount of signal analysis that could be done was very limited. An attempt was made to improve the signal-to-noise ratio by superimposing oscilloscope traces for repeated phenomena. Another approach was to use the signal analyzing capabilities of the human ear. Wever (1949) and Bray detected the output from a cat's auditory nerve using a telephone receiver. Words spoken into the cat's ear were heard through the receiver. In this way the cochlear microphonic was first noted.

Dawson (1951) described a device for the coherent averaging of signals. This featured a rotating multi-contact switch which selected 100

capacitors in turn. The time for a complete sweep of the capacitors was 100 mS. The switch was rotated in synchronism with a device which electrically stimulated a nerve. The cortical response was coherently averaged by adding charge to the capacitors.

Techniques for analysing evoked potentials became more sophisticated as computers developed. Coherent averaging is widely used, and programmes have been written with such refinements as automatic detection and measurement of the peaks of the responses.

Mendel and Windman (1973) describe a set of three programmes for a PDP-12. One programme controls a stimulus generator and stores individual responses. Another programme performs an amplitude and latency analysis on the various peaks within preselected time windows. The third programme summarizes the results and calculates their mean and standard deviation.

Black et al. (1976) describe a similar system using a PDP-11 running either under DOS or under a real-time sharing executive (RSX11D). Patient stimulation is controlled by a hardware pseudo-random timer, in an attempt to minimise habituation effects.

In the method of Aunon (1978), the data is pre-processed by digital filtering. The peaks are then identified automatically, and a latency histogram of the peaks is constructed. Peaks which are found clustered together are corrected to the mean latency of the cluster, and a latency corrected average version of the evoked potential is constructed.

Nielsen et al. (1971) used an IBM 1800 time sharing system for coherent averaging. The EEG signal was pre-processed by an adaptive digital filter. Their system generated on-line displays, as well as hard copy documentation of all data collected in a session.

Horvath (1974) describes a set of LINC programmes for calculating statistics of evoked potential waveforms. The ensemble mean and variance for a run of 128 evoked potentials, each sampled at 0.5 mS for a length of 256 samples, are computed. The initial positive peak of each member of the ensemble is identified. From this, statistics such as the mean latency may be derived. The maximum number of responses that could be analysed by this system was about 900.

Willey and Kellner (1973) describe another PDP-12 programme. Their approach was to try to fit responses to a damped sinusoid of the form:

$$v(t) = v_o \sin (\omega t + \theta) e^{-\lambda t}$$

By estimating ω, θ, λ, the complex waveform is

reduced to a few parameters. Advantages claimed over visual waveform analysis are greater convenience and the provision of numeric output.

The results of evoked response testing using coherent averaging methods may be seen in the surveys of Taylor (1968), Beagley and Kellogg (1970), and Salmivalli (1977). Taylor investigated four groups of children. The first group consisted of 16 children whose response to sounds were consistent and whose speech discrimination capacity correlated with their measurable threshold of detection. The second group of 14 had congenital auditory agnosia or imperception. The third group of 23 were classified as mentally subnormal, while the fourth group consisted of 16 cerebral palsied children. Beagley and Kellogg's survey covered 56 normally hearing schoolchildren of 4-11 years old. Salmivalli studied a sample of 112 Scandinavian children with various degrees of hearing ability, aged between 2 months and 5 years (average age 1.5 years). They were first tested with ERA, and then some years later their hearing thresholds were measured with a pure-tone audiometer. The sample was classified into four groups on the result of the pure-tone test, and the classes were correlated with the ERA results. Results from ERA agreed well in 70% of cases, but poorly in 10% of cases.

2.3 Unstimulated EEG

Methods of analysing ongoing or unstimulated EEG have been reviewed by Saltzberg et al. (1968). These include: correlation, power spectral density, coherence, convolution, and period analysis. The autocorrelation and power spectral density were compared for unprocessed EEG and for infinitely clipped EEG (or 'sgn' function of the EEG) (op. cit.). It was concluded that the sgn function was satisfactory in many applications, such as sleep staging, and led to a large saving in computer time.

A similar approach was adopted by Barr et al. (1978). They detected peaks in the EEG waveform and measured the amplitude and time interval between successive maxima and minima. In this way the complex waveform was reduced to a smaller set of data.

However, it has been more usual to sample the EEG data at equally spaced intervals of time. Smith and Schade (1970) discuss the best choice of sampling rate. Their 7094-IBM programme determines the frequency, amplitude and phase of ongoing EEG.

Cohen (1976) describes a period analysis method which runs on a DEC LINC-8 computer with 4K of memory. It is claimed to be an efficient method of

obtaining spectral information without the cost or complexity of conventional power spectrum techniques. The average rates of zero crossings for the EEG signal and for its first and second derivatives are measured. These zero crossing rates are related to the power spectral density.

Kleiner et al. (1970) describe a set of procedures written in ALGOL, for the spectral analysis of up to fourteen simultaneously recorded EEG channels. The data is smoothed by a digital low-pass filter and demultiplexed. The fast-Fourier transform (FFT) is then performed. Finally, a variety of spectral and cross-spectral functions are computed for preselected channel combinations. The procedures are designed to run in a medium to large size computer.

Kingma et al. (1976) have attempted to reduce the data contained in the EEG power spectrum still further, by considering the spectrum as the sum of a number of Gaussian functions, each of which correspond to a peak in the spectrum. In this way, spectra with a limited number of peaks can be described by a few parameters.

2.4 Models of EEG generation.

A number of models have been proposed to account for features of the electroencephalogram, in the unstimulated state (waking and sleeping), and with sensory stimuli.

Wiener (1961) obtained the power spectrum of a sample of EEG by autocorrelation, using an FM tape recorder with two heads which were a variable distance apart, followed by Fourier transformation (thus making use of the Wiener-Kinchine theorem). He noted the alpha rhythm at a frequency of 9Hz, and drew attention to a sharp drop in power at 9.05Hz. His results also show a smaller fall in power at 8.97Hz. Wiener postulated that the brain contains a number of oscillators which are loosely coupled, and that they tend to pull each other together in frequency.

In support of this hypothesis, Wiener pointed out that the alpha rhythm could be driven by a flickering light or by an alternating electric field. If a light is flickered at a frequency close to the alpha rhythm, the alpha rhythm may be modified so that it is locked to the frequency of the visual stimulus.

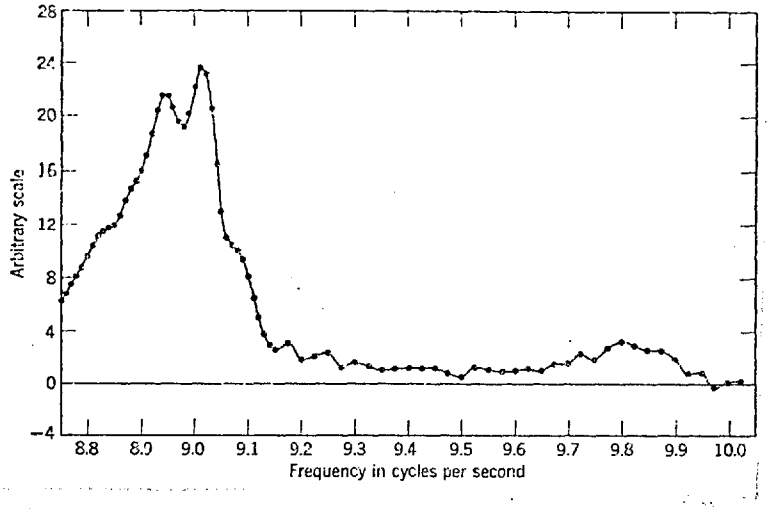


Figure 2.1

EEG spectrum. From Wiener, N. 'Cybernetics: or control and communication in the animal and the machine. 2nd edition 1961, p191. Reproduced by permission of MIT Press.

Wiener concluded that the proposed oscillators must be non-linear mechanisms, and that their natural free-running frequencies are on average somewhat higher than the alpha rhythm, so explaining the much larger drop in the power spectrum above the alpha rhythm peak than below it. He made a comparison with the diurnal rhythm of $23\frac{1}{2}$ hours observed in many species, which is pulled into a 24 hour rhythm by the environment.

Kingma et al. (1976) suggest two models for EEG generation. In the first model, white noise is generated in the deeper regions of the brain tissue. This white noise electrical activity passes through tissue layers which act as tuned filters (modelled by a 2nd order autoregressive process) to the measuring electrodes. The second model is similar to Wiener's, but it is suggested that the coupling causes a Gaussian spread about a particular frequency, This model provides a rationale for their data reduction method outlined above.

Elul (1968) also held that the outputs of a large number of generators were summed to give the gross EEG, and postulated that these generators were of cellular dimensions. He considered three alternative signals that could be summed in this way:

the action potentials of neurons: their slower dendritic spikes: and intracellular wave activity.

The action potential spikes are much shorter in duration than EEG waves (1-3 mS rather than 30-300 mS), but the number of neurons in the brain is in the order of 10^{10}, which is quite adequate to 'smooth' the waveform.

The dendritic spikes are slower and closer in form to the gross EEG. Davis (1976) supports the dendritic potential hypothesis: however, Elul has stated that under certain experimental conditions, such as anoxia, the dendritic spikes may be abolished without affecting the EEG waves.

In order to study the intracellular potentials of nerve and glial cells in the cerebral cortex of the cat, Elul made use of micropipettes filled with electrolyte (3M potassium chloride or 2M potassium citrate), with tip diameters of less than 0.5 micron.

In over 100 cortical neurons impaled in this study, undulations of the resting potential were observed, with amplitudes of 2 to 20 mV. These undulations resembled in their time course the gross EEG, although they were dissimilar in detail. Changes in frequency in the EEG were accompanied by

corresponding changes in the intracellular activity (for example, changes in the EEG when awake and asleep).

Other cells were impaled which did not exhibit oscillations of this type. They were characterized by an absence of spikes, and were tentatively classified as glial cells. Spinal cord neurons do not exhibit oscillations in the same frequency range. Elul concluded that this intracellular wave activity may be endogenous to nerve cells in the cerebral cortex, and possibly in other cerebral structures.

Extracellular waves similar in form and amplitude to the gross EEG were also recorded. These were less than 1% of the amplitude of the intracellular recordings. This led to the conclusion that the extracellular field was most likely to arise from activity in the neurons, rather than vice versa.

Amplitude probability distributions were computed both for the gross EEG and for the intracellular waves. The gross EEG was found almost invariably to approximate closely to a normal distribution, but the intracellular waves had an asymmetrical distribution which deviated from the normal curve. So it is possible that the EEG could be accounted for by invoking the central limit theorem. This theorem states that the sum of a large number of individual random variables always tends to assume a normal distribution, provided only that the component distributions are independent, or at least not linearly related (Loeve, 1963), and possess finite means and standard deviations.

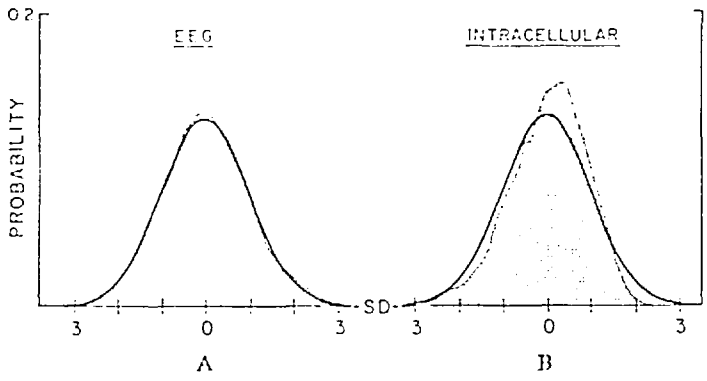


Figure 2.2

Amplitude probability distributions of cortical EEG (A) and of neuronal wave activity (B) over the same period in same preparation. Histograms were computed[48] for a 16-sec epoch at 400 sample/sec. Normal distributions with corresponding standard deviations are superimposed as a solid line. Note the striking similarity to the experimental plot of the EEG. The distribution of the neuronal waves (B), on the other hand, is clearly asymmetrical and deviates from the normal probability curve.

From Elul,R. 'Brain waves: intracellular recording and statistical analysis help clarify their physiological significance', in Enslein,K. (ed.) 'Data acquisition and processing in biology and medicine' vol.5 p93, 1968. Reproduced by permission of Pergamon Press.

The independence condition seems to be the most difficult one to satisfy. There appeared to be practically no linear interaction between waves in two extracellular sites only 30μ apart. The EEG and neuronal waves were tested for coherence, but for the most part the coherence did not exceed that expected by chance.

Fenwick et al. (1971) developed the model of random noise applied to an autoregressive filter to explain the generation of EEG. They took samples of EEG of various lengths and fitted autoregressive series of the form

$$X_t = a_1X_{t-1} + a_2X_{t-2} + ... + a_pX_{t-p} + Y_t$$

to them (where X_t , X_{t-1} , X_{t-2} ... were the samples at times t, t-1, t-2 ..., the a's were constants and Y_t was a random error component.) They started with a second order model, and if this did not give a significantly good fit, they increased the order of the model.

For 5, 10, or 20 second epochs the autoregressive models were very similar to each other, suggesting that the 'EEG generators' changed very little over that period. For 40 second epochs a new and complex model was required to represent the signal. It was not possible to fit a simple model to a 60 second epoch. This suggested that the statistical properties of the EEG were slowly changing and that the optimum length of an epoch for analysis was 20 - 30 seconds.

The impulse response of the autoregressive model could be calculated. When it was compared to the average of two evoked responses to click stimuli, it was found to be very similar in shape. This observation suggests that the ongoing EEG generators and the generators of evoked potentials have some features in common. However, as only two responses were averaged, the result was contaminated by a large amount of noise. The stimuli were 10 seconds apart, and only two stimuli were used because of the need for a short epoch for stationarity.

The problem of non-stationarity has also been considered by Jansen and Hasman (Jansen and Hasman, 1978: and Hasman et al., 1978). They segmented the ongoing EEG into segments of 1.28 s, overlapping each other by 0.64 s, took the power spectrum of each segment and compared them to discover trends. Brazier (1967) studied the non-stationarity of the visual evoked response of the cat. She noted that the amplitude of the response decreased with habituation, in a set of 240 consecutive stimuli arranged in four blocks of sixty.

Models for auditory evoked response generation fall into two main categories. There is the 'additive hypothesis', where a response is simply added to the ongoing EEG. Fenwick's autoregressive filter model would fall into this category, as the filter would be linear and so obey the superposition principle. Alternatively, if the EEG is generated by the weak coupling of a large number of oscillators, as in Wiener's model, the evoked responses may be caused by a temporary increase in synchronization between the

oscillators. This may be referred to as the 'synchronization hypothesis'. It is the purpose of this thesis to compare and test these two hypotheses. This follows on from similar work by Sayers et al. (1974 a,b; 1979), Ross (1978), Beagley et al.(1979).

Sayers et al. (1974a) examined the possibility of developing a method of analysing evoked responses that would be completely objective. This would avoid the need for the visual scoring of records by a skilled operator, a process which is prone to subjective bias. They questioned whether a linear filter method such as averaging could not be improved upon. Averaging is effective if identical responses are evoked by all stimuli and if the response waveform is uncorrelated with the spontaneous activity. These requirements did not seem to be fully met in evoked response audiometry: the tacit assumption that the ERA response consists of an additive contribution to the spontaneous activity needed further examination.

ERA tests were carried out on three adults and three children. The subjects were tested at various stimulus levels, trials at each level consisting of sixty stimuli such as 1kHz tone bursts, of 60mS duration with 10mS rise and fall times. The interstimulus interval was 1.25 seconds and the responses were sampled at 10 mS intervals for a length of 0.94 S, starting 50 mS post-stimulus.

Results from these tests suggested that for moderate stimulus levels, the average power in the post-stimulus averaged signal is not significantly different from that in a length of signal averaged from the pre-stimulus period, where no response occurs. It followed that the ERA response could be formed either by a redistribution of the total signal power amongst the spectral components: or by a modification of the relative phases of the spectral components present in the spontaneous activity. Amplitude and phase spectra were evaluated, and it was found that phase spectra values showed a marked difference in distribution between signals according to stimulus level, particularly for the first ten harmonics. It thus appeared that the ERA responses were formed by a phase constraint mechanism.

This hypothesis was further tested by imposing the average phase spectral properties of responses to a high stimulus level upon the averaged signal from sub-threshold stimuli. This procedure transformed the signal into an acceptable version of the high stimulus level response; that is, the two waveforms were similar and highly correlated. Imposing the average amplitude spectrum of responses from high level stimuli on the averaged signal from sub-threshold stimuli did not have this effect.

The next step was to develop a practical audiometric test, making use of these observations. In further experiments (Sayers and Beagley, 1974b) phase values were calculated for each of the first ten Fourier components and classified into four equal-size groups of 90° each. A χ^2 test with three degrees of freedom was used to test the null hypothesis of uniform phase distribution with 15 out of 60 sweeps in each class, for each harmonic separately. It was found that the 5% significance level occurred near the subjective threshold.

Different lengths of post-stimulus record (between 0.32 S and 0.94 S) were analysed. It was observed that after about 0.75 S post-stimulus the phase constraint effect diminished.

A refined χ^2 procedure is described by Sayers et al. (1979). The EEG records used were sampled at 100/S and were 640 mS in length, starting 150 mS pre-stimulus. Each set of 64 samples was fast-Fourier transformed and the phases of the first 20 harmonic components were computed. Phase histograms for the ensemble of 60 records were constructed for each harmonic H1 - H5. The histograms consisted of 24 bins of 15° width. The rotational χ^2 procedure was then

applied to the results. The two 180° bins used in this test are formed from two sets of twelve contiguous 15° bins. The test is repeated for each of the 12 possible rotations of these bins, and the largest value of χ^2 found by this procedure is accepted.

The reasoning behind the rotational χ^2 procedure is as follows. In the presence of a stimulus, the phases, although constrained to some extent, still exhibit variation over a wide angle. In order to detect this constraint, the minimum number of bins of equal size (two) would in theory lead to the most sensitive test. However, if two fixed bins are used, the boundary between them is arbitrary and may lie near the mean of the phase angles being tested. In this case, the test would be relatively insensitive to phase constraint phenomena. This effect is much reduced by using the rotational procedure. The arbitrary placement of the bin boundaries is now restricted to a range of 15° instead of 180°.

This paper also describes a method of similarity analysis of individual post-stimulus records. The product-moment correlation coefficients between individual records of 0.64 s length post-stimulus, and an averaged response pattern (AVP) were computed. The AVP was determined by coherent averaging of the post-stimulus EEG potentials in one or more trials of 60 suprathreshold stimuli.

The correlation coefficients obtained by this method typically exhibited a wide variation, making comparisons between trials of different stimulus levels difficult. However, by rank-ordering the correlation coefficients, a much clearer display was achieved. This technique assumes independence in the order of the correlation values. Trials with no stimulus, and with stimuli at 20 dB and 40 dB above the subject's threshold, were compared in this way. Increasing stimulus level resulted in a marked increase in correlation.

Ross (1978) compared a number of possible methods for the objective detection of auditory evoked potentials. These fell into three categories: power measures, phase distributional analysis, and template matching by cross-correlation.

In the power test, a simple a.c. power comparison was made between averaged pre-stimulus and post-stimulus waveforms, using a Fisher F-test. 88 trials of 54 sweeps each were used in the analysis. The subjects were five normally hearing adults. Of the methods examined by Ross, this test gave the poorest agreement with the results of subjective tests (pure tone audiogram (SL) and visually scored average response). The reasons for this were investigated by simulating ERA data using a superposition model, and comparing this data with actual ERA data. The simulation was done by taking normally distributed noise, with an amplitude spectrum filtered to conform to that of spontaneous EEG, and adding a typical average response at various signal-to-noise (S/N) ratios. S/N ratios of 0.1 and 0.25 led to coherent averages which were comparable to real data. However, this simulation did not model the non-stationary character of the real data.

The possibility of using the amplitude spectrum was also examined. Synthesized data at S/N ratios which were typical of real data were used. There was often some slight increase in the amplitude of harmonics 1 and 2 when the signal was added to the noise, but this was not significant at the 5% level.

Phase distributional analysis led to more promising results. The χ^2 test with four fixed bins (χ^2_3), and the rotational χ^2 test with 18 bins of 10° each (χ^2_r), were studied. Both these tests gave good agreement with subjective results.

These procedures depend on dividing the phase distribution into arbitrary discrete bins. A procedure which does not have this feature is the 'phase vector' method. In this method, the phase values are viewed as vectors of unit magnitude. The mean phase of an ensemble of vectors is found by vector addition. The angle of deviation between each member of the ensemble and the mean, and thence the phase standard deviation, may then be computed. The expected value of the variance of uniformly distributed phases is

$$E(\sigma^2) = \frac{1}{360}\int_{-180}^{+180} x^2\, dx$$

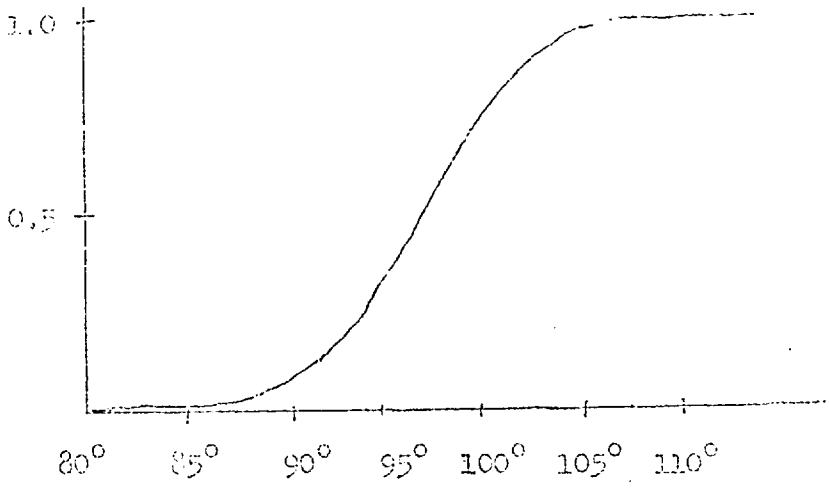
and hence the standard deviation is $E(\sigma) = 104^\circ$. Phase constraint phenomena lead to a decrease in the phase standard deviation.

An important feature of the phase vector approach is its freedom from wrap-around effects. If the phase mean and standard deviation were calculated by treating a sample of phase values as a set of scalars over the range -180° to $+180^{\circ}$, say, then misleading results could occur. A sample of phase values aggregated around $\pm 180^{\circ}$ would be split into two sets, one near $+180^{\circ}$ and the other near -180°, giving a misplaced mean and an incorrectly large standard deviation.

In order to interpret the results of the phase vector test, the sampling statistics of phase standard deviation ($sd\vec{\psi}_i$) have to be known. Ross derived a total of 680 estimates of mean phase vector, magnitude and standard deviation, from unstimulated EEG records. From these she constructed an ogival cumulative frequency distribution curve, from which confidence limits may be read. The standard deviation was a biased estimator, depending on the sample size.

This bias was investigated further (Ross et al. 1979). It can be explained by considering a small sample from the uniformly distributed variable. There is a finite probability that all the random values will aggregate, by chance, in one half of the 360° range, in which case the mean will be centred in this part of the range, and the standard deviation will be much

Figure 2.3



Cumulative frequency distribution of $_{sd}\vec{\psi}_i$, derived from the phase ensembles of spontaneous EMG. (Sample size 54). Reproduced with permission from Ross (1978).

Table 2.1

N	5%	2.5%	1%	0.5%
40	86.3°	83.5°	80.7°	78.7°
48	87.8°	85.5°	83.1°	80.5°
54	88.5°	87.5°	84.0°	81.8°
60	90.1°	87.5°	84.6°	82.7°
70	91.0°	88.8°	87.7°	86.2°

Confidence limits for the standard deviation $sd\,\vec{\psi}_i$ as a function of sample size N.

Reproduced with permission from Ross (1978) (excerpt.)

smaller than 104°. To take the extreme case, with two samples, the standard deviation can never be greater than 90°. The effect becomes less important with increasing sample size.

Ross also examined the cross-correlation method. An exploratory study was made using records from 17 normal hearing adults. The averaged response to an 80dB HL tone burst was used as the reference waveform. Each subject was tested at two different tone burst frequencies, at levels ranging from -10dB to 80dB HL. As before, there were 54 stimuli in a trial. This procedure usually detected the presence of the AEP to within +15dB of subjective threshold.

Following this study, an on-line investigation was undertaken, the analysis being performed by a Hewlett-Packard 2100 computer. Fifteen normal hearing subjects aged from 18 to 31 were chosen for this on-line study.

The results from these various techniques were compared with results from the pure-tone audiogram (SL) and the visually-scored coherent average. A table was drawn to show the percentage agreement, false positives, and false negatives, between tests.

Test		SL			Coherent Average		
		A	FP	FN	A	FP	FN
Power	F	58%	10%	32%	64%	11%	25%
Phase	χ^2_3	83%	5%	12%	88%	5%	7%
"	χ^2_r	83%	3%	14%	90%	3%	7%
"	sd	84%	5%	11%	88%	5%	7%
Template Matching	$\bar{r}_o$	81%	3%	16%	84%	4%	12%

Table 2.2 Comparison of subjective and objective procedures for estimating auditory threshold. A= % agreement, FN = false negatives, FP = false positives. Reproduced with permission from Ross (1978).

It can be seen from this table that the phase vector method agrees well with the two subjective methods, with the advantage of objectivity. It is a simpler and faster algorithm than the rotational χ^2 procedure - Ross states that the computing time is reduced by at least a factor of three. She suggested that a special purpose mini-computer or microprocessor system could be developed to perform the analyses required for extensive on-line trials of the technique, and this led to the present programme of research.

CHAPTER 3

THE STIMULUS GENERATOR

3.1 A review of previous designs for auditory stimulus generators.

A number of circuits have been proposed for generating tone burst stimuli of the type required for audiological work, using mostly analogue techniques. This contrasts with the present design, which is essentially digital, apart from the output circuits.

These designs have invariably consisted of: a sine-wave source, a circuit for generating an envelope waveform such as a trapezoid, and a modulator for multiplying the two signals together. A general requirement of stimulus generators is that there should be a minimal amount of sound produced in the periods between successive stimuli, and this appears to have been the greatest problem in the design of suitable modulators.

Glaser (1964) described a circuit which used a Hall effect device as a modulator. When a magnetic field and an electric current are passed through perpendicular planes of a semiconductor crystal, an e.m.f. is produced which is proportional to their product, along the direction perpendicular to both the magnetic field and the current. An on-off ratio of 60 dB was achieved with this modulator. A choice of triangular, trapezoidal and Gaussian envelopes

was provided. The triangle waveform was generated by integrating a rectangular pulse. The trapezoidal waveform was generated by limiting the amplitude of the triangle, and the Gaussian envelope was produced by passing the triangle signal through a diode-shaping network. A further type of envelope that could be produced was one with a flat central section but with Gaussian rise and fall. A synchronizing circuit was provided, so that successive stimuli were in phase with each other.

Olson and Ludwig (1965) described an improvement to this idea. A transistor switch was added, in the path of the sine-wave signal, before it was applied to the Hall multiplier. This increased the on-off ratio from 60 dB to 80 dB. No synchronization was provided between the sine-wave signal and the envelope generator, so that successive stimuli were not necessarily in phase with each other.

Disadvantages of the Hall multiplier were its limited frequency response and dynamic range. Arlington (1969) designed a modulator using four field-effect transistors in a balanced series-shunt configuration. An on-off ratio of 90 dB was attained with this circuit. The envelope was approximately trapezoidal. A particular feature of Arlington's stimulator was that the inter-stimulus period could be of fixed duration or of random duration. This

latter mode was intended to reduce anticipatory effects in experiments. Succcssive stimuli were not synchronized in phase with each other.

Ludwig (1970) described a stimulus generator using an integrated circuit analogue multiplier (Motorola MC1595L) as a modulator. The on-off ratio of this modulator was only about 60 dB, so again it was found necessary to include an additional fast switch for switching the sine-wave signal before applying it to the modulator. This increased the on-off ratio to 90 dB at 20 kHz and 80 dB at 50 kHz. A trapezoidal envelope generator, with phase synchronization, was used with this modulator.

Modulators using bipolar transistors in an emitter-coupled configuration have been described by Klig et al.(1970) and Roberts and Watson (1974). In the former design, problems of transistor matching were minimised by using two transistors on the same integrated circuit (RCA CA3006) in the emitter-coupled configuration. A trapezoidal envelope generator which could be triggered externally was used, but triggering circuits were not described. Roberts and Watson used discrete 2N2926 transistors in their stimulator. The envelope generator was triggered by a special-purpose computer which was used for EEG processing. Consequently, successive stimuli were not necessarily in phase.

A design for a stimulus generator using digital techniques was proposed, as a number of advantages over previous analogue designs were apparent:

1) Stimuli could be reproduced accurately and would always start in the correct phase relationship with previous stimuli.

2) A wide variety of waveforms could be produced simply by re-programming. This flexibility is not readily available with analogue circuitry.

3) An accurate modulator would not be needed. Noise between stimuli would consist mainly of internally generated noise from the power amplifier, and this could be kept at a very low level.

4) A microprocessor-based system, capable of producing such stimuli, would also have the power to perform other tasks such as signal analysis.

5) Microprocessors had become sufficiently low in price for the microprocessor-based stimulus generator to be a reasonable proposition from the cost point of view.

3.2 Initial design of the stimulus generator

A specification of the proposed stimulus generator drawn up in September 1977 called for the following features:

1) Wide band 'clicks' or rectangular pulses of for example 100uS width. Any number of pulses from 1 to 2048 in a train of PRF $\frac{1}{2}$,1,2....32/second.

2) Tone bursts of variable frequency; 250 Hz, 500 Hz, 1,2,4,8 kHz. Controlled rise and fall with a half-cosine envelope. The rise and fall times to be specified either in terms of milliseconds or in terms of a number of cycles of the tone burst.

It was found during development of the software that there was little to be gained by limiting the frequency to a few discrete steps, and so the tone-burst frequency was made variable from 10-9999 Hz.

3) Narrow band filtered clicks or 'logons'- a sine wave multiplied by a Gaussian envelope.

4) Polarity of the stimuli to be positive, negative or alternately positive and negative.

5) Trigger pulses for triggering other pieces of equipment to be generated. When the software was originally written one such trigger pulse with variable

pre-stimulus time was provided, but later it became clear that four such trigger outputs would be needed.

6) The audio output sampling rate to be 200kHz, with a resolution of eight bits.

Widely available microprocessors such as the 6800 or 8080 would not have been capable of reading samples from memory and outputting them to a D/A converter at such a high rate. The first suggested designs used various forms of direct memory access (DMA) to overcome this problem. The waveform would be stored in a block of memory, the address lines of which could be connected either to the microprocessor or to a 200 kHz counter. The major problem was how to generate the envelope of a tone burst, and three solutions were proposed:

1) Compute the entire tone burst (rise, plateau and fall sections) and store it as one array of data in memory. Then an 8k byte memory would be able to store a tone burst not longer than 40mS.

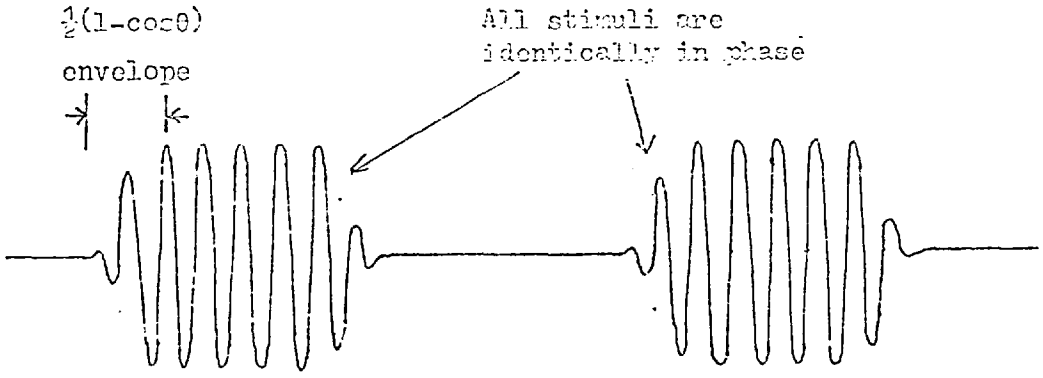
2) Store one cycle of the tone burst and read it out repeatedly. The generation of the envelope would then be a separate function, performed by a digitally controlled attenuator using CMOS transmission gates. This system would be capable of producing tone bursts of unlimited length.

3) Store the tone-burst in three sections in memory; the rise section, the fall section, and one cycle of the plateau section, which would be repeated as many times as required. The rise and fall times would be limited by the memory capacity.

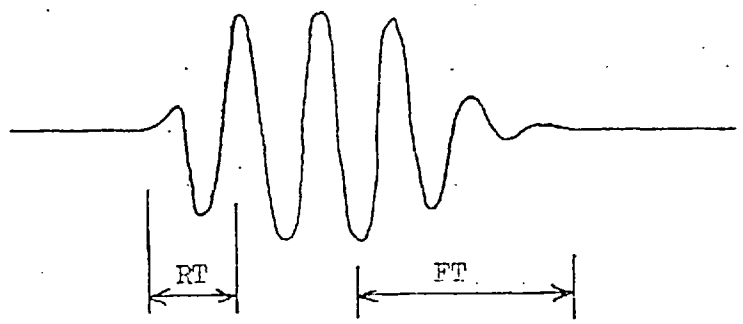
Preliminary tests with an IBM 1800 computer indicated that a lower sampling rate would in fact be adequate. Sampled, quantised and low-pass filtered versions of a sine-wave were computed, along with their power spectra. A sampling rate of 8 samples per cycle (i.e. four times the Nyquist rate) was found to give reasonably good results, with little power in harmonics 7 and 9, and less in the other unwanted harmonics. As the highest specified frequency of the stimulus generator was 8 kHz, this corresponded to a sampling rate of 64 kHz.

At this time the Motorola MEK6800D1 evaluation kit was being used in order to gain experience with the 6800 microprocessor. A number of subroutines were written in machine language, such as multiplication, division, and decimal-to-hexadecimal conversion, which were later to be used in the stimulus generator programme. It was noted that a short routine could be written which would output a sequence of data at a rate of one sample every 14 microprocessor clock cycles.

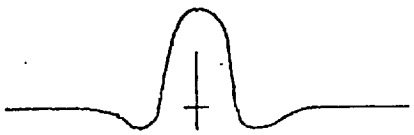
The required sampling rate of 64 kHz. minimum would now be within the capabilities of the microprocessor, without using DMA techniques. The frequency of tone-burst stimuli would be related to the microprocessor clock frequency, which would be crystal-controlled and hence very stable.



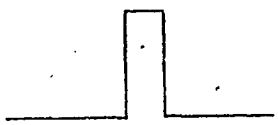
Tone burst stimulus



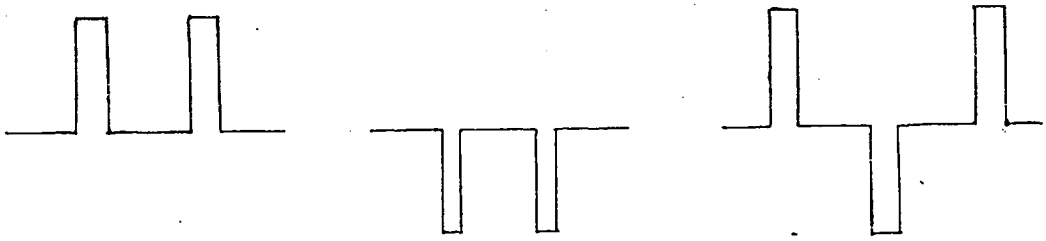
Rise and fall times may be different - they may be specified in mS or in number of cycles.



Logon



Pulse



Stimuli may be positive, negative, or alternate.

Figure 3.1 Examples of waveforms produced by the stimulus generator.

3.3 Introduction to the 6800 microprocessor.

As digital integrated circuits became more and more complex, the microprocessor was introduced out of economic necessity. The problem was that the variety of possible integrated circuits seemed endless, while in order to manufacture them cheaply it was necessary to sell millions of the same type. It was realized, through the work of Turing and Post (Minsky, 1967), that a relatively simple finite-state machine could perform all the computational functions of a much more complex machine (though possibly at a lower speed), as long as it was connected to a sufficiently large memory, in which data and programmes could be stored and read. The microprocessor is such a device, consisting of one integrated circuit (or sometimes a small number of ICs.). It can execute a limited set of simple instructions, though it is fair to say that microprocessors are now rivalling the more basic minicomputers in their capabilities. The versatility of the device makes it possible to market the very large numbers required for the economic viability of large-scale integration.

Microprocessors are connected to memory via a data bus and an address bus, and they are classified by the width of the data bus. In 1977, widely used devices included the four-bit Texas TMS1000, mainly intended for simpler applications such as calculators and point-of-sale terminals; eight-bit devices such as the Motorola 6800, Intel 8080, Zilog Z80 and Signetics 2650; and the more expensive sixteen-bit devices such as the Texas TMS 9900. The Motorola 6800 was chosen for this project for several reasons, apart from its low price and availability from a number of sources;

i) The 6800 had been designed with the problem of interfacing very much in mind. The 6800 family includes interface IC's which simplify this problem to a great extent, allowing the programmer to treat peripherals as if they were locations in memory. This was considered an important advantage, as the system would have a number of inputs and outputs, both digital and analogue.

ii) Software support in the form of a cross-assembler for the 6800 was provided by Imperial College Computer Centre. This speeded up the process of assembling and editing programmes. (Cross-assemblers were also available for the 8080 and 2650).

iii) As the analogue output from the system was to be to 8-bit accuracy, the 8-bit structure of the 6800 was ideal for the application.

iv) The instruction set for the 6800 includes binary and decimal arithmetic operations and a wide range of logical operations. Eight-bit and sixteen-bit arithmetic operations were to be performed by the system: the sixteen-bit operations could be done by using two eight-bit bytes with little difficulty.

v) An important feature of the 6800 is the stack, which is used for handling subroutines and interrupts. It was realized that the stack control instructions could also be used for reading out a block of data at a high rate. This technique was used in the stimulus generator programme.

3.3.1 6800 Instructions.

The complete instruction set is described in the M6800 Microprocessor Applications Manual (Motorola, 1975). The following is intended as a brief guide to the types of instructions that are available.

The 6800 contains six registers that are directly under programme control. They are: two 8-bit accumulators (A and B); three 16-bit registers, called the index register, the programme counter, and the stack pointer; and a six-bit condition codes register.

The accumulators are used in most arithmetic and logical operations. The index register is mainly intended for use in indexed addressing, which will be described shortly. The programme counter points to the location in memory of the next instruction to be executed. It is modified by branch and jump instructions, and by interrupts. The stack pointer points to the next free location of a block of memory arranged as a last-in first-out (LIFO) stack. When a subroutine occurs, the address of the next instruction after the subroutine is stored on the stack. (When an interrupt occurs, the contents of the accumulators, index register and condition codes register are also stored on the stack). As the depth of the stack is only limited by the memory available, subroutines may be nested very deeply.

The condition codes register consists of six flags (labelled H,I,N,Z,V,C) which are set or reset as a result of arithmetic or logical operations. For example, if the effect of an instruction is to clear an accumulator, the Z bit is set. The flags may be used to control the flow of a programme through conditional branch instructions.

Many instructions involve only the internal registers of the microprocessor. The accumulators may be cleared, complemented, negated, shifted, rotated, incremented or decremented, and added to or subtracted from each other. The contents of one accumulator may be transferred to the other one. The index register and the stack pointer may be incremented or decremented and transfers can be made between them. The contents of the condition code register can be transferred to accumulator A and vice versa.

In order to use data stored in the memory, the microprocessor must be able to address each location as required. The addressing modes of the 6800 are;

i) Immediate
ii) Direct
iii) Extended
iv) Indexed
v) Relative

Not all modes are available for every instruction. With immediate addressing, one operand of the instruction is contained in the instruction itself. With direct and extended addressing, this operand is in a location pointed to by the instruction. The difference between the two is that direct addressing instructions consist of two eight-bit bytes and can only address the first 256 bytes of memory, while extended addressing instructions are three bytes long but are not limited in this way.

In indexed addressing, the address of one operand is found by adding a byte in the instruction as an unsigned integer to the index register. This addressing mode can save programme bytes, and makes programme relocation easier. Relative addressing is used only in branch instructions. A byte of the instruction is added as a two's complement number to the programme counter, causing a branch over a limited distance forwards or backwards in the programme.

The one-operand instructions mentioned above for the accumulators can also be done in memory, although they take a longer time. Two-operand instructions, which use one operand from memory and one from an accumulator, and place the result in the accumulator, exist for many common arithmetic

and logical operations (add and subtract with or without carry, AND, OR, exclusive-OR). There are 'compare' instructions which do not alter the contents of the accumulators or memory, but which set the condition codes register in preparation for a conditional branch. Data may be transferred between accumulators and memory by 'store' and 'load' instructions.

Other instructions that should be mentioned are: the 'jump', which, although unconditional, does not have the distance limitation of the 'branch'; the 'push' and 'pull' instructions, which allow the contents of the accumulators to be stored in the LIFO stack; and the 'decimal adjust' instruction which is designed to simplify programmes which use BCD arithmetic.

3.4 Description of microprocessor system

The microprocessor was a 6800 type with 8-bit architecture. Although it was capable of operating at a 1 MHz clock rate, a 921.6 kHz crystal was used, as this frequency could be divided by simple ratios to give standard baud rates.

A monitor programme (Motorola MINIBUG) was used to control the operation of the system. It was contained in a read-only memory, MC6830L7. This had associated with it a scratch RAM of 128 bytes, MC6810. The main random access memory consisted of 4 k byte RAM boards. At first, two such boards were used, but as the programme became more complex it was found that another board was required. These boards were buffered by means of 8T97 tri-state buffers in the address lines, and 8T26 bi-directional tri-state buffers in the data lines. Bi-directional buffers are necessary if the memory is to be both read from and written into. The intention was that one RAM board would be replaced by programmable read-only memory (PROM) when the programme was in a completed form.

Communication with an RS232 standard data terminal was done by means of an Asynchronous Communication Interface Adapter (ACIA), type MC6850. This performs the necessary conversions between parallel data, as used by the microprocessor, and asynchronous serial data, as transmitted and received by

the terminal. The clock for this IC was generated by dividing the microprocessor clock waveform by 3×2^n, where n is selectable such as to give standard baud rates from 75 to 9600. This division was done by a CMOS IC, MC14040. The ACIA handles data at TTL levels, while the RS232 standard uses voltage levels of +6V and -6V. The necessary level shifting was done by an 8T15 line driver and 8T16 line receiver.

A Peripheral Interface Adapter (PIA), MC6820, was used to interface the microprocessor with a digital-to-analogue converter for the generation of audio signals. The eight-bit D/A converter was a Ferranti ZN425E integrated circuit, which had a voltage output with a range of 0V to +2.5V. This was buffered and amplified by a 741 operational amplifier which was arranged to give a voltage output from -2.5V to +2.5V (i.e. symmetrical about zero).

Restart and interrupt vectors were generated by 8T96 and 8T98 tri-state buffers, which were taken out of their normal high impedance state when a restart or interrupt condition was detected by the microprocessor.

The 4K random access memory boards were assembled from kits supplied by Newbear Micro-computer Systems Ltd. They contained thirty-two 1K bit RAM integrated circuits type 2102-1, and were double Eurocard size (160mm x 234mm). The remaining components of the stimulus generator were mounted on printed circuit boards of the same size. 64 way indirect edge connectors were used for connecting the boards together.

Power supplies of +5V, +12V and -12V were used. These simply consisted of a transformer, full-wave rectifier, reservoir capacitor and a suitable integrated circuit regulator.

The entire unit was housed in a card frame about 7" high for mounting in a standard 19" rack.

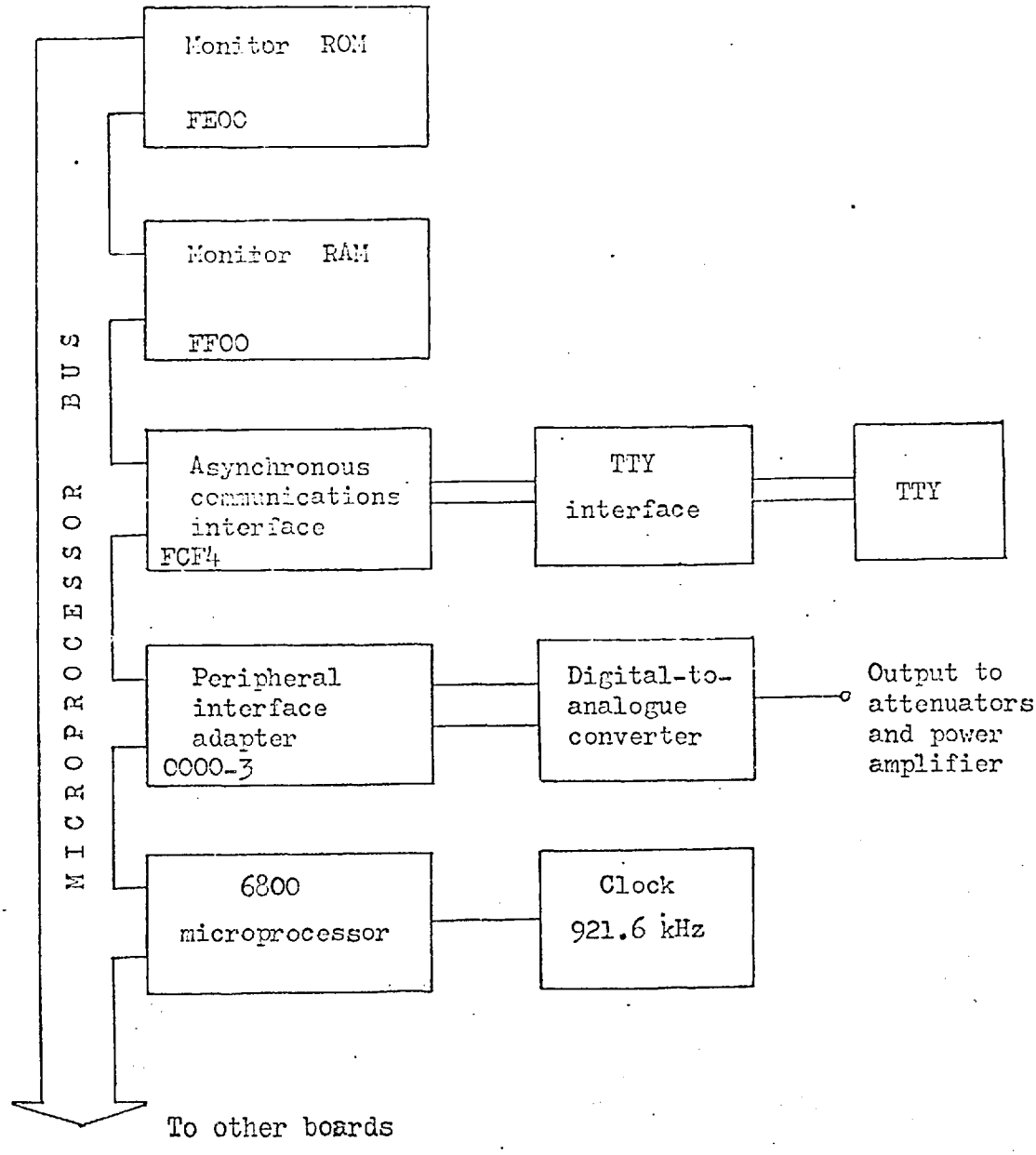


Figure 3.2 Block diagram of microprocessor board.

FFFF FFFE	Restart Vector	FED6
FFFB FFFA	SWI Vector	FF57
FFF9 FFF8	IRQ Vector	FF57
FF7F FF00	RAM 128 bytes	
FEFF FE00	MINIBUG ROM	
FCF5 FCF4	UART	
4FFF 2000	12K RAM	
017F 0100	Buffer RAM 128 bytes	
0083 0080	PIA Audio	
0043 0040	PIA Video	
0003 0000	PIA Time	

Figure 3.3 System memory map.

3.5 Safety device.

It was felt that, while short tone bursts of high amplitude would not damage the ear of the listener, longer tone bursts might do so. Tone bursts of excessive amplitude could be generated by incorrect setting of attenuators, for example. An automatic device was therefore constructed which had the following functions;

1) Tone bursts of less than 16mS duration and of any amplitude would be unaffected.

2) Tone bursts of greater than 16mS duration would not be affected if their amplitude did not exceed a preset critical value.

3) A tone burst with amplitude greater than the critical value would not be affected for the first 16mS. After that a gate would be operated which would greatly reduce the output until the end of the programmed sequence.

A fraction of the output voltage is full-wave rectified by a circuit using one 741 operational amplifier. The signal is then compared with a threshold voltage of 3V by a 710 comparator. Whenever the threshold is exceeded, the first of a pair of 74121 monostables is fired. After 16mS this fires the second monostable. If the threshold is exceeded

at any time while the second monostable is firing, a latch is set. An LED lights up to indicate that the safety device has operated, and a CMOS gate is turned on, reducing the stimulus generator output to a low level. The latch is reset by the 'Trigger' signal, which is low before a programmed sequence is generated.

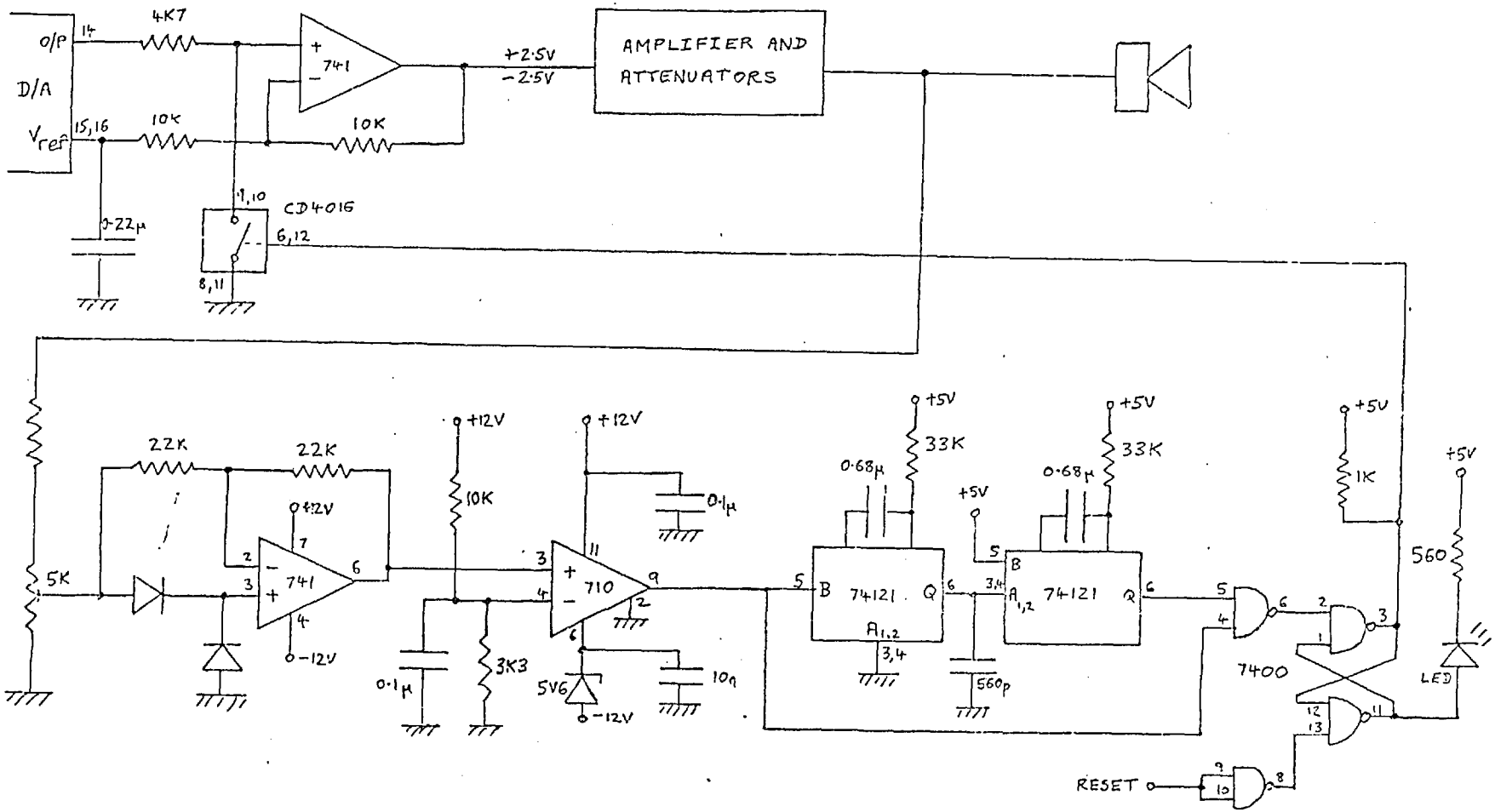


Figure 3.4 Safety device.

3.6 Problems arising while testing the microprocessor board.

1) There were delivery problems with the microprocessor clock (MC6871) and the remainder of the board was wired up long before this clock was expected to arrive. In order to test the board, a clock circuit was built on a small piece of Veroboard as a temporary measure. This used a 74123 dual monostable, and two discrete transistor buffer circuits. This was based on a Motorola design, but 2N2905 pnp transistors and 2N3053 npn transistors were used instead of the suggested four-transistor package MPQ6842, as they were immediately available. The circuit depends on delays through the monostables to generate two clock phases with the required non-overlapping properties.

The clock circuit worked completely satisfactorily until it was replaced by the MC6871, although as it was not crystal controlled, it could not be expected to have the frequency stability of the MC6871.

2) The 'MINIBUG' monitor ROM worked correctly when used with a Texas 'Silent 700' printer and keyboard. However, a problem occurred when trying to load programs that had been recorded on data cassettes. Lines of less than about 32 characters could be loaded, but if a line was longer than this, one in every ten or eleven characters would not be read. This would result in the line having the wrong length and wrong checksum, and the monitor would escape from the 'load' routine.

This was thought to be due to a timing problem in the ACIA (asynchronous communications interface adapter) which handles data communication between the microprocessor and the teleprinter, converting parallel to serial data and vice versa. Firstly the ACIA clock was checked to ensure that it was running at the same frequency as the clock in the teleprinter. This was within 1% of the correct frequency (the 74123 clock was in use at this time). The two clocks were then locked together in frequency, but even this did not cure the fault.

Some of the ACIA functions are under software control, and are selected by the monitor programme in the 'MINIBUG' ROM. The problem was found to be caused by the fact that 'MINIBUG' set up the ACIA to receive serial data with two stop bits per character, but that the teleprinter, when running at 150 or 300 baud, only transmitted one stop bit per character.

The system worked correctly at 110 baud (when two stop bits are transmitted) ; however, operation at this speed would have meant that loading programmes would be very time-consuming.

Changing the software to set the ACIA for one stop bit was not straightforward. The ACIA control register is reset at various points in 'MINIBUG'. For this reason it could not be changed by a simple 'Memory Change' operation. Also 'MINIBUG' itself could not be changed as it resided in read-only memory.

The solution was to insert a line at the top of the file to be loaded, which would set the ACIA to the required format. This had to have the correct line length and checksum bytes in order for it to be accepted by 'MINIBUG'. Being only a short line, no difficulty was encountered in loading it. Succeeding lines could then be of any length up to 256 characters.

The extra line can be inserted (by editing) into files produced by the cross-assembler on the College CDC computer. It is;

S104FCF4B556

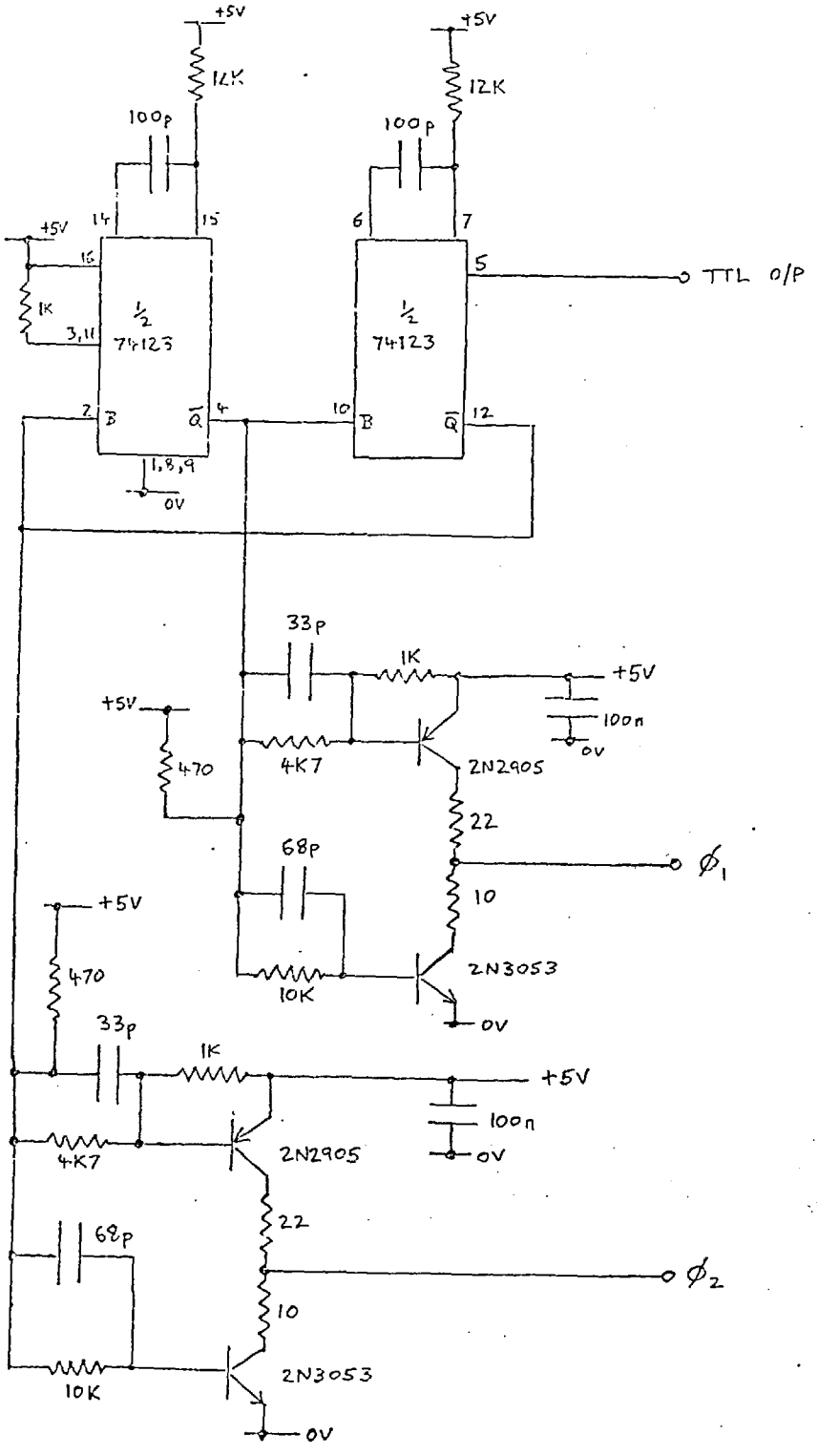


Figure 3.5 Microprocessor clock.

3.7 Software Description

The operating system of the machine is the Motorola MINIBUG, which resides in ROM at location FEF0 to FEFF (all addresses in hexadecimal). This has associated with it a small RAM of 128 bytes at FF00 to FF7F.

The first version of the stimulus generator programme to be written (called STIMB), used the microprocessor board and 8K of random-access memory - two 4K RAM boards located at 2000 - 2FFF and 3000 - 3FFF. Later, an improved version of the programme was written (STIMC) ; this entailed the use of a further 4K RAM board located at 4000 - 4FFF and also used some extra timing hardware on a fifth board. The stimulus generator programme consisted of three major sections:

(i) INFORM. This is an interactive programme which collects all the information required from the operator. This information is stored in a convenient format in a specially reserved area.

(ii) COMPIL. When a tone burst or logon is to be generated, this section uses the data collected in INFORM to compute the required digitised waveform and stores it in the waveform storage area.

(iii) EXEC. This is the section which actually generates the stimulus.

3.7.1 EXEC routine

On entering this part of the programme the PIA (Peripheral Interface Adapter) is initialised, with all I/O ports being set up as outputs. The TTY prints 'READY' and awaits a response from the operator. On responding, a trigger pulse is generated which may be used to start other equipment, then, after a trigger delay time, the first stimulus is generated, as follows.

A 'mode word' stored at a fixed location is examined to determine whether the stimulus is a tone burst, pulse or logon. Valid mode words are:

01	Pos. pulse	02	Neg. pulse	81 (hex)	Alternating pulse
04	Pos. logon	08	Neg. logon	84 "	Alternating logon
10	Tone starting with positive half cycle				
20	Tone starting with negative half cycle			90	Alternating tone

If a positive pulse is called for, the byte FF is sent to the D/A converter, giving maximum positive output. If a negative pulse is requested, the byte 01 is sent to the D/A. After a delay equivalent to the pulse width, the D/A output is set to zero volts.

If a tone burst or a logon is indicated, it is generated by reading out a list of data which is kept in a stack. There are two routines for reading out the stack; one reads the data out directly, and the other inverts the data. The routine to be used is determined by the mode word. If alternate positive and

negative signals are required, the mode word is changed each time to select the two routines alternately. The stack begins at a starting address SO which depends on the length of the stimulus, and always ends at a location which contains the word 00, which is not regarded as a valid input to the D/A converter, and is an indication to the machine to stop reading the stack.

A count is maintained of the number of stimuli that have been generated. If there are more stimuli to be generated, an 'inter-stimulus delay' time elapses before the programme branches back to generate the next stimulus.

In tone or logon mode, the samples are read out at a rate of 65.829 kHz. This is derived from the system clock frequency of 921.6 kHz, which was chosen so that standard terminal baud rates could be generated by simple division. Thus a sample is read out once every fourteen microprocessor clock cycles. The frequency of 65.829 kHz (which is approximately 257 x 256 Hz with 0.05% error) means that more than eight samples per cycle are provided at the highest stimulus frequency of 8 kHz.

3.7.2 COMPIL routine

This routine is skipped in the pulse mode, but in the logon mode or the tone burst mode it sets up the stack described in the EXEC routine.

COMPIL uses data stored by the INFORM routine. The nature of this data will become clear during the description of COMPIL.

COMPIL uses special registers in reserved locations for various functions. Two consecutive locations contain the current address CA (a two byte word) of the data point which is currently being computed. CA will point to a location somewhere between the starting address SO, and the end address ENDHL, incrementing as the compilation proceeds. The other special registers used by COMPIL have different functions depending on whether a tone burst or a logon is being computed.

In the logon mode, two consecutive locations are used as a logon register LR. This is incremented for each data point by an amount L (also a two byte word) which is stored during INFORM and depends on the logon time constant. The most significant byte of LR is used in the calculation of the logon, although both bytes are in general incremented at each new data point. This is done in order to reduce the possibility of cumulative errors in timing which could occur if a logon register of only one byte was used.

The logon function of LR is found from a lookup table of 64 bytes. If the mode word is 8, the logon is negated. After each data point has been calculated, the current address is incremented and tested. If then CA = ENDHL, a 0C byte is stored at this location and the programme branches to EXEC; otherwise the next data point is calculated.

In the tone mode, three consecutive locations are used as a cycle register CR. All three bytes are, in general, incremented at each new data point, although only the most significant two bytes are used in the computation of the sine function. This allows for better frequency resolution than would be obtained if a cycle register of only two bytes was used. The cycle register is initially cleared.

The sine function is computed and stored at a reserved location. The current address CA is tested to determine whether it is in the rise section at the beginning of the tone burst, the fall section at the end, or the plateau between these sections. If CA is in the plateau section, nothing more remains to be done except to store the sine at the address pointed to by CA. In the rise and fall sections, the envelope or weight function has to be computed. This is done by using a three byte rise/fall register in a similar way to the cycle register. The weight function is computed and stored. The weight function and the sine

function are multiplied together to give the required result. This is stored at the address pointed to by CA. CA is incremented and the process is repeated until CA = ENDHL. This byte is then cleared and the programme branches to EXEC. This is indicated by a message 'READY' typed by the system.

The cycle register is incremented by a two-byte word N between data points. During the rise section, the rise register is incremented by a two-byte word R, and during the fall section it is incremented by a two-byte word F.

3.7.3 INFORM routine

This is an interactive routine which collects the data required from the operator in order to define a train of stimuli. After initialising the system, INFORM asks the first question,

NO. OF STIMULI

The operator responds with an integer in the range 1 to 9999. If more than one stimulus is requested, the next message will be

PRF HZ

The operator may respond with an integer, an 'X' character or an '=' sign. If he responds with an 'X', an alternative question is asked;

REPT PERIOD MS

to which the same choice of responses apply. During a second or subsequent run of INFORM, an '=' sign has the effect of maintaining the values that were loaded in previous runs.

Regardless of whether the PRF or the repetition period were loaded, this information is stored as a word P which is proportional to the period. (P was a two-byte word in units of 14 microprocessor clock cycles, corresponding to the output sample rate, in the original programme STIMB, but was later changed to a one-byte word

in units of 10 mS in STIMC to exploit extra timing hardware that had been added to the system).

The programme then requests the timing of the four trigger outputs. These are positive pulses 10mS long, and the trigger time is measured from the positive going edge of the trigger pulse to the onset of the stimulus. The four outputs may all have different timings, and the timing resolution is 10 mS.

The next decision to be made is.

PULSE, TONE, LOGON:

The operator responds P,T or L. The next message is

POLARITY:

and the response is P, N, or A. A corresponds to alternating positive and negative pulses, the first pulse in the train being positive. The mode word is set according to the last two responses. The course of the programme from this point depends upon which mode has been chosen.

In the tone burst mode, the message

TONE FREQ HZ:

is printed. This may be responded to by an integer, equals sign or 'X' character, the 'X' giving the alternative message

TONE PERIOD US:

The amount by which the cycle register is incremented at each new data point, N, is then calculated. The next message is

BURST WIDTH MS:

or, alternatively, NO. OF CYCLES:

The numerical response is used in calculating the total number of samples (which is tested to ensure that there is sufficient memory available in which to store the samples). The starting address S0 is then computed. The burst width is also tested to ensure that it is not greater than the repetition period.

The responses to the next two messages,

RISE TIME MS: (or NO. OF CYCLES:)
and FALL TIME MS: (or NO. OF CYCLES:)

are used in calculating the number of samples in the rise and fall sections of the tone burst. The sum of the rise and fall times is tested to ensure that it is not greater than the total time for the tone burst. S1 (the starting address of the plateau section), S2 (the starting address of the fall section), R and F (the increments of the R/F register during rise and fall respectively), are all computed and stored in special registers. The programme then branches to COMPIL.

If the pulse mode is selected, the next message after 'POLARITY:' will be 'PULSE WIDTH MS:' , while if the logon mode is selected, the message will be 'LOGON TC US:'. The time constant of the logon, in microseconds, is then typed in. This determines the increment L of the logon register. The programme then branches to COMPIL as before.

Most of the questions may be responded to by typing an '=' sign, which means that the quantity used in the most recent run is retained. Typing an 'X' in response to the first question 'NO. OF STIMULI' causes a jump past many of the earlier questions. This is useful when only one parameter is to be changed, for example the frequency of a tone burst.

3.7.4 Subroutines

OUTSTR prints a string of characters. The location of the first character is pointed to by the index register, and from there consecutive bytes are printed out. Return from this subroutine occurs when a carriage return character has just been output.

INDEC gets between 0 and 4 decimal digits from the TTY and stores then in X,X+1. The digits are justified so that the least significant digit is always in the rightmost four bits of X+1. Exit from INDEC may be by a number of routes. If a decimal point is typed, the programme branches to the decimal/hex conversion routine. If an '=' sign or an 'X' character is typed, it is considered a valid response, but flags are set accordingly. Invalid responses

generate a carriage return and line feed which allow re-typing of the correct response.

DHEX converts the two-byte BCD number stored in X,X+1 by INDEC into hexadecimal. X+2 is used as scratch.

DPD is a double-precision division routine. It calculates

$$Q = \frac{DD}{DS} \times 2^{S}$$

where DD is in X,X+1
DS is in X+2,X+3
Q is in X+4,X+5
S is in X+6

DD,DS and S are lost in execution.

MULT is a multiply routine which multiplies together the contents of ACCA and ACCB. The product is a two-byte word in ACCA,ACCB. Locations FF00 - 2 are used as scratch.

3.7.5 The sine subroutine

The range of the sine function is set by the D/A converter which handles eight bits. If the zero level is represented by 80 hex, then maximum positive will be FF hex and maximum negative will be 01 hex. The representation of the domain of the function is chosen so that all possible levels of the range may be selected by selecting different values in the domain. This is equivalent to the criterion

$$\left|\frac{\delta y}{\delta x}\right| \leq 1$$

where δy is the increment in the sine function brought about by an increment δx along its domain. This condition may be met by making 100hex (256 dec) equivalent to 90°. A complete cycle then requires 10 bits for its representation.

It is sufficient to be able to calculate sines from 0 to 90°, as a very short subroutine (FQS) will extend this to four quadrants. The sine function may be computed in two different ways; by means of a look-up table or by means of a subroutine which generates a polynomial approximation. A look-up table would be the fastest method but would require a fair amount of memory (256 bytes). The polynomial approximation method was therefore considered. The sine series

$$\sin\theta = \theta - \frac{\theta^3}{6} + \frac{\theta^5}{120} - \frac{\theta^7}{5040} \cdots\cdots$$

converges rapidly and in an oscillatory manner. If it is truncated after the fifth order term, then the error between $\theta = 0$ to 90° will be small, and may be estimated and

to some extent corrected. The truncation error ranges from zero at 0° to a maximum of 0.006 at 90°.

The angle θ is in radians and may be represented as an 8-bit byte with the binary point after the most significant bit; then θ = 80 hex = 1 radian. However, the operand is scaled so that x = 100 hex = 90° so a conversion factor is required:

$\theta = \lambda x$, $\lambda = 0.785$ decimal.

Note that the multiplication routine will produce a result with the binary point after the two most significant bits if two numbers with the format of θ are multiplied together. Thus, if all numbers involved have an assumed binary point after the most significant bit, then each use of this routine implies an extra division by 2.

The result of evaluating the polynomial must be scaled to give 80 hex for $x = 0^{\circ}$ and FF hex for $x = 90^{\circ}$. This is done by multiplying the result by $\tau = 0.994 \times 127/128$ and adding 80 hex. The factor 0.994 is a correction for the truncation error while 127/128 scales from 80 hex to 7F hex. Hence,

$$\sin x = \tau\lambda x - (\tau\lambda x)^3 \cdot \frac{4}{6\tau^2} + (\tau\lambda x)^5 \cdot \frac{4}{6\tau^2} \cdot \frac{4}{20\tau^2}$$

where the factors of 4 are for the purpose of locating the binary point in the correct place after a multiplication. Now $\tau\lambda$ = C6 hex; $2/3\tau^2$ = B0 hex; $1/5\tau^2$ = 34 hex, are all constants and so sin x can be evaluated by a small number of multiplication operations.

This sine subroutine was used in the original stimulus generator programme (STIMB), and it worked correctly; however, because of the very large number of calls of the subroutine during COMPIL, the programme required some 30 seconds to compute a long tone burst with large rise and fall times. When the programme was updated, more memory was then available, and so the subroutine was replaced by a lookup table. This drastically reduced the computation time. The lookup table was computed by the College CDC computer.

3.7.6

Logon Generation

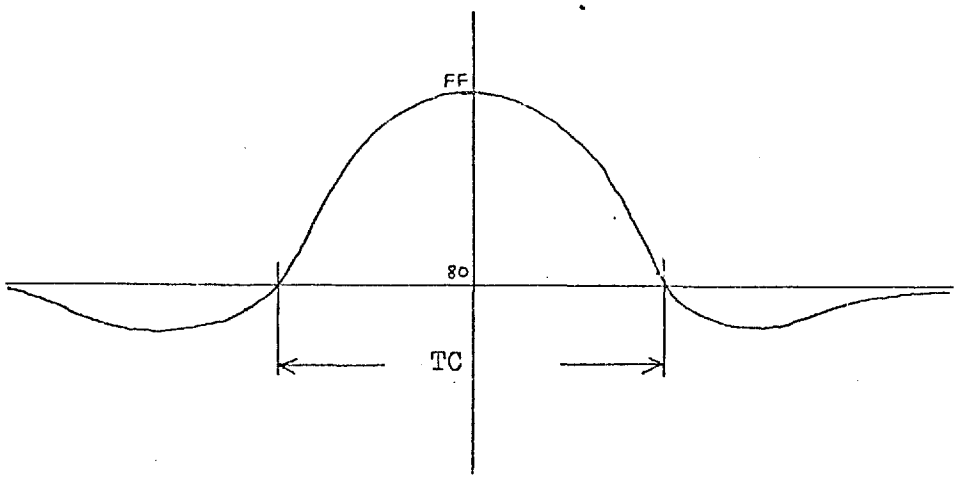
A logon is an elementary signal which can be used for the representation of a 'quantum of information' as described by Gabor (1946,1947). They are of the form

$$s(t) = \exp -a^2(t - t_o)^2 . \exp j2\pi f_o t$$

This admits an infinite variety of possible wave shapes. The stimulus generator produces a symmetrical 'cos type signal'

$$f = \exp -\frac{t^2}{2} . \cos t . \frac{\pi}{2}$$

with suitable scaling factors.



One half of this symmetrical signal is stored in a lookup table of 64 bytes, in which TC is equivalent to 40 bytes. The other half is obtained by negation of the value to be looked up.

3.8 Interrupt Handling

The restart address generator has been configured to respond to a reset with the address FED6, which is in the MINIBUG ROM. An interrupt request (IRQ) or software interrupt (SWI) will generate the address FF57, which is in RAM. This allows for a flexible response in handling interrupts.

IRQ is derived from a clock via a PIA. It may be masked at the microprocessor or at the PIA. The PIA can be programmed to respond to either positive or negative going clock edges. The interrupt routine beginning at FF57 can be arranged to read the clock and compare it with stored values, for example.

SWI is an instruction (3F) which can be placed anywhere in a programme. It is particularly useful in programme development. If the following interrupt routine is stored;

```
FF57    7E      JMP   FECB
FF58    FE
FF59    CB
```

then, on encountering a SWI in the user programme, the contents of all registers will be printed out and control will return to MINIBUG.

3.9 Provision of trigger signals.

Four independently programmable trigger signals were required. These were to be digital outputs from the PIA (peripheral interface adapter) on the microprocessor board.

A routine in 'INFORM' requests the four pre-stimulus trigger times, and stores them in four reserved locations, in units of 10mS. This gives a maximum time of 2.55 seconds.

The trigger pulses are derived from a 100Hz clock. This 100Hz frequency was originally generated by a software delay subroutine (in STIMB), but later more hardware was added, which made the generation of trigger pulses more accurate and less wasteful of microprocessor time.

The 100Hz clock also controls the sampling of analogue signals from the patient. It is derived from the crystal-controlled microprocessor clock by division. The eight bits of the clock may be read by the microprocessor at any time, via another PIA. The clock may also be reset under software control.

Every 10mS the clock produces an interrupt request (IRQ). This may be masked, or gated out, either at the PIA or at the microprocessor. During a stimulus, a mask is set so that interrupts are ignored. When the

stimulus has ended, the mask is cleared. Each time an IRQ occurs during the following inter-stimulus period, the programme branches to an interrupt routine. This reads the clock, and checks whether any trigger outputs are to be set. Outputs which are not set are cleared. When the clock reading is equal to the requested repetition period, the clock is reset, the interrupt mask is set and the next stimulus is generated. The interrupt routine takes only a small fraction of 10mS to execute, and so the microprocessor is available for other uses.

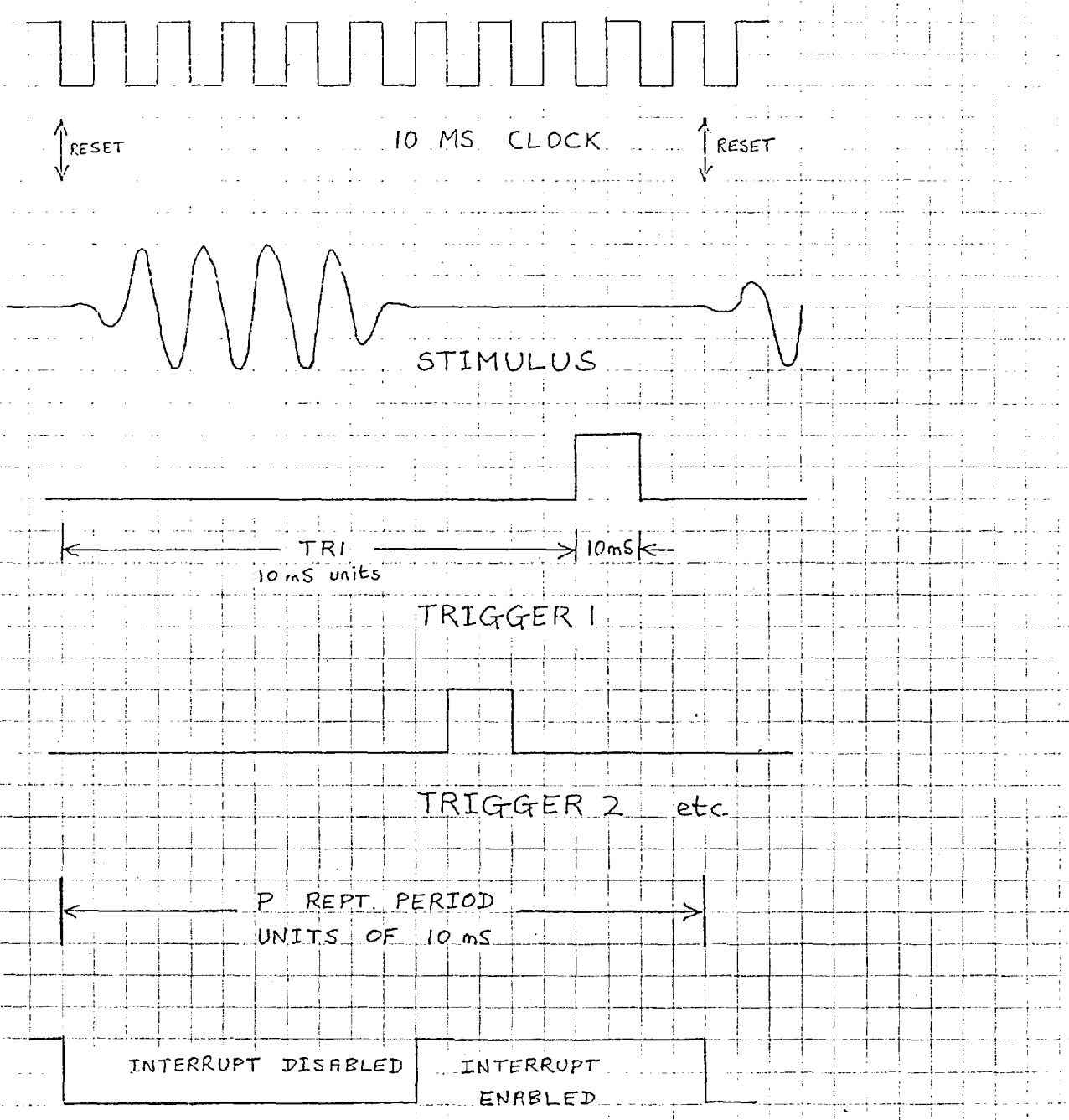


Figure 3.6 Timing of trigger signals.

3.10 Improvements to the Stimulus Generator programme

The stimulus generator, which at the time consisted of the microprocessor board and 8K of RAM, was delivered to the Department of Electrophysiology at the R.N.T.N.E.H. on 25th July 1978. A number of improvements to the programme were suggested, and these were included in an updated programme (called STIMC). Among these improvements were the following:

1) Timing of trigger signals and initiation of stimuli was to be derived from extra timing hardware, making use of the interrupt system of the microprocessor. This allowed for more accurate timing, and made the microprocessor available for other tasks during inter-stimulus intervals.

2) Use was made of some memory locations on an extra 4K memory board. In particular this meant that the maximum tone burst width, which had previously been 96mS, could be extended to the 100mS of the original specification.

3) It was arranged that the train of stimuli could be stopped by pressing a key at the terminal, and that the train could be started again from the beginning, without having to re-type the parameters. This allowed the operator to check the stimulus parameters quickly before beginning a trial.

4) The new programme was written in such a way that it could be relocated easily by the CDC cross-assembler, in preparation for implementation in PROM (programmable read-only memory).

5) The Medelec signal averager, which was to be used in conjunction with the stimulator, sometimes rejected responses if they caused it to saturate. It was required that, if the stimulus generator was working in the alternate mode, it would stay in the same polarity, positive or negative, until the signal averager stopped rejecting. The count down of stimuli would also be stopped during a reject. The reason for this was that the signal averager loaded accepted responses into two buffers, one for responses to positive stimuli, the other for responses to negative stimuli. The stimulus generator had to provide the correct number of positive and negative stimuli with acceptable responses.

3.11 Interfacing the stimulus generator with the signal averager.

The 'reject' signal from the signal averager was at TTL level. It was connected to the microprocessor system via one input of a PIA (peripheral interface adapter). This signal was normally low, but could go high at any time during the 'analysis time' of the averager, that is, during and immediately after a stimulus. If it did go high, it was latched high until the start of the next analysis time.

Correct operation of the reject system depended upon the microprocessor testing the reject signal at the right time. This had to be done after the averager analysis time, otherwise some late rejects could have been missed; but before the next stimulus, when the reject signal would have been reset.

The routine EXEC was arranged such that the reject signal would be tested just before triggering the averager for the next response.

The reject system was tested by intentionally causing rejects, and was found to work correctly.

CHAPTER 4

THE PHASE SPECTRUM ANALYZER

4.1 Phase spectral analysis using the microprocessor.

The phase vector method for the analysis of cortical EEG responses has been described in an earlier chapter. It was suggested that this algorithm could be implemented using a minicomputer or microprocessor.

After completing preliminary work on the stimulus generator, the implementation of the phase vector method was examined. This could have been done by building another microcomputer, similar to the stimulus generator but with different input and output facilities. However, it was considered better to use the same microprocessor with a larger programme and extended peripheral facilities. This would enable much of the same hardware to be used. By using the same clock for stimulus generation, triggering, and data sampling, problems concerned with synchronizing two different units are avoided.

The phase spectral procedure used an analogue-to-digital converter for the input of amplified EEG signals. This circuitry was mounted on an extra board, the data acquisition and display board.

4.2 Data acquisition and display board

This board was designed to perform a number of functions in the microprocessor system while using only a small number of components. It could provide data collection facilities for phase spectral analysis, and was also used by the stimulus programme. The following features were included;

1) Data collection (up to 128 points) at the rate of 100Hz could continue while the microprocessor was fully occupied, for example with generating an auditory stimulus.

2) Trigger and timing signals could be generated very conveniently with short routines.

3) Graphics output was provided very cheaply by two 8-bit digital-to-analogue converters which were connected to the X and Y inputs of an ordinary oscilloscope. This could be used for producing cluster diagrams, etc.

In a typical EEG experiment samples are taken at a rate of 100 per second. 64 samples constitute a 'sweep' and there is one sweep per second. There is therefore a gap of 360mS between sweeps. A Fast Fourier Transform (FFT) programme for 64 points was written during the initial period of becoming familiar

with the 6800 microprocessor system. Its execution time was about 250mS, though it possibly could have been made faster. So a fair amount of pre-processing could be done between sweeps. However, as the system stood, the stimulus generator programme could not be run concurrently with data collection, as the microprocessor was fully occupied during the period of the stimulus.

Some intermediate storage was required for data collection, therefore. A small random-access memory of 128 bytes was used, with data and address lines routed by data selectors, which were themselves controlled by software. This RAM could be connected to the microprocessor so that it operated in exactly the same way as any other memory in the system. Alternatively, the data lines could be connected to the digitised input data, while the address lines were connected to a 100Hz clock. The clock also controlled the sample/hold analogue circuit so that successive samples were stored in successive locations in the 128 byte RAM. The microprocessor was free for other functions while this was happening.

The 100Hz clock was a simple counter of the same design as the baud rate generator on the microprocessor board. The baud rate generator already produced a 600Hz signal of crystal-controlled accuracy, and this was simply divided by six to provide the sample rate of 100Hz. The clock provided an 8-bit

count in increments of 10mS, which could be read by the microprocessor. Thus the time for the clock to go through a complete counting cycle was 2.56 seconds. The clock could be reset at any time by software control, allowing flexibility in the length of count.

Control of the clock was facilitated by the microprocessor interrupt system. Every 10mS the clock generated an interrupt request, which the microprocessor could be programmed to ignore if it was busy. An accepted interrupt caused a jump to a service routine which began at the memory location FF57. On completion, the system was restored to the point before the interrupt.

Previously, the provision of trigger signals had entailed the use of rather long subroutines. The stimulus period and the inter-stimulus interval had to be taken account of, and variable delays had to be calculated, in order that the various signals would be generated at the correct time. However, with the hardware clock, timing functions became much less of a problem to programme. Accuracy was improved as timing errors could not accumulate.

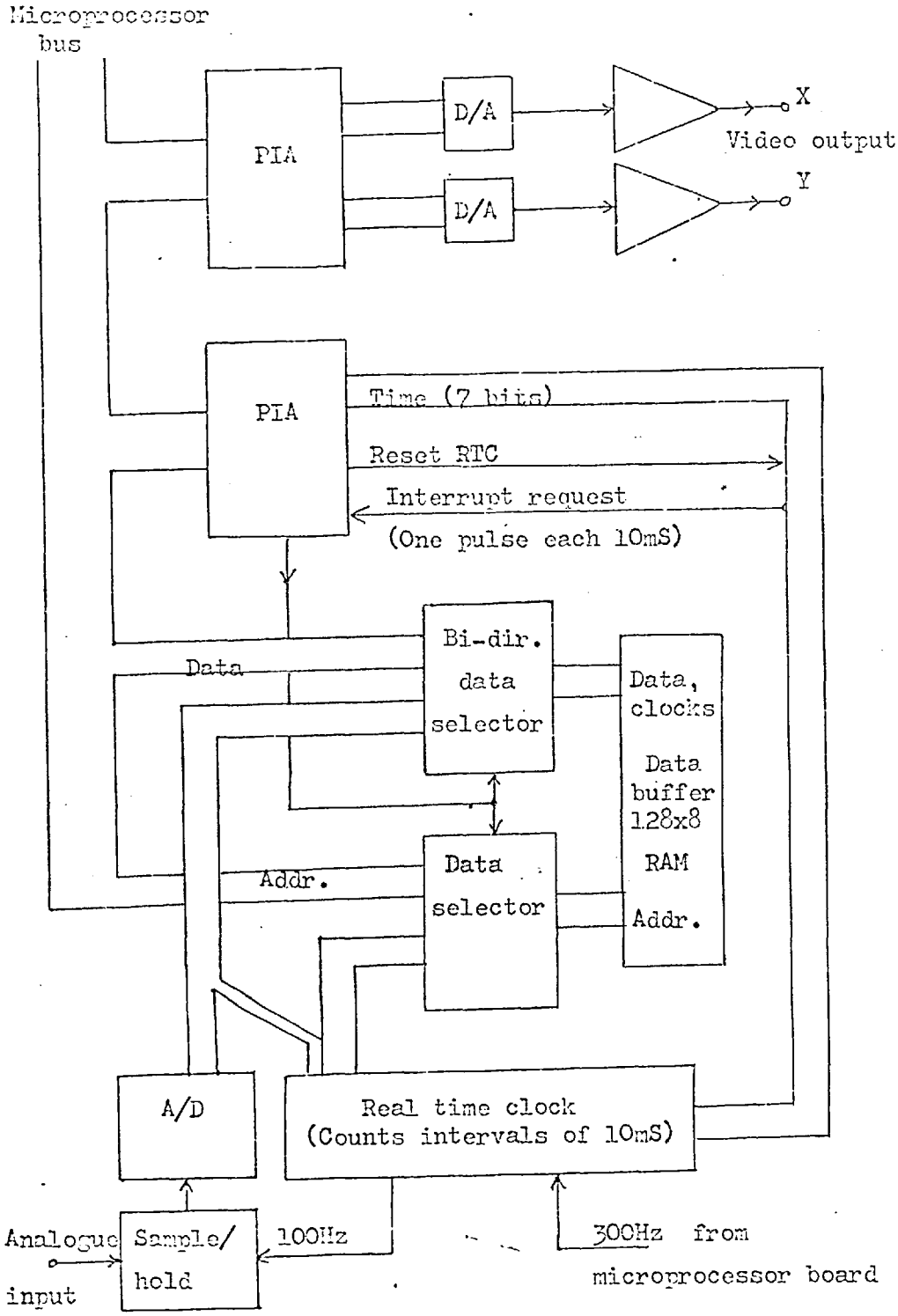


Figure 4.1 Data acquisition and display board.

4.3 Analogue-to-digital converter.

The A/D converter accepts an analogue signal from the patient via an isolation amplifier and converts it to 8-bit digital form. The input should be in the range -2.5V to +2.5V, and it is sampled once every 10 mS.

The A/D converter uses a ZN425E integrated circuit, which contains an 8-bit D/A ladder network, a voltage reference, and an 8-bit counter. The counter may be used to switch the D/A network, so that if it is clocked by a square wave, a staircase is produced at the analogue output. This is compared with a d.c. input voltage by a 710 comparator, which is arranged to switch when the staircase equals or just exceeds this voltage. This stops the clock and holds the counter at the value it has reached. The counter reading is then stored in a data buffer.

Timing signals are derived by division from the microprocessor clock. The sample/hold function is performed by one LF398 integrated circuit. This is clocked by a 100 Hz square wave, so that the output follows the input for 5mS, and is then held for 5mS, during the period of A/D conversion.

The output from the sample/hold circuit is taken via a resistor to the + input of the comparator. This comparator input is also connected to the +2.5V voltage reference of the ZN425E by another resistor of the same value. In this way, the input voltage to the sample/hold circuit, which is in the range -2.5V to +2.5V, is scaled down to a range of 0V to +2.5V at the

comparator input. This is the range of the analogue output of the ZN425E. The resistors had to be selected to balance the relatively high output impedance of the ZN425E.

To test the A/D converter, a short routine was written which printed the digital output in hexadecimal form at the data terminal about once every second.

```
        4000    0F      SEI             Initialise system
                86      LDAA    ?FF
                FF
                97      STAA    00
        4004    00
                86      LDAA    ?80
                80
                97      STAA    02
        4008    02
                86      LDAA    ?DB
                DB
                97      STAA    01
        400C    01
                97      STAA    03
                03
LP1             86      LDAA    ?FD     Reset clock
        4010    FD
                97      STAA    02
                02
                7C      INC     02      Connect data buffer to
        4014    00
                02                      A/D converter.
LP2             08      INX
                01      NOP
        4018    26      BNE     LP2     Delay, approx. 700mS.
                FC
                86      LDAA    ?7F
                7F
        401C    97      STAA    02
                02
                CE      LDX     ?0101
                01
        4020    01
                BD      JSR     OUT2HS  In monitor ROM
                FE
                C5
        4024    20      BRA     LP1
                E9
```

(All figures in hexadecimal. ? indicates immediate addressing.)

The analogue-to-digital converter was calibrated by comparison with a Solartron 7040 digital voltmeter. Test voltages were provided by a Weir variable 0-30V power supply, with its output divided approximately by ten, using a 2K2 and an 18K resistor in series, to give finer control of the applied voltage.

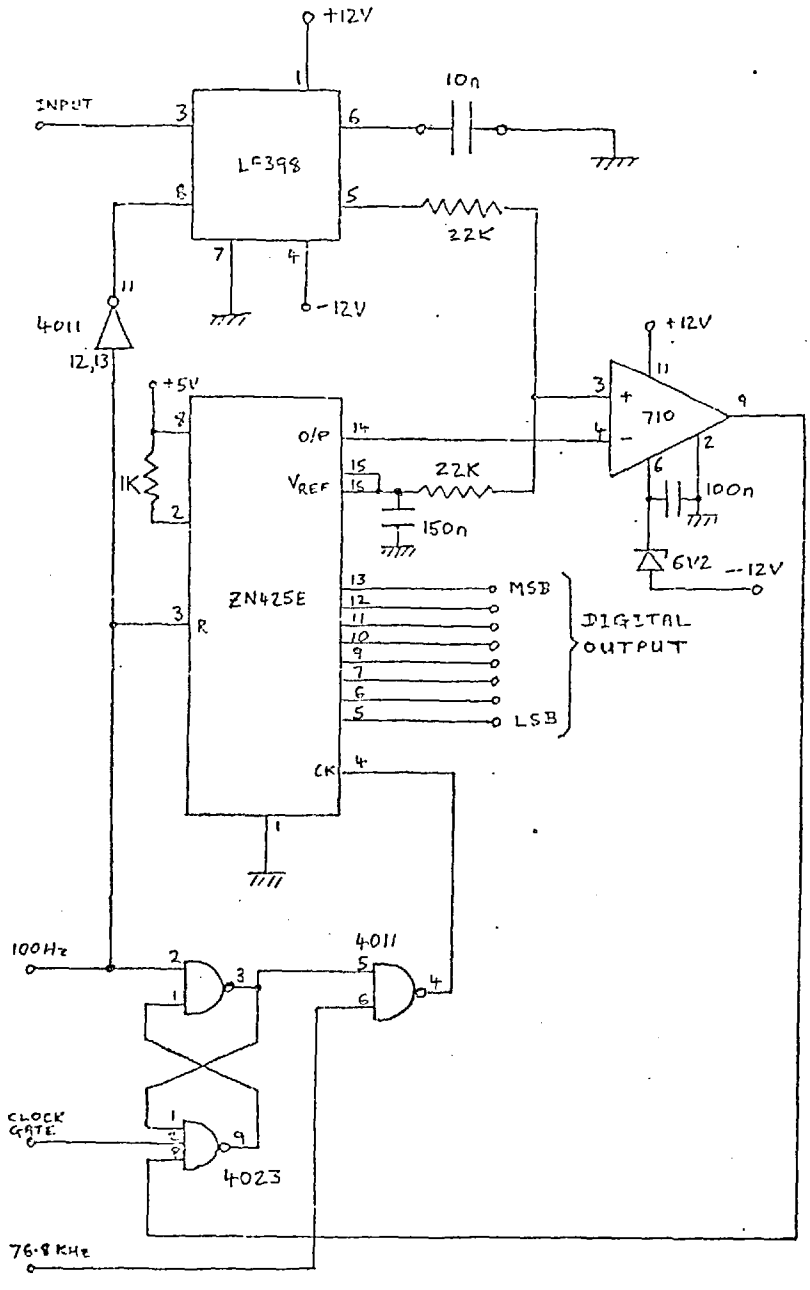


Figure 4.2

Analogue to digital convertor.

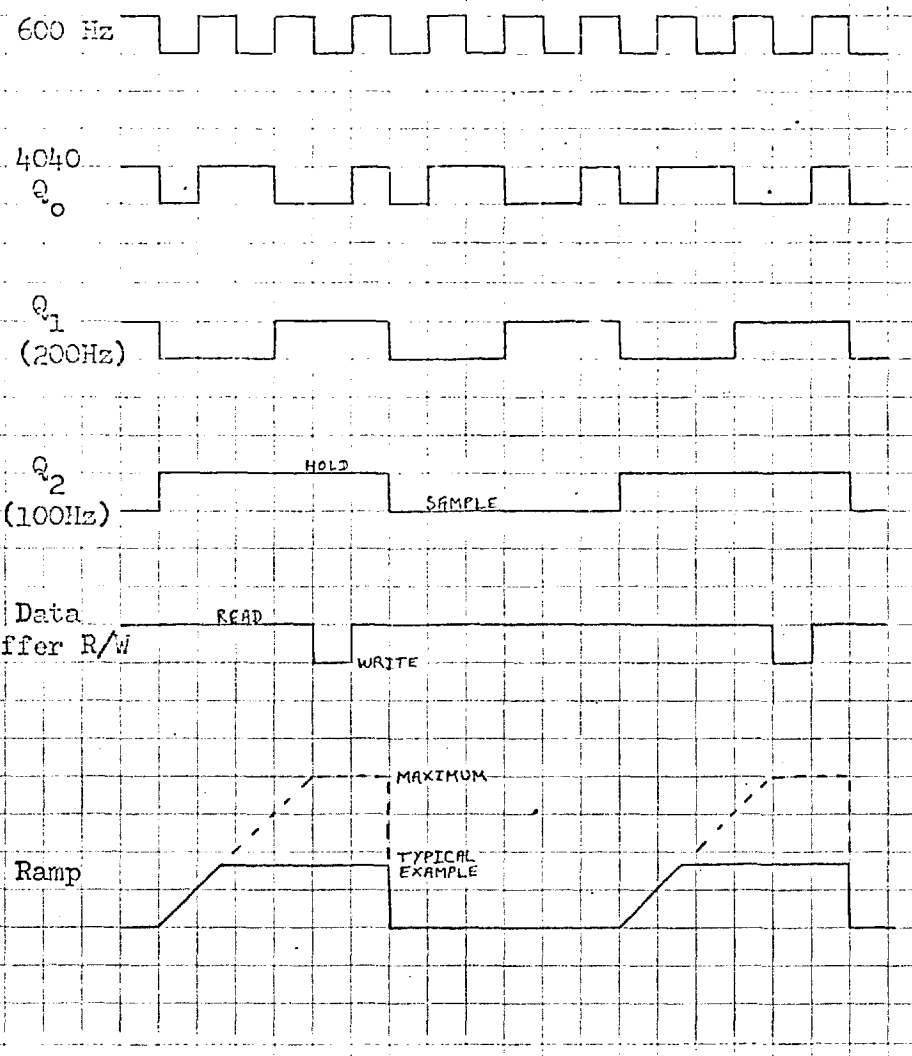


Figure 4.3

Analogue to digital conversion timing.

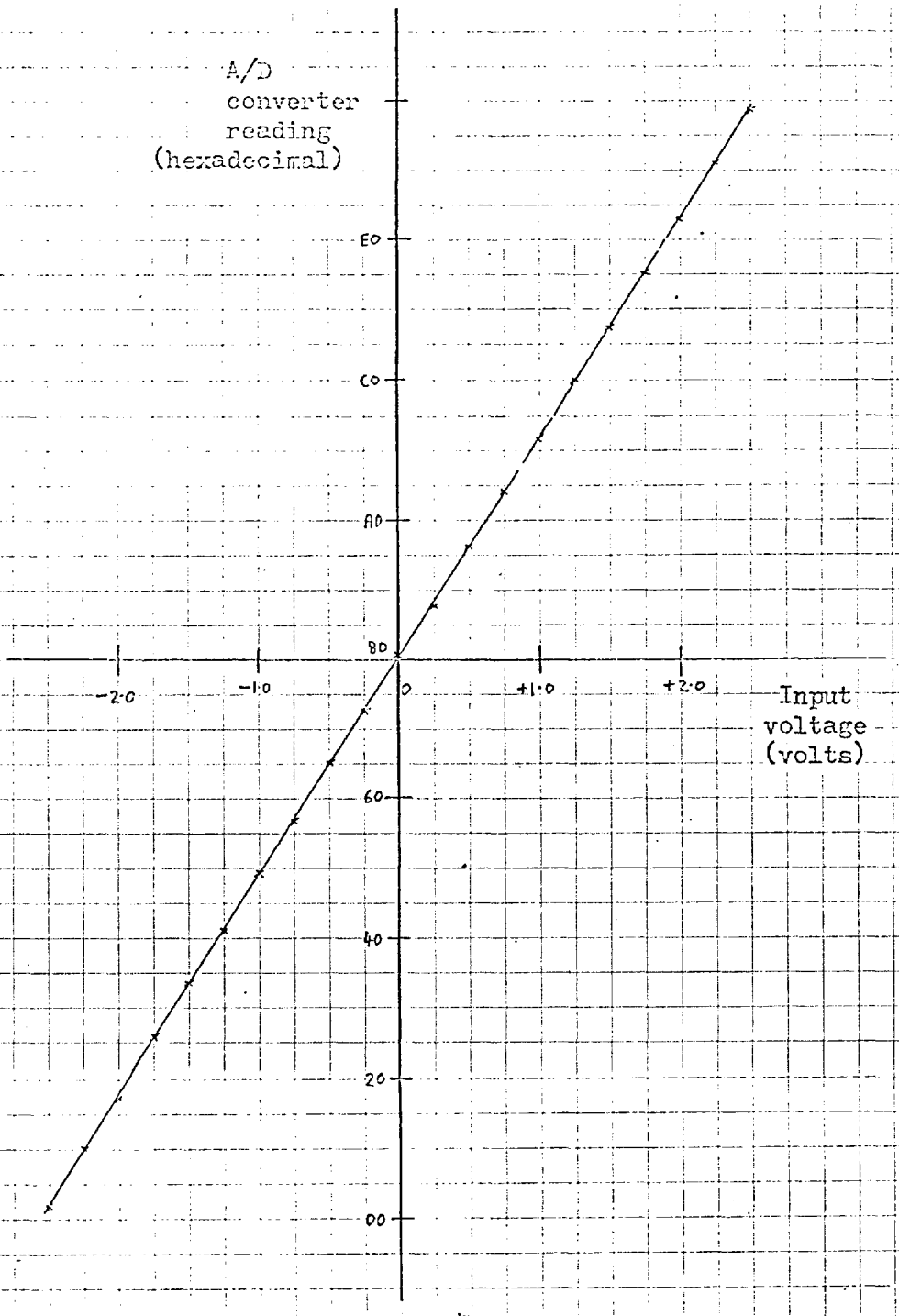


Figure 4.4 Calibration of A/D converter

4.4 X-Y Display

A graphic display is provided by connecting the X and Y inputs of an oscilloscope to two analogue outputs from the system. The oscilloscope is also used for checking the waveform of stimuli, and it can be switched between the two functions.

The X and Y coordinates of a point to be displayed are written into a peripheral interface adapter. The two input/output ports of the PIA are each connected to D/A converters. The outputs from these are scaled up from a range of 0 to +2.5V to a range of -2.5V to +2.5V by operational amplifiers, in the same way as the audio output. However, the operational amplifiers are faster types, so that the trace is hardly visible when moving between points to be displayed.

When using this display technique it is necessary to ensure that all the points to be displayed are refreshed at a sufficient rate to avoid flicker. Also, when using the facilities provided by the data acquisition and display board, it should be noted that the 8T26 bidirectional buffers, used for buffering data lines, invert the data. This makes no difference when using the random access memory boards, or the analogue-to-digital converter, as in these cases the data undergoes two inversions. However, when using the two PIA's on the data acquisition and display board, all data must be inverted by software. This includes the PIA control words, the reading from the 10 mS clock, and data to the X and Y outputs.

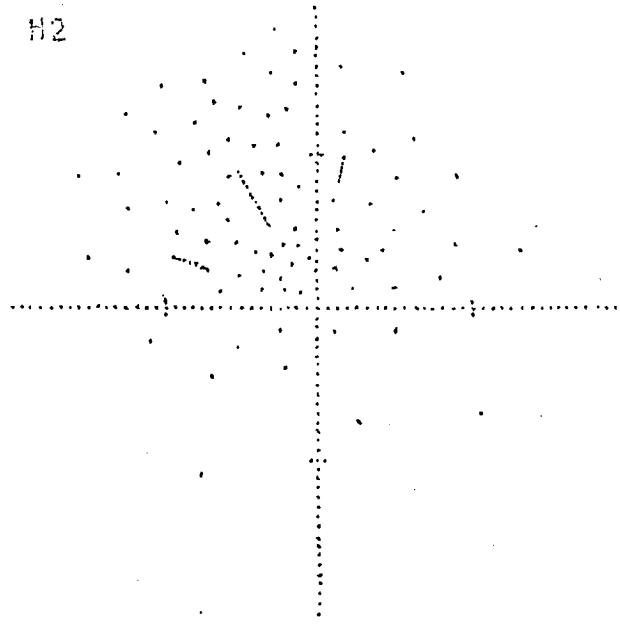


Figure 4.5

Form of visual display, showing axes, heading, and mean and standard deviation markers. The markers flash on and off for easier identification against a cluster of points.

4.5 ANALYS routine.

This routine analyses the evoked EEG responses from a patient in response to stimuli produced by the microprocessor. Analysis of sixty responses per trial was requested, but it was convenient to make 64 the maximum number per trial, or to use the last 64 responses of a longer trial.

ANALYS consists of two parts;

i) a subroutine TRANS which computes and stores the first six harmonics of the discrete Fourier transform of the response to each stimulus,

ii) a programme STATS which computes statistics of the transformed data, namely the amplitude mean, phase mean and phase standard deviation of each harmonic.

4.5.1 Linkage with stimulus generator programme.

Although ANALYS is run in conjunction with STIMC, it is also possible to run STIMC by itself without the analysis programme. This is useful when the stimulus generator is to be used for BSER or electrocochleography, as the stimulus repetition rates used in these techniques are normally higher

than those used for cortical responses. The discrete Fourier transform in ANALYS limits the repetition period to about one second. When STIMC is used by itself, two dummy subroutines, EXEC20 and EXEC30, take the place of ANALYS.

In the version written for programmable read-only memory implementation, a short routine which performs the necessary linking when required was added. This prints a message which asks the operator whether the analysis programme is to be used, as the first question in a run.

4.5.2 Storage of transformed data.

A discrete Fourier transform (DFT) which computed six harmonics was used. A fast Fourier transform (FFT) algorithm was not used as there would have been no advantage in speed, as only a few harmonics were needed. Two bytes (one real, one imaginary) are required to store each point of the result. Thus 128 bytes are stored for each harmonic, or 768 bytes in total.

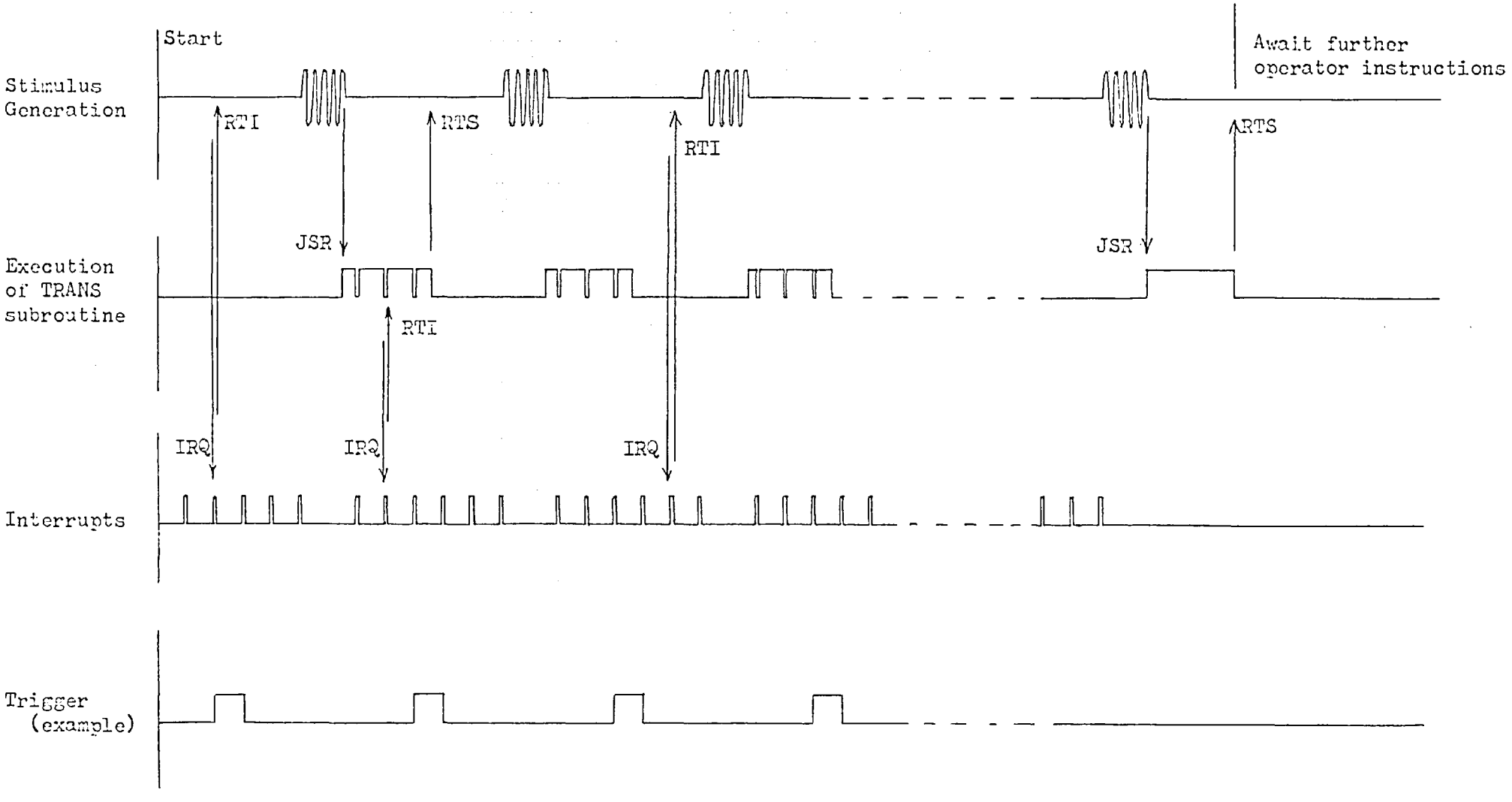


Figure 4.6 How control passes between stimulus generation, trigger generation, and data acquisition functions.

4.5.3 Execution of TRANS subroutine

The discrete Fourier transform subroutine TRANS takes the DFT of the response to previous stimuli. It is executed during inter-stimulus intervals, when the microprocessor is not being used by the stimulus generating programme. This saves both time and memory capacity, as the transformed data takes much less space in memory as would the data as first collected. This is best explained by reference to a timing diagram and flow chart (see figure 4.6).

At the end of each stimulus, a JSR instruction causes a jump to TRANS. When TRANS has been executed, control returns to the stimulus generation programme. Interrupts occur every 10 mS of inter-stimulus time, and these cause the microprocessor to leave the programme briefly and to set up any trigger outputs that have been requested.

A data buffer collects data from the output of an analogue-to-digital (A/D) converter every 10 mS starting at the beginning of the stimulus. TRANS first ensures that the data buffer is full by waiting until 640 mS after the beginning of the previous stimulus. This means that the DFT will be applied to 64 points. The data buffer is then disconnected from the A/D converter and connected to the microprocessor (by software). The DFT is calculated for six harmonics and the result is stored in memory.

It may be that an inter-stimulus time has been selected which is too short for the execution of TRANS. If this is the case then a warning is given.

4.5.4 Programme STATS

STATS is a programme which evaluates certain statistical parameters from the data collected and Fourier transformed by the TRANS subroutine. It may be entered, if desired, upon completion of a train of stimuli by the stimulus generator programme. Output of data from STATS may take two forms;

1) a tabular listing from a data terminal.
2) a graphic plot of the transformed data points on an oscilloscope, using the X-Y inputs.

The parameters calculated by STATS, for each harmonic number, are as follows;

1) Mean amplitude.
2) Mean phase.
3) Standard deviation of phase..

The transformed data from the execution of TRANS is stored in an area labelled HARBUF. During execution of STATS a new buffer, PHABUF, is built up. Points in PHABUF correspond to points in HARBUF but contain no amplitude information, that is, they have all been reduced to unit amplitude vectors. This is done by taking a (complex) point in HARBUF, calculating its amplitude, and dividing both real and imaginary parts by the amplitude. This is equivalent to taking the cosine and sine of the phase angle, or 'projection onto the unit circle'.

At the beginning of STATS the number of responses, N, transformed by TRANS is found. If there were less than 64 stimuli in the trial, then N will be the number of stimuli; otherwise N will be 64. The process of reducing the data to vectors of unit amplitude is performed next. As this involves finding the amplitude of each point, the mean amplitude for each harmonic number is calculated at the same time.

The mean and standard deviation of the phases of the transformed responses, for each harmonic number, are computed using an algorithm equivalent to that of Cheung (1977). The unit amplitude vectors are all added together to give a resultant vector. The phase angle of this new vector is the mean of the phase angles of the original points.

The routine for calculating standard deviations exploits the eight-bit representation of numbers in the microprocessor. Phase angles are scaled such that 100hex = 360°. Then if two angles are regarded as unsigned integers and one is subtracted from the other, disregarding overflow, the result will be a two's complement number with a modulus representing an angle of 180° or less. When squared, using a two's complement subroutine, the sign vanishes, so that it is always the smaller angle between two phases that is selected.

4.5.5 AMPLI and SQRT subroutines

AMPLI computes the amplitude of a complex number whose real and imaginary parts are in twos complement form in ACCB and ACCA. These two quantities are squared and added, and the programme continues with the SQRT routine.

SQRT computes the square root of the two-byte unsigned integer (ACCA,ACCB) and places the result in ACCB. It uses the Newton-Raphson iterative method, where if a is the number to be square-rooted and x_n is an estimate of $\sqrt{a}$ then a better estimate is

$$x_{n+1} = \frac{1}{2}\left(x_n + \frac{a}{x_n} \right)$$

Iteration continues until two consecutive estimates are equal or differ by one least-significant bit.

As the operands of AMPLI are in twos complement form and cannot have an absolute value greater than 80 hex, the (unsigned) result cannot be greater than B5 hex.

4.5.6 ARC subroutine

This subroutine finds the angle whose sine is in ACCA and whose cosine is in ACCB. Unit radius is equivalent to 40 hex and 360° is equivalent to 100hex. The absolute value of sin and cos is taken and they are compared. The smaller value is selected, so that the angle to be looked up will never be greater than 45°. The same lookup table is used as for the sine function in STIMC. After this angle has been found, it is added to or subtracted from 0°,90°,180°, or 270° depending on the octant.

Advantages of this routine are; accuracy, as the function (sin or cos) of maximum slope is chosen for comparison with the lookup table; and reasonable speed, as no more than 32 points of the table have to be searched. The tangent function is not used and so large values which might cause arithmetic overflow are avoided.

4.5.7 Output routines.

The results are listed in tabular form at a data terminal. As they are required in decimal form, a binary to decimal conversion routine is needed (labelled HDEC). This converts a 9 bit binary number to a 3 digit decimal number. Printer control routines from the stimulus generator programme are used in the production of the listing.

After printing the results, a graphic display of the transformed responses may be obtained. The X and Y inputs of an oscilloscope are driven from D/A converters with buffer amplifiers. For each harmonic number, a cluster diagram is provided, with markers showing phase mean and standard deviation, X and Y axes, and a heading giving the harmonic number.

The asynchronous communications interface (ACIA) is interrogated frequently during the display to determine whether a key has been pressed on the data terminal. The display routine starts with transformed responses of harmonic number 1. Typing a number from 1 to 6 changes the harmonic number. Typing a letter 'X' returns the system to the stimulus generator programme. Other characters are ignored.

4.5.8 Scaling of printed results.

When the phase mean and standard deviation angles are evaluated, 360° is represented by 100 hexadecimal. Therefore, when these angles are printed out in degrees, they must be multiplied by 360/256. This is done before binary-to-decimal conversion.

The amplitude mean is also multiplied by a scaling factor before printing it out, to give the result in volts/Hz at the input of the A/D converter, but this scaling factor corrects for a number of explicit and implicit multiplications that the signal has undergone, namely;

1) Scaling by the A/D converter. By reference to the slope of the A/D calibration curve, it is seen that one volt is represented by 252/5 (decimal).

2) The subroutine TRANS divides by 16 in order to obtain a one-byte result. However, in order to save time, it does not multiply by the sampling period (0.01 seconds), which should be done in order to obtain the correct DFT.

3) After conversion to decimal, a three-digit result is obtained. Results were expected sometimes to exceed 0.1 V/Hz but never to exceed 1V/Hz: therefore the decimal point was placed before the three decimal digits. This implied a further division by 1000.

Putting these factors together, the necessary scaling correction is:

$$\frac{5}{252} \times 16 \times 0.01 \times 1000 = \frac{800}{252} = \frac{203}{64} \cdot \text{approx.}$$

The multiplication by 203 is done by the MULT subroutine and the division by 64 is done by shifting.

The practice of Chirlian (1973) was followed in computing the discrete Fourier transform. He includes the sampling rate explicitly in the formula for the DFT, so that the units are V/Hz rather than volts, as given by other writers. This is because he derives the Fourier series for periodic functions as a special case of the Fourier transform for non-periodic functions. The spectral lines thus obtained may be regarded informally as having infinite amplitude but finite area.

4.6 Testing of discrete Fourier transform subroutine.

When the discrete Fourier transform subroutine TRANS was first tested, it failed to run. Not only did it either get stuck in a loop or else print out a string of meaningless characters, but it often also corrupted the programme so that it had to be reloaded. The cause of this particular problem took some time to find, and was fairly subtle.

In order to locate more accurately where the programme was failing, a series of small changes to the subroutine were tried. It was found that if the call in TRANS to the sine subroutine FQS was removed, then TRANS would run. However, FQS had worked in the stimulus generator programme and so there was no obvious reason why it should stop TRANS working. The execution timing would be altered, though, by leaving out FQS, and this would affect the positions of interrupts in the running of the subroutine TRANS. These occurred every 10 mS.

Investigation of the interrupt system failed to reveal any obvious faults. It was possible that the interrupt request signal to the microprocessor was racing with the microprocessor clock. This possibility was ruled out by adding an inverter to shift the transitions of $\overline{IRQ}$ by a quarter of a cycle with respect to the microprocessor clock. The effect of this was a small improvement, but not a complete cure.

As the fault seemed to be associated with interrupts and subroutine calls, the area of memory in which the stack was stored was examined after each attempt to run TRANS. The stack contains data enabling the microprocessor to return to the correct address after an interrupt or subroutine call. Thus,

by examining the stack, some information about the progress of the programme could be obtained. It was noted that sometimes the stack contained data which did not correspond to an address within the programme, as it should have done. It was suspected that data on the stack was somehow being corrupted during the execution of TRANS.

The fault was finally traced to the fact that the area of memory in which the stack was stored was pattern sensitive. Although the memory had appeared to work correctly when it was first tested, particular sequences of reads and writes caused corruptions. For example, location 4FF6 was loaded with FF. Location 4FF2 was then changed from 00 to FF and back to 00. On reading 4FF6 again, it was found to have changed to FB. This type of fault is extremely difficult to test for, even with high speed automatic test equipment, because of the immense variety of possible sequences.

This problem did not seem to be due to a fault in one particular memory IC, as sometimes more than one bit was affected. It depended on the +5V supply to the memory board, which at that time was rather low in voltage (+4.8V). Pulling out one of the other boards, thus reducing the load on the +5V regulator, corrected the fault. This regulator was a 3A type, and it was running close to its maximum rating. It was changed for a 5A type, and extra decoupling capacitors were added to the memory board. When the programmable read-only memory board was added (to be described later), the RAM board concerned was no longer needed, so circumventing the problem.

4.7

Timing of TRANS subroutine

When the discrete Fourier transform subroutine TRANS was first written, it took 1010 mS to run, including a 'wait time' of 640 mS while the input data was sampled and stored. As the maximum run time was intended to be one second, some improvement was needed in the speed of execution. This was done by identifying areas of the subroutine which took a large number of machine cycles to run, and rewriting them to save machine cycles, although possibly using more bytes of memory for programme storage. Several changes were made, each of which contributed significantly to an overall improvement in speed, reducing the run time for TRANS from 1010 mS to less than 990 mS. This brought it well within the design requirements. These changes were as follows:

1) Instructions which use indexed addressing generally take one cycle longer to execute than corresponding instructions with extended addressing. However, extended addressing instructions are three bytes long while indexed addressing instructions are only two bytes long. So indexed addressing instructions were used in parts of TRANS which were to be executed only once or only a few times, while extended addressing was used for instructions which were to be executed many hundreds of times, during a run of TRANS.

2) The branch-to-subroutine (BSR) instruction takes 8 machine cycles, and the more general jump-to-subroutine (JSR) instruction takes 9 machine cycles to execute. At the end of each subroutine there is a return-from-subroutine (RTS) instruction which takes a further 5 machine cycles. Therefore, the use of subroutines was avoided when the concomitant saving in memory would not have been large.

3) Improvements in speed were made to subroutines in the stimulus generator programme which were called by TRANS. The multiplication subroutine was changed so that temporary results would be stored in reserved locations rather than in relocatable locations. This meant that extended addressing could be used instead of indexed addressing. Some of the instructions involved were within loops, so this made a considerable improvement in the speed of multiplication.

4.8

Testing the system with analogue test signals.

The system was programmed to produce 64 stimuli with a repetition period of 1.28 seconds. (The stimuli were positive pulses but the audio output was not used in these experiments.) Various test signals were applied to the A/D input. In each test, a train of 64 stimuli was generated, and then the STATS programme was run (by typing 'A' in response to the question 'NEXT(S,G,A?)')

In the first tests, a d.c. level was applied to the A/D converter. Three voltages were tried, OV(short circuit), -2V and +2V. The expected mean amplitudes were zero for harmonics 1 to 6, with undefined phases. However, it was found initially that the mean amplitudes were small but non-zero, and that the phase means were all close to 225° for all harmonics. This was found to be due to the DFT subroutine and not to the subsequent statistical programme. The DFT subroutine contained a truncation after multiplication, but before summation, and this gave a systematic error to the result. This was corrected by introducing steps in the programme to round off the results of multiplication. After this change, the correct zero result was obtained for each harmonic at each of the three d.c. voltages.

The system was then tested with sine waves, square waves and triangular waves applied to the A/D input. Sine waves with the fundamental frequency of f = 1000/640 Hz and frequencies of 2f, 3f, and 4f were used. The amplitudes were approximately 1V peak. Square and triangle waves of the fundamental frequency were also tried, to see whether the Fourier analysis obtained agreed with theory.

Test signals were provided by a variable frequency signal generator. The microprocessor and the signal generator were not synchronized electrically, but the frequency of the signal generator was adjusted by hand to maintain synchronism. For this reason, the 'phase standard deviations' in the results were non-zero.

The 'sine wave' output of the signal generator was not precisely sinusoidal but was an approximation with five straight line segments representing each quadrant. The analysis by the system indicated that the power in the fundamental was very much greater than that in any of the harmonics, as expected. The results are given below.

Analysis of square and triangle waves by the system gave results which were in agreement with their theoretical harmonic contents, i.e. no even harmonics, and odd harmonics with amplitudes which are fixed fractions of the fundamental. These are $\frac{1}{3}$ and 1/5 for the third and fifth harmonics of the square wave, and 1/9 and 1/25 for the corresponding harmonics of the triangle wave.

Table 4.1 - Tests with known analogue signals.

Sine wave, approx. 2V peak-to-peak, frequency 1/0.64 Hz (Harmonic 1 frequency).

Harmonic Number	Amplitude mean computed by microprocessor (V/Hz)	Expected relative harmonic content
1	0.288	0.288
2	0.006	0
3	0.002	0
4	0.000	0
5	0.002	0
6	0.000	0

Sine wave, same amplitude, frequency 2/0.64 Hz (harmonic 2)

Harmonic Number	Amplitude mean computed by microprocessor (V/Hz)	Expected relative harmonic content
1	0.000	0
2	0.288	0.288
3	0.000	0
4	0.002	0
5	0.000	0
6	0.002	0

Sine wave, same amplitude, frequency 3/0.64 Hz (harmonic 3)

Harmonic Number	Amplitude mean computed by microprocessor (V/Hz)	Expected relative harmonic content
1	0.000	0
2	0.000	0
3	0.288	0.288
4	0.002	0
5	0.000	0
6	0.002	0

Sine wave, same amplitude (2V pk-pk), frequency 4/0.64 Hz (harmonic 4).

Harmonic Number	Amplitude mean computed by microprocessor (V/Hz)	Expected relative harmonic content
1	0.000	0
2	0.000	0
3	0.002	0
4	0.288	0.288
5	0.002	0
6	0.000	0

Triangle wave, amplitude 2V pk-pk, frequency 1/0.64 Hz

Harmonic Number	Amplitude mean computed by microprocessor (V/Hz)	Expected relative harmonic content
1	0.278	0.278
2	0.002	0
3	0.028	0.031
4	0.000	0
5	0.008	0.011
6	0.000	0

Square wave, amplitude 2V pk-pk, frequency 1/0.64 Hz

Harmonic Number	Amplitude mean computed by microprocessor (V/Hz)	Expected relative harmonic content
1	0.382	0.382
2	0.008	0
3	0.126	0.127
4	0.008	0
5	0.072	0.076
6	0.008	0

4.9 Analysis of analogue signals recorded on magnetic tape.

Although the system was intended to be operated 'on line', it was decided that it would be desirable to include a facility whereby ERA signals which had been recorded on magnetic tape could be analyzed by the system at a later time. This facility would enable signal analysis programmes to be developed and tested without requiring the presence of subjects except for the initial recording.

The recording was carried out using an f.m. tape recorder ('Store 4', Racal). The ERA signal was recorded on one track, and a trigger signal, synchronized with the original stimulus, was recorded on another track. A voice track was used to record comments identifying different trials.

The main problem in analyzing such records lay in triggering the microprocessor system from the tape recorder. Normally, the stimulus generator programme would send trigger signals out from the system, but in this case trigger signals were to be fed into the system to control its operation. Fortunately, this did not involve any modification to the hardware, as the PIA (peripheral interface adapter) connected to the four trigger sockets was a bi-directional device and could be programmed to act as an input instead of an output. However, some programme modification was necessary.

As the trigger pulses were normally generated during interrupt service, it seemed that the best way to modify the programme would be to write an alternative interrupt routine. This had the advantage that no modification to the main body of the programme would be needed.

The new interrupt routine first set up a PIA bi-directional port as an input, then waited for a trigger input. After this a fixed delay elapsed before the next stimulus was initiated. Although in this mode it was not strictly necessary to produce auditory stimuli, they provided an indication to the operator that the system was being triggered by the tape recorder.

There were initially problems in writing an interrupt routine which would perform as intended. These were found to be due to the following points: If the $\overline{\text{IRQ}}$ (interrupt request) line to the microprocessor is not cleared before returning from the interrupt, then the system will be interrupted again immediately after the return. This clearing is done by reading the output register of the PIA originating the interrupt request. The $\overline{\text{IRQ}}$ line is set once every 10 mS, so that if the interrupt service routine takes longer than this, it should be reset just before the return.

The magnetic tape reading routine was as follows;

```
4FC7  B1 FF 11   MAGTP2   CMPA   FF11
4FCA  26 0E              BNE    RET
4FCC  7F 3A 4F   NEWST    CLR    SCR+15     Here to start
                                            new stimulus
      C6 FD              LDAB   ?FD
4FD0  D7 02              STAB   PIAD        Reset clock
      5C                 INCB
4FD4  5C                 INCB
      D7 02              STAB   PIAD
      F7 FF 10   RETFL   STAB   FF10
4FD8  3B         RET     RTI                Return to
      B7 FF 11   MAGTP4  STAA   FF11        main
4FDC                                        programme
      5F                 CLRB
      96 82              LDAA   PIAB        Test for
4FE0                                        trigger
      44                 LSRA
      25 F3              BCS    RETFL
4FE4  3B                 RTI
      01                 NOP
      01                 NOP
      5F         MAGTP   CLRB               Here on
4FE8  D7 83              STAB   PIACRB       interrupt
      5A                 DECB
      F7 3A 4F           STAB   SCR+15
4FEC                     DECB
      5A
      D7 82              STAB   PIAB        Set Trig 1
4FF0                                        as input
      86 24              LDAA   ?24
      97 83              STAA   PIACRB
4FF4  96 00              LDAA   PIAC
      7D FF 10           TST    FF10
4FF8  27 CB              BEQ    MAGTP2
      80 **              SUBA   **          ** Insert
      20 DB              BRA    MAGTP4      here delay in
4FFC                                        units of 10mS
4FFF
```

4.10 Restart Generator

This circuit initiated the operation of the system after a reset or an interrupt.

On a system reset, the microprocessor addressed locations FFFE and then FFFF. These locations contained the high and low bytes of the programme starting address. On an interrupt, the microprocessor addressed locations FFFA and FFFB, which contained the starting address of the interrupt routine.

These functions could have been performed by a standard semiconductor ROM, but as only four locations were involved, the restart generator was built from a few simple gates. The Motorola monitor ROM programme started at FED6, and so the restart circuit was originally designed to generate this address on a reset, and address FF57 on an interrupt. The interrupt routine was then in a small area of random-access memory between FF40 and FF57.

Later, when considering the changes that would be needed when incorporating programmable read-only memory (PROM) into the system, it was realized that some modification to the restart generator was called for. Ideally, the system should be ready to run as soon as it is switched on. Therefore, the restart generator should address locations in the PROM rather than in the monitor ROM or in volatile RAM. The circuit was modified by adding a switch which would enable the user to select either the original restart and interrupt locations or locations in PROM. These were:

	MINIBUG Monitor	PROM
Restart	FED6	4E66
Interrupt	FF57	4FE7

4.11 The programmable read-only memory (PROM) board.

The stimulus generator and phase analysis programmes required a total of 3¼ K of memory for programme storage and just over 8K of memory for temporary data storage. At first, the programmes were loaded into random access memory from digital cassettes each time the microprocessor was used. When the programmes had been further developed, it was decided that the programmes should be stored on UV erasable and electrically reprogrammable PROMs, to avoid the loading process.

Some thought was given to ways of reducing the amount of memory taken by the programmes. In particular, the possibility of having a small (128 byte) random-access memory in the area 0000-007F or 0080-00FF was examined. This would have allowed direct addressing to be used. This mode of addressing uses two bytes instead of three bytes for some instructions. However, by experimenting with the CDC assembler, it was found that the total reduction in programme length possible would only be 128 bytes. This idea was rejected because the programme would still need more than 3K bytes of PROM, so no savings in the number of PROM integrated circuits could be made. Also, the PIA address decoding circuitry would have required modification; and the possible increase in execution speed was not significant.

It was decided that the EPROMS should be mounted on a board which would be interchangeable with the 4000-4FFF random-access memory board. The 2000-2FFF and 3000-3FFF boards would remain to form a contiguous 8K block of RAM. This would facilitate the development of programmes by replacing the original

random access memory board. The EPROM board included one 128 byte RAM IC, as 8K of RAM would not have been quite sufficient. It also included four 1K by 8 bit EPROMs, type 2708. The total 4K byte capacity was not needed, so the decoding logic was arranged so that only 3½K bytes were addressed. The 128 byte RAM was placed at locations 4000-407F, and the EPROMs were placed at 4200-4FFF.

The EPROMS were programmed by means of a PROM programmer (Data I/O System 19), loaded from the College CDC computer. The PROM programmer not only generated the signals required to programme the EPROM devices, but also verified their operation.

The stimulus generator and phase analysis programmes were divided into four parts, to fit the addressing range of each of the EPROMS. The format of these programmes differed from that required by the PROM programmer. The necessary reformatting was done by a CDC programme written by M. Brookes.

The EPROMS required three power supplies: +12V, +5V, and -5V. The +12V and +5V supplies were already included in the system. The -5V supply was derived from the -12V supply by means of a Zener diode and emitter follower, which were mounted on the EPROM board.

The programme used in the PROM implementation contains a routine for initialising the system. It starts at location 4E66, which is the address generated by the restart generator in the PROM mode. The asynchronous communications interface (ACIA) is initialised, and the header

* MICROPROCESSOR SYSTEM *

is printed, followed by the question

STIMULUS GENERATOR + PHASE ANALYSIS (A)
OR STIMULUS GENERATOR ONLY (G) ? :

By typing G, the stimulus generator programme is selected. This mode would normally be used for ECochG or BSER tests, where a high stimulus repetition rate is required. By typing A, the phase analysis programme is linked to the stimulus generator programme. This mode is used when phase analysis of cortical responses is to be carried out. Note that in this mode, the stimulus repetition rate is limited to 1 Hz or below, because of the time taken for data collection and Fourier transformation.

Typing any character other than G or A returns the system to MINIBUG control. This facility may be used for loading other programmes.

CHAPTER 5

EXPERIMENTAL STUDIES

5.1 Experimental procedure.

In order to demonstrate the complete system, a sample of 20 subjects were tested, usually only in one ear, at three different frequencies and at a variety of stimulus levels. The subjects were drawn mainly from the hospital staff, and none had any serious hearing defect. One subject was tested 'on line' (IG) ; that is, the phase analysis was done at the time of testing. However, it was considered better for the purposes of this research to keep EEG records on analogue magnetic tape, as previously described, and to run the phase analysis programme at a later time.

Tone burst stimuli were used, with a repetition period of 1.25 seconds, a total length of 100 mS, and 10 mS rise and fall times. The number of stimuli in a trial was slightly more than 64. This ensured that 64 post-stimulus records would be available when the analogue tape was played back. An announcement was recorded on a voice track before each trial, and trigger pulses were recorded on another track. The ensemble averages were computed and recorded at the time of testing, using the 'Medelec' signal averager.

The procedure for playing back the tapes was as follows. The stimulus generator programme, phase analysis programme, and magnetic tape reading routine were loaded into the microprocessor.

A trial length of 64 stimuli was selected, and the microprocessor was prepared so that a trial would commence on typing 'S'. The tape was started and the relevant announcement was located. The trigger pulses recorded on the tape could be observed both on an oscilloscope and by watching a peak meter on the tape recorder. The trial was started after the first of these trigger pulses to follow the announcement. This procedure ensured that the same set of 64 records would be selected if the analysis was repeated.

The results from these tests are presented in the tables which follow. The ensemble averages are included for comparison. These were visually scored using a five-point scale, from ++ for a definite response, through +, O, - down to -- for a complete lack of response. An equivocal trace scored O. Also included in the results is the approximate subjective threshold. This was determined at the time of testing, by asking the subject whether the trains of stimuli could be heard or not. If the subject heard all the stimuli at one amplitude level and none of the stimuli at the next lower level, then the mean of the two levels was taken as the subjective threshold. If the subject heard all the stimuli at one level, some of the stimuli at the next lower level, and none of the stimuli at the next lower level after that, then the subjective threshold was taken as the second of these three levels.

When the visual scoring was carried out, the scorer was shown the complete set of ensemble averages for all stimulus levels at one frequency. The scorer was not told the names of the subjects, who were identified by numbers.

The following points should be noted when interpreting the results from the phase analysis method. It will be seen by interpolation from the results of Ross, quoted above, that the 5% confidence limit for the phase standard deviation, with a sample of 64 points, is approximately 90.5° . Thus figures of 90° or less may be taken as significant, while figures of 91° or more are not significant.

However, for each trial there are not one but six values of phase standard deviation, one for each harmonic number. Thus, random white noise would be expected to give significance in one particular harmonic in 5% of trials, by chance, while significance would be expected in any one of six harmonics in a larger proportion of trials.

For m independent random variables, the probability of any n being significant follows a binomial distribution. If $m = 6$, and each variable is significant in 5% of trials, then the probability of the event

$n = 0$ is $0.95^6 = 0.735$

$n = 1$ is $6 \times 0.05 \times 0.95^5 = 0.232$

$n = 2$ or more is 0.033

These figures indicate that if only one harmonic has a phase standard deviation of 90° or less, then this is not highly significant: it would be expected to occur by chance

in over 25% of tests on random white noise. If any two harmonics have phase standard deviations of this magnitude, then this is significant at $3\frac{1}{2}\%$.

By analogy with the scale for visually scoring the ensemble averages, the results have been summarised by scoring + for any one harmonic significant, ++ for two or more harmonics significant, and - for no significance in any harmonic.

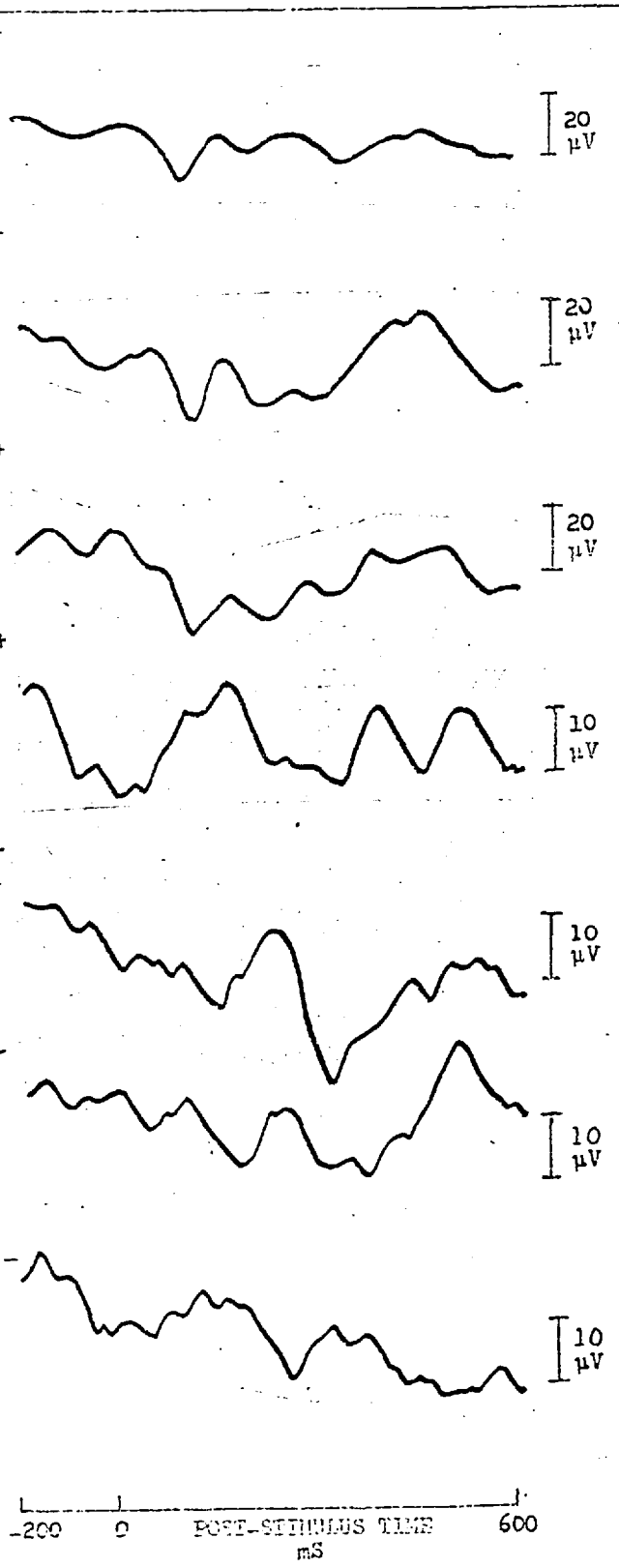
The microprocessor prints out the amplitude mean of each harmonic in V/Hz at the A/D converter input. The gain of the amplifiers prior to this stage is noted in the results. This is such that the voltage at the A/D converter input is not too large, thus overloading the A/D converter, or too small, causing excessive errors of quantization. With a reasonable signal level at the A/D converter input, the first harmonic has a mean amplitude of from 0.02 to 0.1 V/Hz.

The total gain prior to the A/D converter was 25000 in most tests. However, in some trials it was found that the level of the signal recorded on tape was somewhat low, so the gain on playback was increased by a factor of 2.5. This is noted in the results as (x 62500) , above the printout for the relevant trials.

Table 5.1 Subject AMcK . F, 20 yrs.

Left Ear 500 Hz

Microprocessor Results				Ensemble Average
RN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.040	208	094	
2	.034	202	088	
3	.024	007	085	
4	.014	302	081	
5	.014	019	075	
6	.008	105	091	
60 dB		Score	++	++
1	.046	234	084	
2	.030	106	088	
3	.030	007	097	
4	.014	012	087	
5	.014	078	087	
6	.008	111	088	
40 dB		Score	++	++
1	.044	236	090	
2	.034	035	101	
3	.028	039	094	
4	.014	015	088	
5	.012	007	084	
6	.008	136	094	
20 dB		Score	-	+
1	.050	262	092	
2	.038	071	099	
3	.024	030	095	
4	.018	036	099	
5	.012	104	099	
6	.008	250	101	
10 dB		Score	++	+
1	.100	295	090	
2	.076	189	084	
3	.062	281	085	
4	.040	085	088	
5	.028	262	099	
6	.022	352	097	
0 dB		Score	+	+
1	.100	267	085	
2	.068	196	092	
3	.052	053	105	
4	.030	156	098	
5	.030	229	095	
6	.018	315	095	
-10 dB		Score	-	-
1	.098	291	104	
2	.066	056	099	
3	.046	213	098	
4	.038	016	092	
5	.028	156	092	
6	.022	180	098	



Subjective Threshold = -5dB

Table 5.2 Subject AMcK

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
BN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.034	164	097	
2	.060	243	098	
3	.056	247	092	
4	.038	005	082	
5	.030	061	081	
6	.018	115	073	
60 dB		Score	++	++
1	.052	182	084	
2	.034	261	104	
3	.030	313	088	
4	.018	338	088	
5	.014	077	085	
6	.008	123	095	
40 dB		Score	++	++
1	.040	208	098	
2	.030	057	101	
3	.024	247	097	
4	.014	007	081	
5	.012	036	092	
6	.008	105	080	
20 dB		Score	+	++
1	.044	244	090	
2	.028	067	091	
3	.022	265	098	
4	.014	025	091	
5	.014	327	092	
6	.008	154	095	
10 dB		Score	+	+
1	.040	227	090	
2	.030	208	095	
3	.024	337	092	
4	.014	302	105	
5	.014	350	095	
6	.008	111	091	
0 dB		Score	+	0
1	.044	284	094	
2	.034	244	082	
3	.024	264	097	
4	.018	188	092	
5	.012	000	095	
6	.006	307	094	
-10 dB		Score	+	- -
1	.046	323	099	
2	.034	112	104	
3	.024	064	082	
4	.018	021	092	
5	.014	115	099	
6	.008	098	105	

Subjective Threshold = -5dB

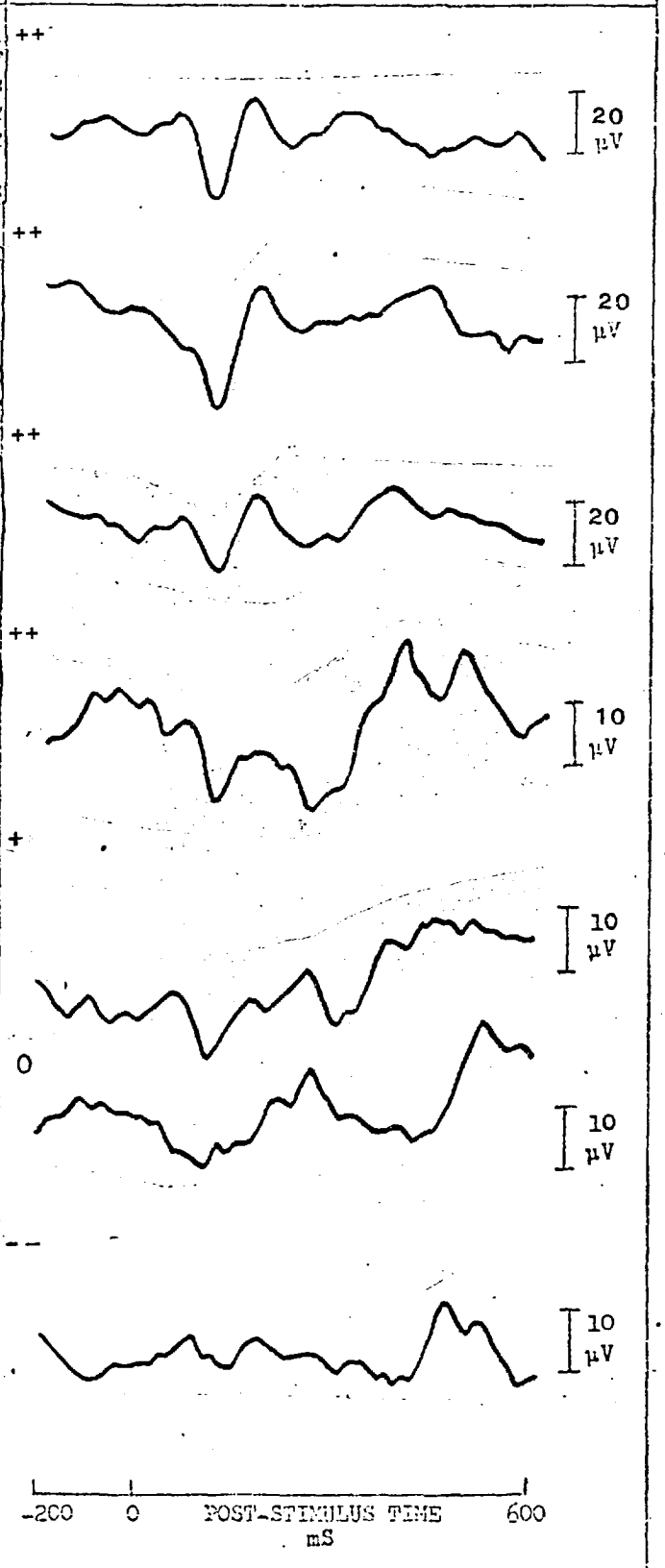
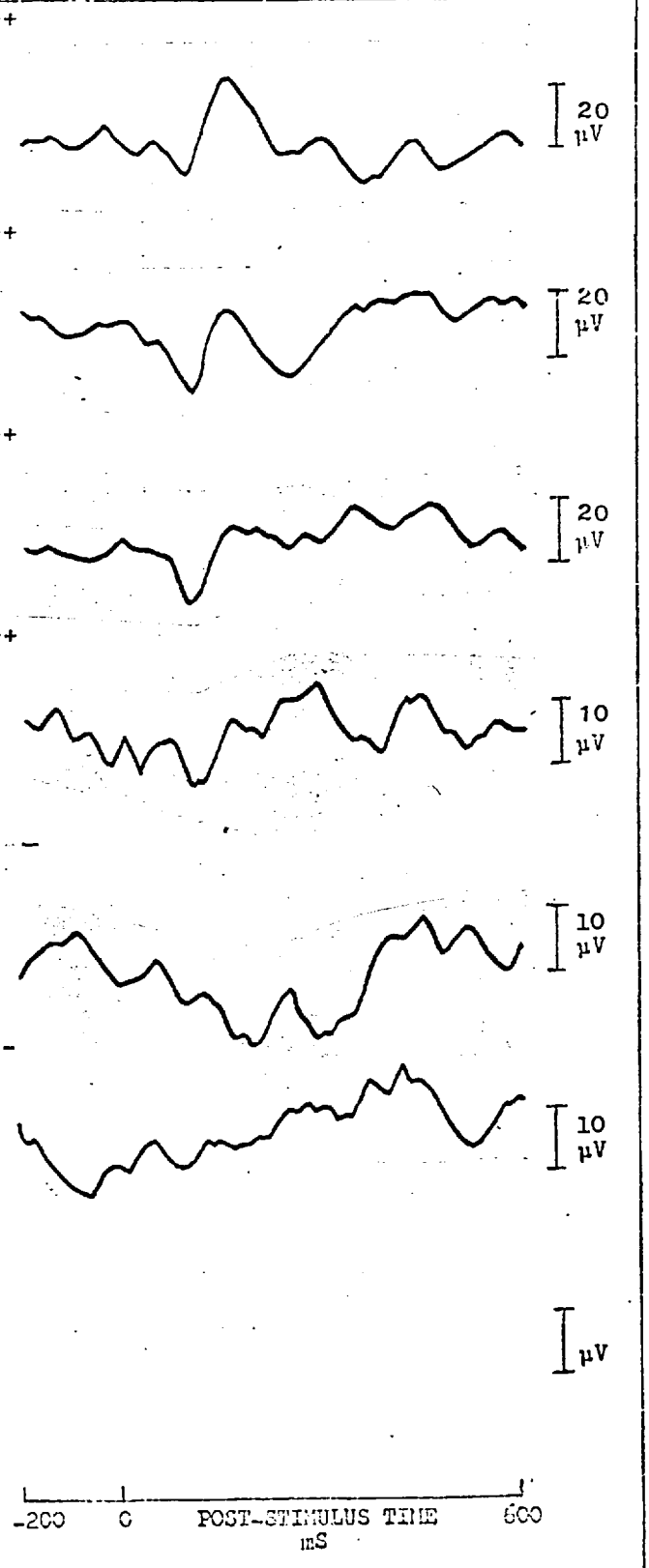


Table 5.3 Subject AMcK

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz × 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	+	++
1	.034	043	091	
2	.030	156	092	
3	.024	241	095	
4	.014	296	080	
5	.012	049	094	
6	.008	053	094	
60 dB		Score	++	++
1	.040	241	085	
2	.030	118	098	
3	.028	260	087	
4	.018	313	078	
5	.012	054	095	
6	.008	105	084	
40 dB		Score	++	++
1	.046	178	092	
2	.030	149	094	
3	.024	288	094	
4	.014	303	087	
5	.012	057	099	
6	.008	077	074	
20 dB		Score	-	++
1	.040	001	102	
2	.030	331	098	
3	.028	000	092	
4	.014	268	101	
5	.014	115	094	
6	.008	084	101	
10 dB		Score	++	-
1	.046	262	090	
2	.038	208	101	
3	.028	352	088	
4	.018	181	095	
5	.014	317	099	
6	.008	341	090	
0 dB		Score	-	--
1	.040	192	097	
2	.030	357	099	
3	.024	316	094	
4	.014	243	098	
5	.012	355	094	
6	.008	098	101	
dB		Score		

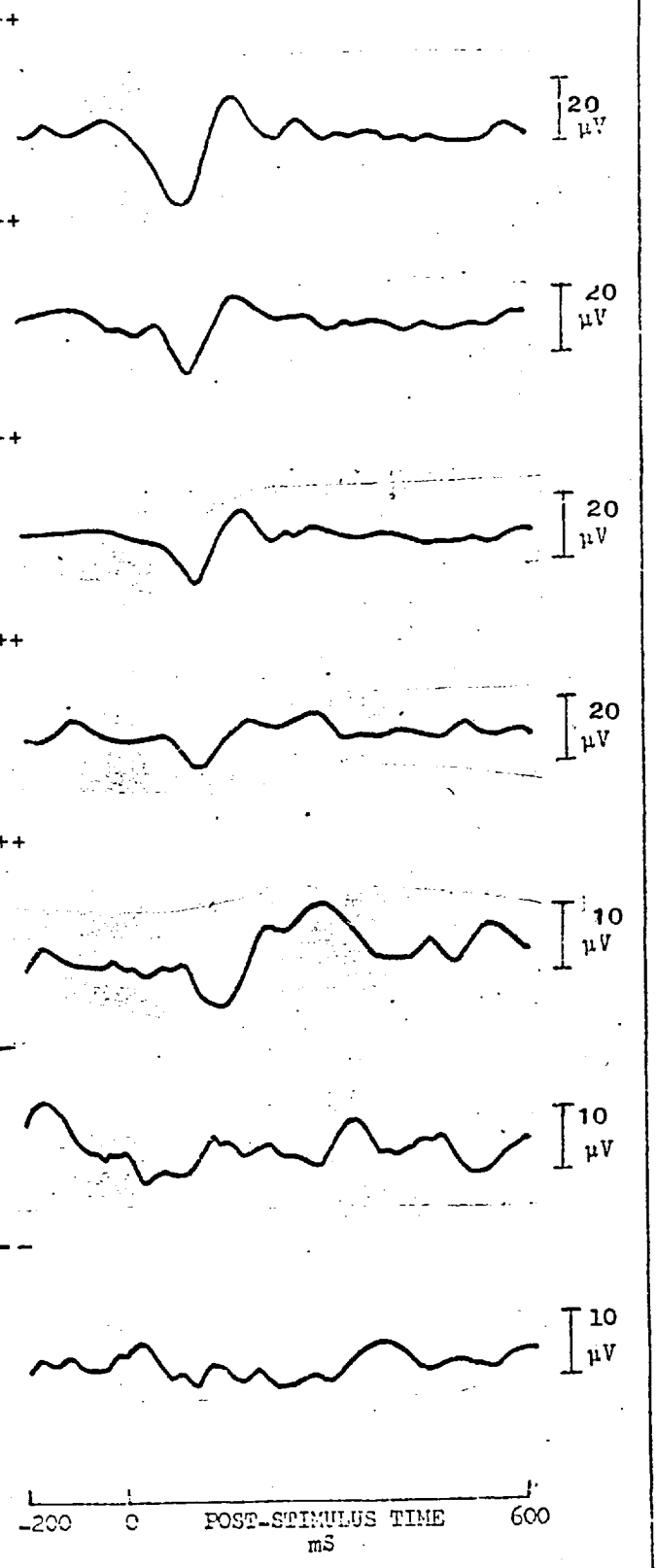


Subjective Threshold = 5dB

Table 5.4 Subject LL . F, 31 yrs.

Left Ear 500 Hz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.030	144	090	
2	.038	212	075	
3	.024	262	071	
4	.018	312	070	
5	.018	014	081	
6	.008	091	080	
60 dB		Score	++	++
1	.056	195	099	
2	.040	239	094	
3	.024	291	074	
4	.018	306	084	
5	.014	007	087	
6	.012	084	091	
40 dB		Score	++	++
1	.056	184	090	
2	.044	232	087	
3	.030	270	084	
4	.018	309	080	
5	.012	005	070	
6	.008	118	087	
20 dB		Score	++	++
1	.044	161	090	
2	.040	222	090	
3	.024	316	090	
4	.018	009	087	
5	.014	045	088	
6	.012	146	082	
10 dB		Score	++	++
1	.030	127	095	
2	.028	284	082	
3	.018	043	084	
4	.012	125	099	
5	.014	129	094	
6	.008	094	104	
0 dB (x 62500)		Score	++	-
1	.104	146	087	
2	.078	298	102	
3	.052	281	095	
4	.046	299	085	
5	.046	234	091	
6	.028	357	102	
-10 dB		Score	-	--
1	.050	007	097	
2	.038	347	097	
3	.022	225	091	
4	.018	227	104	
5	.018	016	099	
6	.012	133	094	

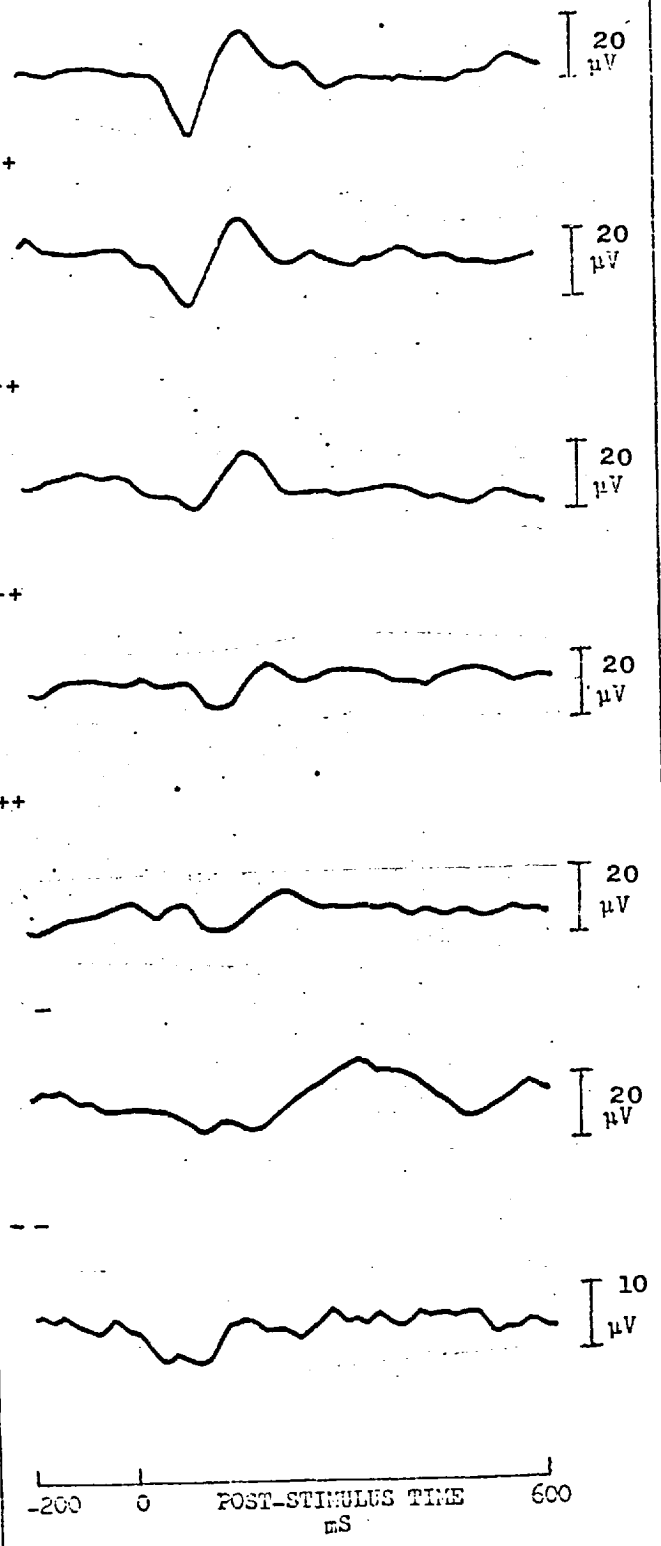


Subjective Threshold = 5dB

Table 5.5 Subject LL

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.038	084	091	
2	.034	216	075	
3	.024	268	085	
4	.014	326	077	
5	.012	029	067	
6	.008	077	070	
60 dB		Score	++	++
1	.034	191	097	
2	.028	201	084	
3	.024	279	071	
4	.014	316	074	
5	.012	028	075	
6	.008	129	090	
40 dB		Score	++	++
1	.040	095	094	
2	.030	201	084	
3	.024	262	085	
4	.018	345	092	
5	.008	046	080	
6	.006	108	087	
20 dB		Score	++	++
1	.034	174	098	
2	.028	241	091	
3	.018	008	091	
4	.012	021	075	
5	.008	118	081	
6	.006	187	090	
10 dB		Score	++	++
1	.050	073	097	
2	.040	250	099	
3	.022	354	088	
4	.018	070	091	
5	.012	099	091	
6	.008	143	090	
0 dB (x 62500)		Score	++	-
1	.034	178	073	
2	.034	331	078	
3	.052	275	088	
4	.040	223	090	
5	.038	247	102	
6	.024	022	099	
-10dB		Score	-	- -
1	.040	194	094	
2	.030	151	095	
3	.022	233	092	
4	.014	278	092	
5	.012	340	098	
6	.008	018	093	

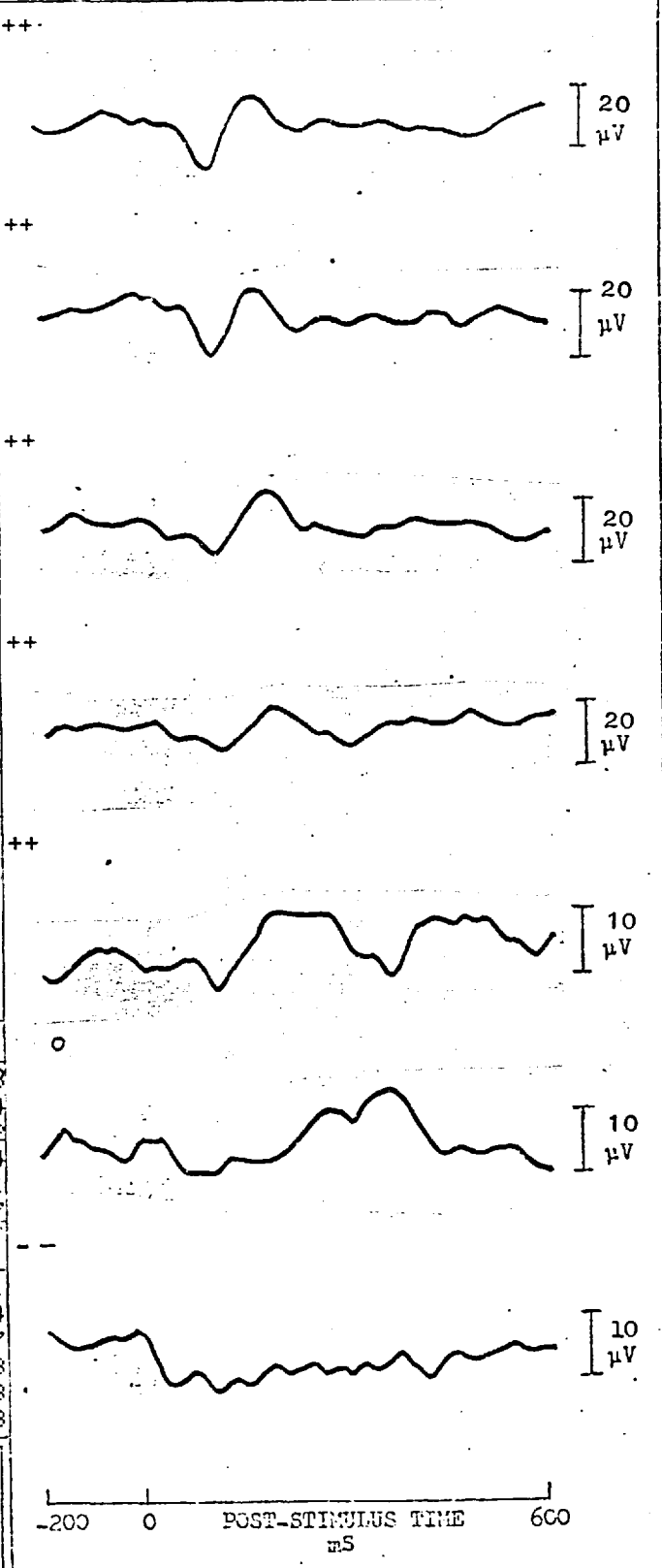


Subjective Threshold = -5dB

Table 5.6 Subject LL

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.038	123	097	
2	.028	225	094	
3	.028	270	082	
4	.014	319	074	
5	.012	032	082	
6	.008	122	080	
60 dB		Score	++	++
1	.034	268	090	
2	.030	241	097	
3	.022	270	087	
4	.014	336	080	
5	.008	047	066	
6	.008	064	091	
40 dB		Score	++	++
1	.038	144	099	
2	.034	174	087	
3	.024	312	077	
4	.014	009	074	
5	.012	059	088	
6	.008	164	090	
20 dB		Score	++	++
1	.034	026	102	
2	.028	194	091	
3	.024	293	090	
4	.012	019	077	
5	.008	302	101	
6	.006	154	095	
10 dB		Score	+	++
1	.046	101	094	
2	.038	182	091	
3	.024	009	085	
4	.014	022	091	
5	.014	043	094	
6	.008	097	101	
0 dB (x 62500)		Score	++	o
1	.084	139	078	
2	.068	338	094	
3	.052	023	102	
4	.038	082	094	
5	.024	316	091	
6	.018	046	087	
-10 dB		Score	-	- -
1	.046	279	101	
2	.034	262	094	
3	.024	267	097	
4	.018	309	098	
5	.014	258	098	
6	.008	205	098	



Subjective Threshold = -5dB

Table 5.7 Subject LL

Right Ear 500 Hz

HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
80 dB		Score	++
1	.030	077	094
2	.024	178	080
3	.024	261	073
4	.014	289	064
5	.014	350	068
6	.008	066	075
60 dB (x 62500)		Score	++
1	.066	170	097
2	.078	213	080
3	.050	253	082
4	.046	324	074
5	.050	028	067
6	.024	095	090
40 dB		Score	++
1	.046	167	098
2	.034	203	087
3	.024	279	101
4	.018	347	071
5	.012	011	085
6	.008	118	088
20 dB		Score	++
1	.040	226	098
2	.034	220	081
3	.024	292	084
4	.018	334	088
5	.022	049	084
6	.012	161	088
10 dB		Score	++
1	.028	129	087
2	.028	255	078
3	.018	022	097
4	.012	199	097
5	.024	312	102
6	.012	217	097
0 dB		Score	+
1	.050	077	091
2	.034	251	097
3	.022	262	088
4	.014	153	094
5	.018	265	095
6	.012	279	102
-10 dB		Score	-
1	.050	143	097
2	.038	172	091
3	.024	234	099
4	.018	270	098
5	.018	303	095
6	.014	109	102

Subjective Threshold = 5dB

Microprocessor Results

Ensemble Average

Score

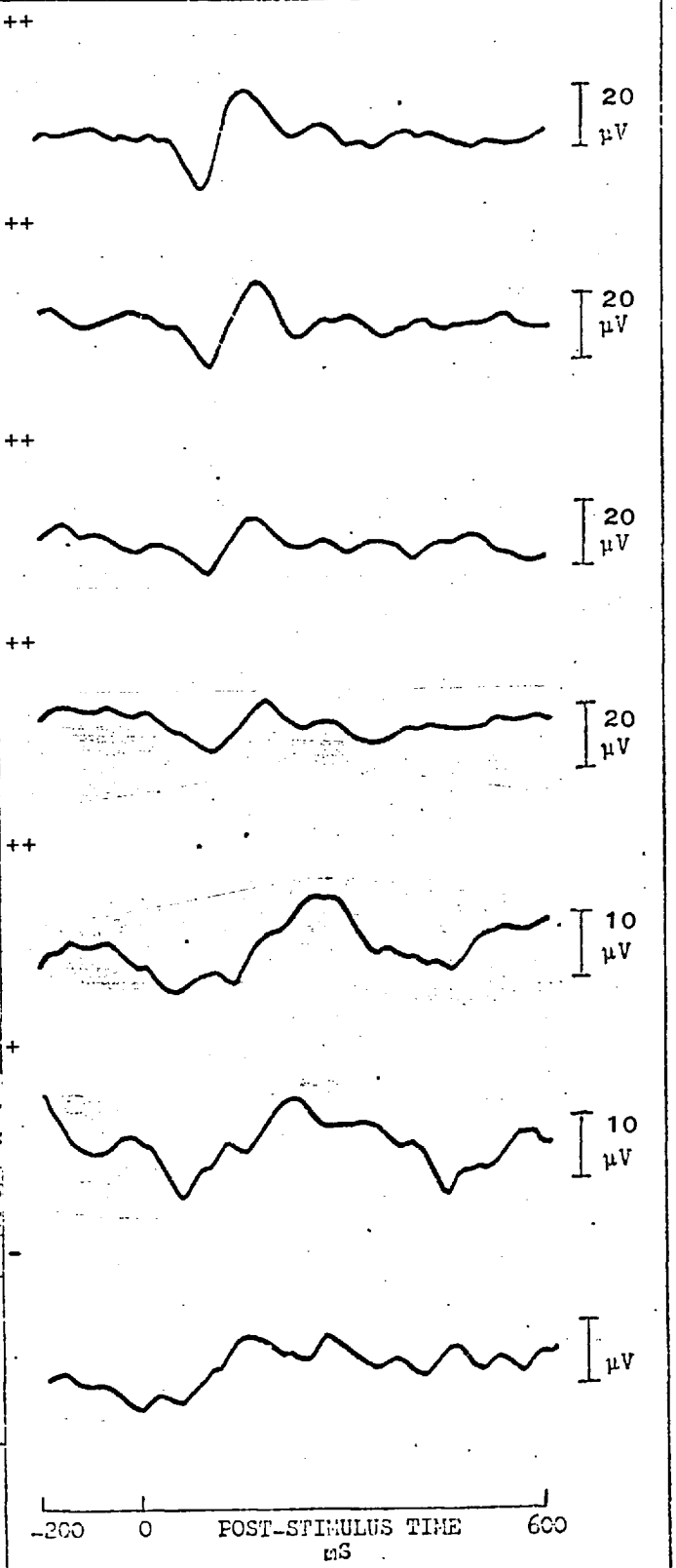
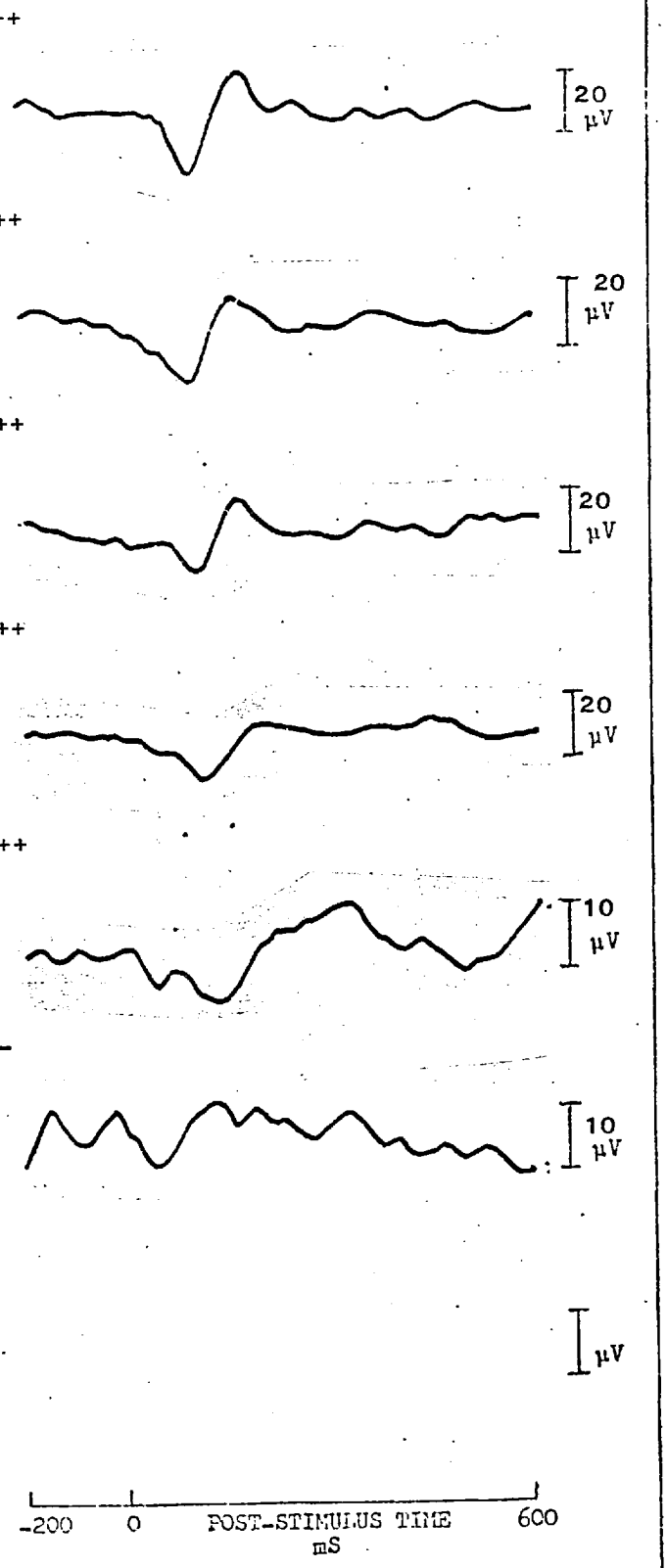


Table 5.8 Subject LL

Right Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.052	143	097	
2	.040	216	088	
3	.028	274	084	
4	.018	352	075	
5	.018	016	074	
6	.008	092	081	
60 dB		Score	++	++
1	.038	151	084	
2	.030	219	084	
3	.024	272	063	
4	.018	319	068	
5	.012	350	080	
6	.008	120	087	
40 dB		Score	++	++
1	.034	178	099	
2	.028	187	088	
3	.022	248	081	
4	.014	310	080	
5	.014	005	078	
6	.006	064	084	
20 dB		Score	++	++
1	.040	185	075	
2	.030	240	094	
3	.022	336	080	
4	.018	015	088	
5	.014	081	092	
6	.008	154	095	
10 dB		Score	++	++
1	.038	147	085	
2	.034	300	081	
3	.022	330	092	
4	.014	270	097	
5	.012	174	091	
6	.008	277	101	
0 dB		Score	-	-
1	.050	136	091	
2	.038	084	098	
3	.024	187	092	
4	.018	279	101	
5	.014	019	102	
6	.008	341	097	
dB		Score		

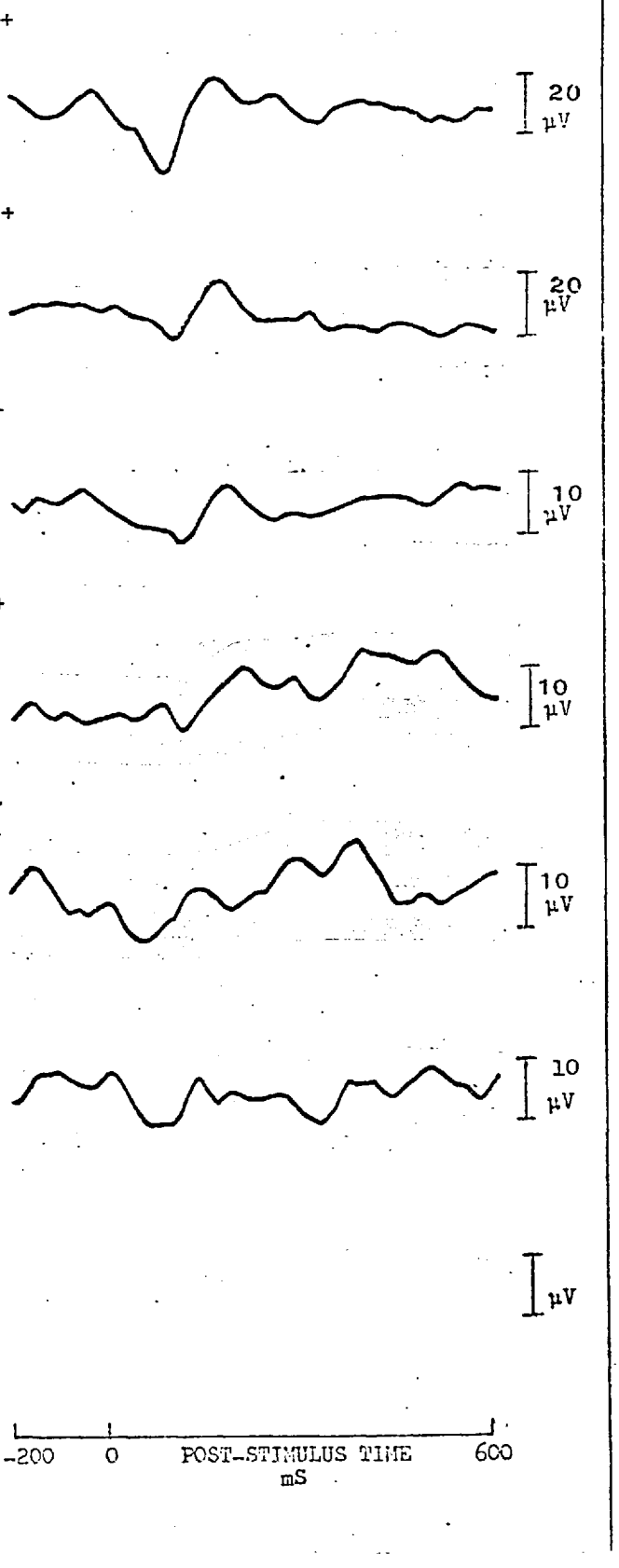


Subjective Threshold = 5dB

Table 5.9 Subject LL

Right Ear 2KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.036	137	092	
2	.040	223	087	
3	.024	299	064	
4	.018	313	070	
5	.014	005	070	
6	.012	098	092	
60 dB		Score	++	++
1	.034	068	098	
2	.028	199	092	
3	.022	241	092	
4	.018	319	078	
5	.012	052	088	
6	.008	102	084	
40 dB		Score	++	++
1	.044	285	095	
2	.034	212	087	
3	.024	279	077	
4	.014	340	091	
5	.014	064	092	
6	.012	157	090	
20 dB		Score	+	++
1	.034	167	092	
2	.034	182	087	
3	.024	323	094	
4	.014	097	092	
5	.012	082	091	
6	.008	164	094	
10 dB		Score	++	-
1	.030	156	090	
2	.028	357	098	
3	.018	229	090	
4	.014	225	091	
5	.018	300	098	
6	.012	226	098	
0 dB		Score	++	-
1	.044	236	099	
2	.038	203	090	
3	.024	223	099	
4	.018	274	097	
5	.018	298	087	
6	.012	160	101	
dB		Score		



Subjective Threshold = 10dB

Table 5.10 Subject DA-K F, 37yrs.

Left Ear 500 Hz

Microprocessor Results

HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
80 dB		Score	++
1	.030	187	092
2	.028	234	068
3	.022	295	063
4	.014	000	061
5	.012	068	074
6	.006	133	073
60 dB		Score	++
1	.034	279	098
2	.028	232	075
3	.024	312	066
4	.014	005	064
5	.012	070	082
6	.008	137	084
40 dB		Score	++
1	.044	090	099
2	.024	227	085
3	.022	258	092
4	.014	046	080
5	.012	105	085
6	.008	106	099
20 dB		Score	+
1	.044	210	087
2	.034	284	087
3	.024	074	095
4	.014	212	088
5	.012	354	099
6	.008	056	097
10 dB		Score	-
1	.046	203	091
2	.030	005	095
3	.024	201	095
4	.014	331	091
5	.012	050	098
6	.008	279	106
0 dB		Score	-
1	.056	160	091
2	.034	140	092
3	.022	012	090
4	.014	099	092
5	.014	035	098
6	.008	046	101
-10dB		Score	-
1	.028	216	098
2	.028	009	105
3	.022	351	094
4	.014	046	095
5	.012	306	097
6	.008	334	097

Subjective Threshold = 5dB

Ensemble Average

Score

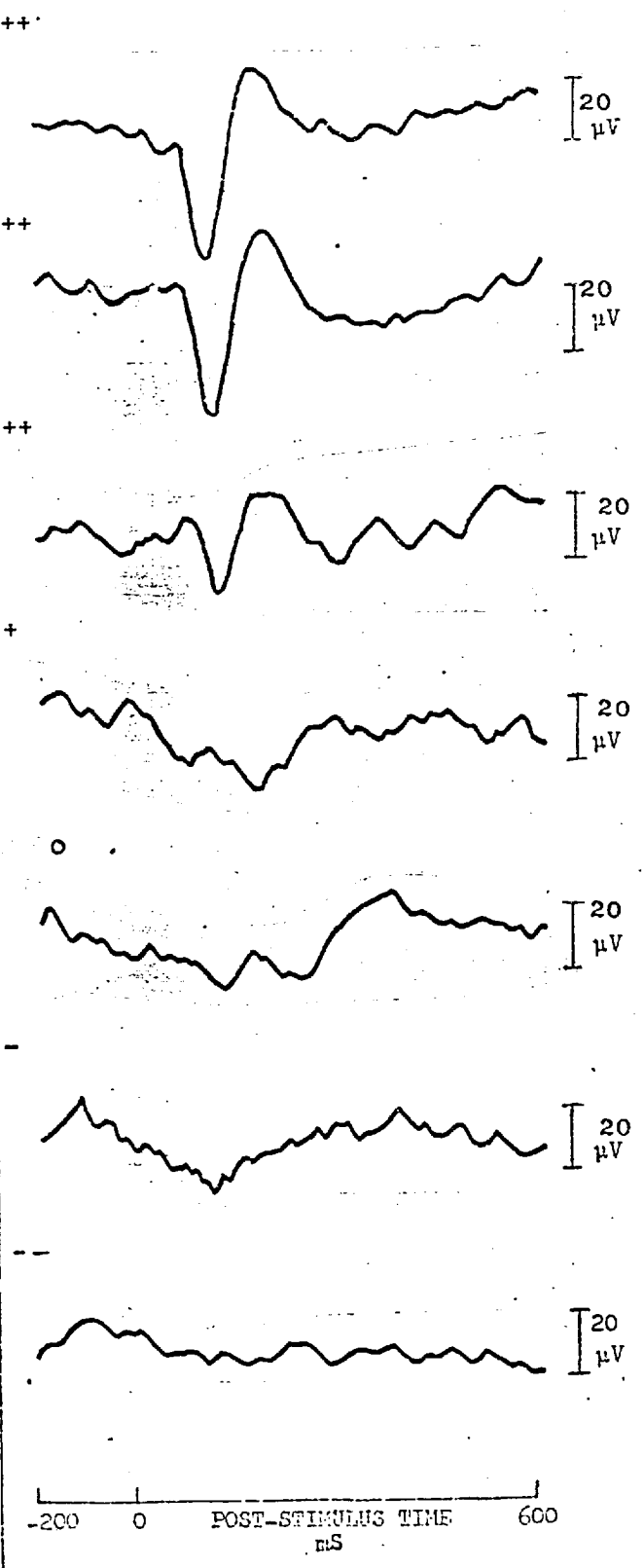
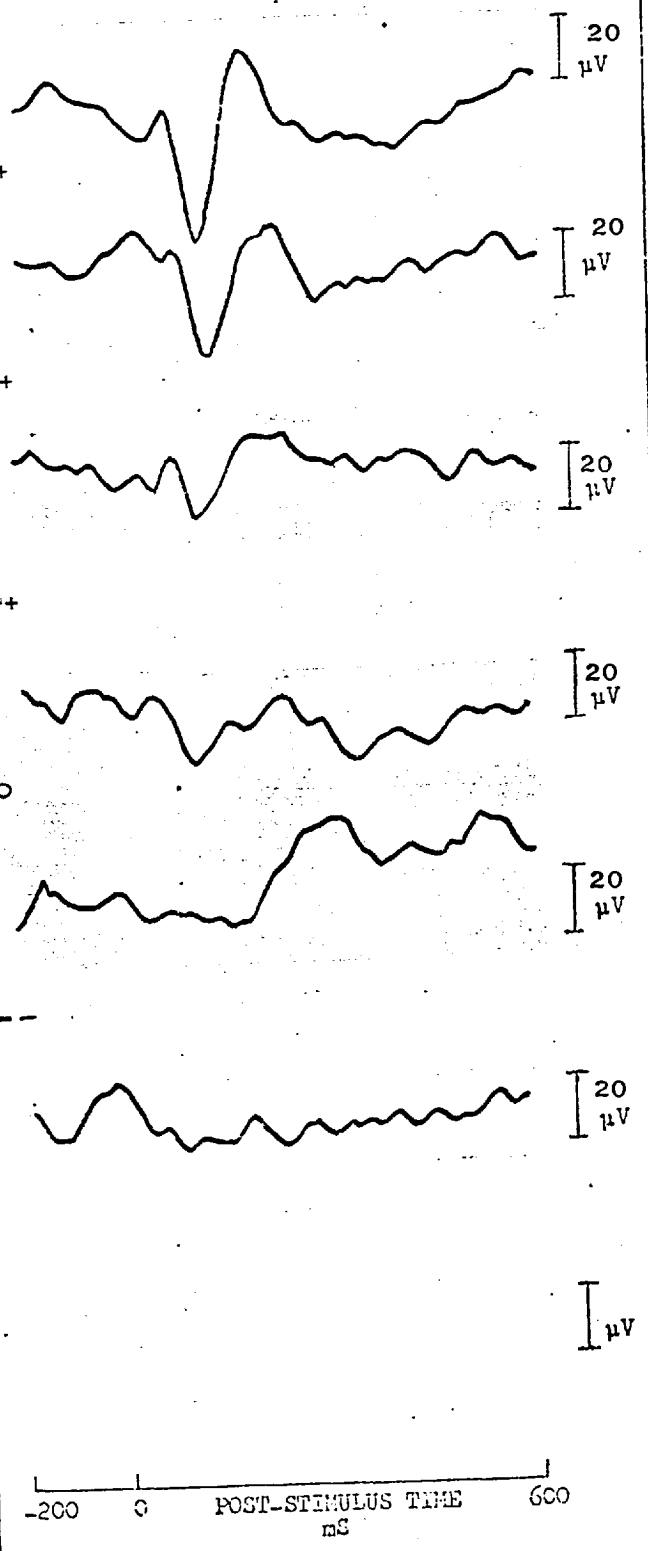


Table 5.11 Subject DA-K

Left Ear 1 KHz

HN	Microprocessor Results: Amplitude Mean V/Hz × 25000	Phase Mean o	Phase S.D. o	Ensemble Average: Score
65 dB		Score	++	++
1	.034	291	097	
2	.028	234	075	
3	.022	296	073	
4	.014	354	066	
5	.012	073	080	
6	.008	142	077	
45 dB		Score	++	++
1	.046	265	092	
2	.030	239	084	
3	.022	322	073	
4	.018	064	082	
5	.008	116	085	
6	.008	237	099	
25 dB		Score	+	++
1	.034	087	098	
2	.028	233	087	
3	.022	331	092	
4	.014	104	097	
5	.008	099	091	
6	.008	118	102	
15 dB		Score	-	++
1	.050	345	097	
2	.030	268	095	
3	.022	347	092	
4	.014	043	102	
5	.012	030	095	
6	.008	122	099	
5 dB		Score	++	o
1	.046	146	090	
2	.038	264	081	
3	.024	099	094	
4	.018	149	095	
5	.008	157	098	
6	.008	047	099	
-5 dB		Score	-	--
1	.046	046	106	
2	.034	327	098	
3	.024	275	094	
4	.018	251	101	
5	.012	102	099	
6	.012	302	101	
dB		Score		

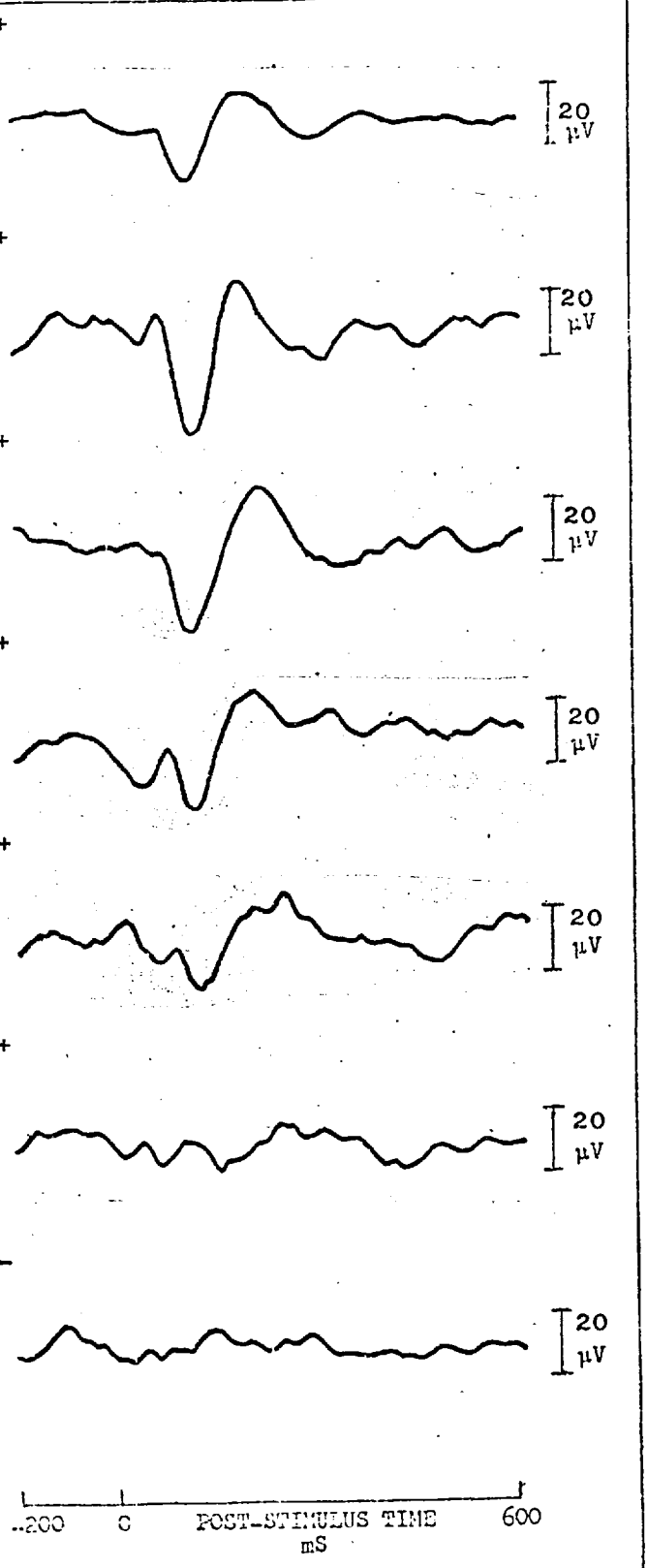


Subjective Threshold = 0 dB

Table 5.12 Subject DA-K

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Ms x 25000	Phase Mean o	Phase S.D. o	Score
65 dB		Score	++	++
1	.040	187	084	
2	.030	216	084	
3	.024	295	067	
4	.014	009	068	
5	.012	035	091	
6	.008	122	087	
45 dB		Score	++	++
1	.024	237	097	
2	.022	247	081	
3	.018	295	067	
4	.014	021	068	
5	.008	063	073	
6	.006	139	081	
35 dB		Score	++	++
1	.030	164	095	
2	.028	234	070	
3	.022	317	070	
4	.014	030	075	
5	.008	075	091	
6	.008	123	090	
25 dB		Score	++	++
1	.028	149	084	
2	.024	246	087	
3	.018	315	080	
4	.012	016	091	
5	.008	105	087	
6	.006	185	091	
15 dB		Score	+	++
1	.044	087	091	
2	.030	247	092	
3	.024	326	088	
4	.014	126	095	
5	.012	077	099	
6	.008	129	091	
5 dB		Score	-	+
1	.028	196	097	
2	.022	296	101	
3	.018	142	094	
4	.012	212	098	
5	.008	239	099	
6	.006	351	099	
-5 dB		Score	-	-
1	.024	042	093	
2	.022	158	099	
3	.018	230	099	
4	.012	236	095	
5	.008	334	098	
6	.006	195	095	



Subjective Threshold = 0 dB

Table 5.13 Subject RM F, 30 yrs.

Right Ear 500 Hz

Microprocessor Results				Ensemble Average
MN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.052	040	105	
2	.034	151	093	
3	.024	289	091	
4	.018	004	090	
5	.012	111	085	
6	.008	139	088	
60 dB (x 62500)		Score	++	++
1	.068	143	094	
2	.062	202	084	
3	.046	261	081	
4	.030	352	082	
5	.024	030	084	
6	.022	011	099	
40 dB (x 62500)		Score	++	++
1	.068	209	085	
2	.060	187	084	
3	.044	275	085	
4	.034	358	091	
5	.024	172	092	
6	.018	258	094	
20 dB (x 62500)		Score	+	+
1	.078	126	085	
2	.076	241	094	
3	.052	035	091	
4	.038	084	092	
5	.028	060	098	
6	.018	156	098	
10 dB (x 62500)		Score	-	o
1	.062	005	099	
2	.050	270	098	
3	.040	007	097	
4	.030	025	092	
5	.024	291	097	
6	.022	184	095	
0 dB (x 62500)		Score	++	-
1	.094	237	087	
2	.084	067	094	
3	.050	344	092	
4	.038	255	093	
5	.028	071	095	
6	.018	014	088	
-10 dB		Score	-	- -
1	.034	233	106	
2	.028	040	104	
3	.022	306	101	
4	.012	350	097	
5	.012	021	091	
6	.008	060	101	

Subjective Threshold = -5 dB

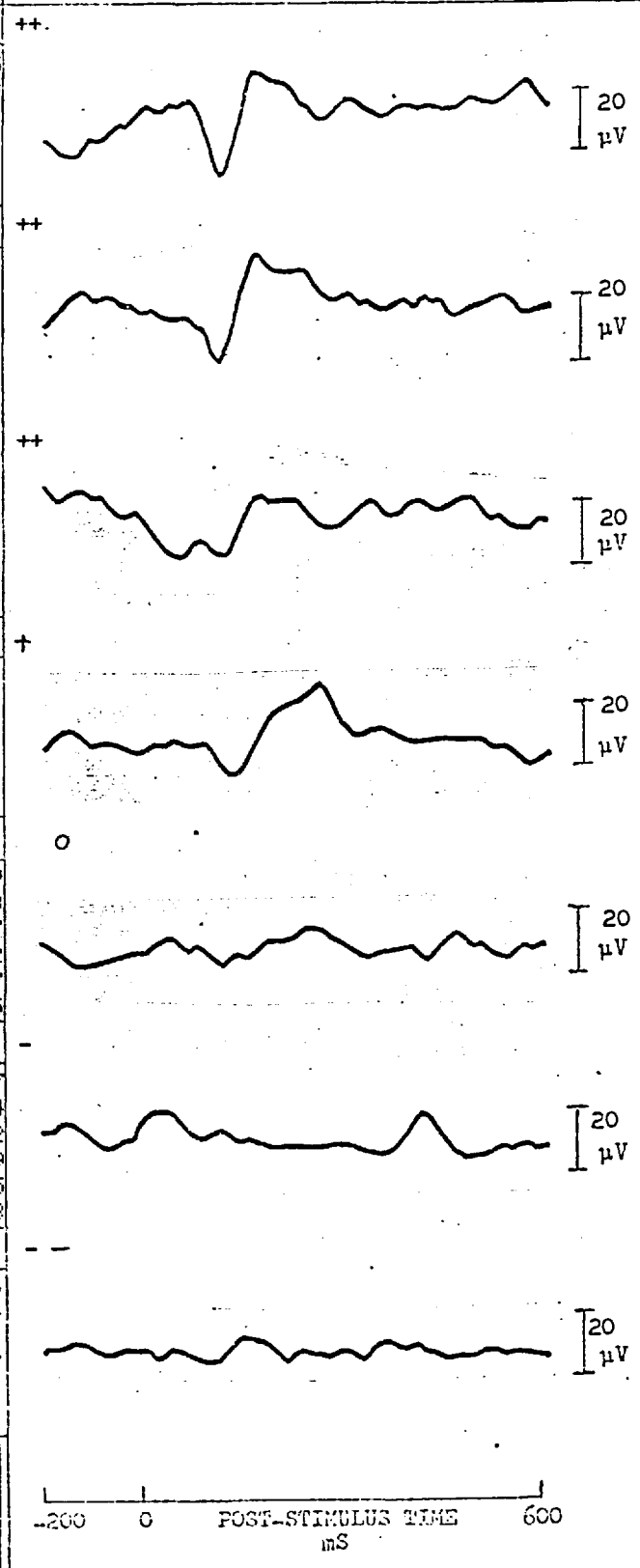


Table 5.14 Subject RM

Right Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB	(x 62500)	Score	++	++
1	.110	068	097	
2	.066	250	094	
3	.046	272	078	
4	.040	347	080	
5	.030	032	084	
6	.022	132	087	
60 dB		Score	++	++
1	.038	344	101	
2	.030	195	084	
3	.018	272	090	
4	.012	037	094	
5	.012	026	087	
6	.006	133	088	
40 dB		Score	++	++
1	.030	208	094	
2	.024	184	091	
3	.018	344	090	
4	.012	007	082	
5	.008	047	084	
6	.008	085	092	
20 dB		Score	-	+
1	.028	205	094	
2	.024	264	097	
3	.014	253	101	
4	.014	046	097	
5	.006	099	097	
6	.006	244	101	
10 dB		Score	+	+
1	.030	185	091	
2	.022	180	094	
3	.014	047	087	
4	.012	160	099	
5	.008	272	095	
6	.006	358	092	
0 dB		Score	-	-
1	.030	151	101	
2	.024	237	092	
3	.018	015	099	
4	.012	285	102	
5	.008	016	091	
6	.006	045	104	
dB		Score		

Subjective Threshold = 5 dB

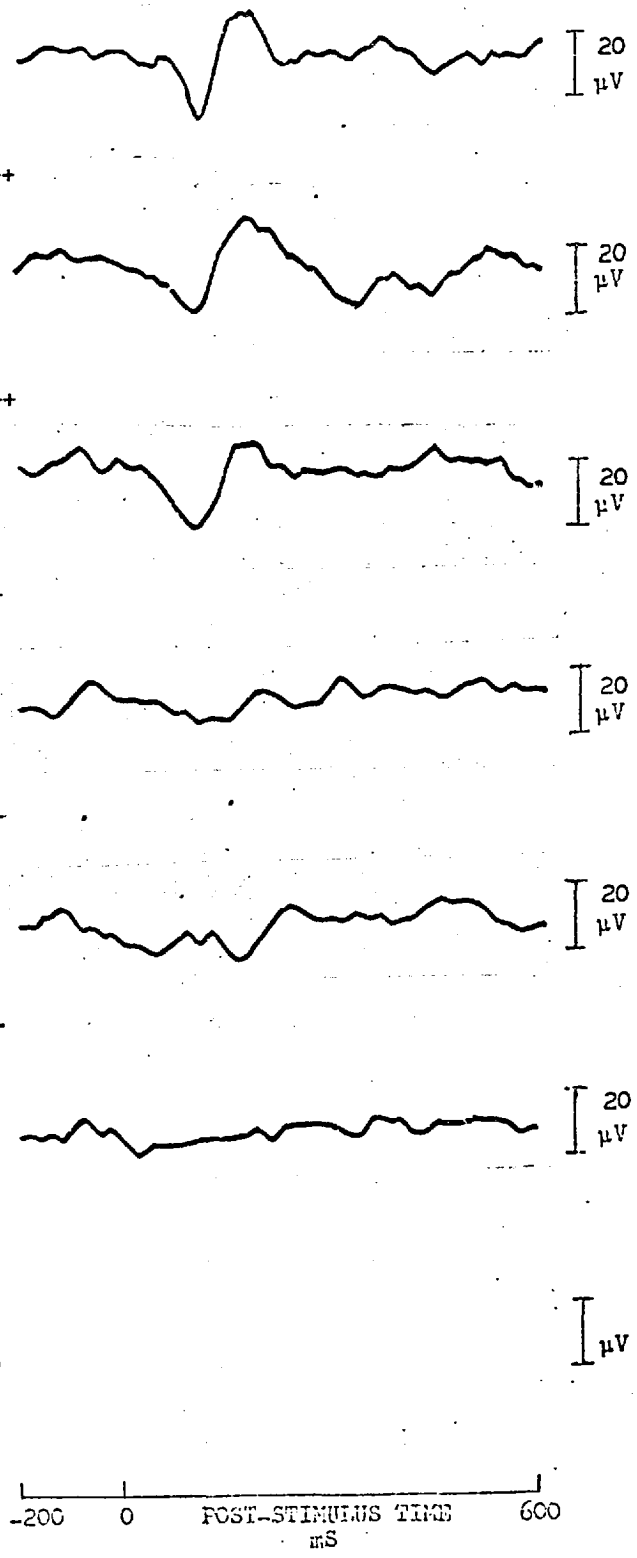
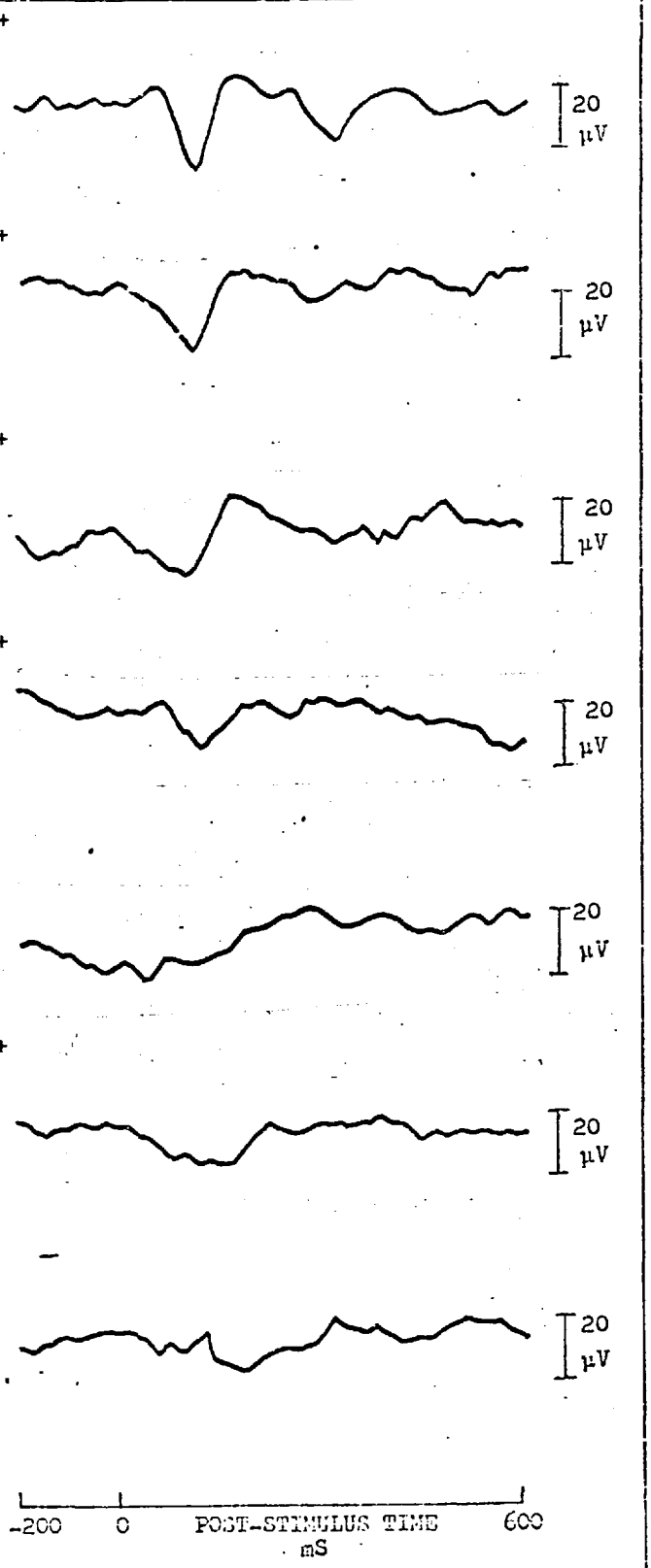


Table 5.15 Subject RM

Right Ear 2 KHz

Microprocessor Results				Ensemble Average
NN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.044	135	101	
2	.030	213	099	
3	.022	305	078	
4	.014	015	092	
5	.008	036	068	
6	.008	087	092	
60 dB		Score	++	++
1	.034	132	098	
2	.028	205	095	
3	.018	295	077	
4	.012	334	087	
5	.008	071	091	
6	.008	053	085	
40 dB		Score	++	++
1	.034	161	095	
2	.022	208	084	
3	.014	293	085	
4	.012	007	081	
5	.008	066	098	
6	.006	161	085	
20 dB		Score	+	++
1	.034	174	098	
2	.024	347	101	
3	.014	327	099	
4	.012	037	085	
5	.008	106	095	
6	.006	229	095	
10 dB		Score	+	+
1	.028	153	094	
2	.018	262	087	
3	.014	293	099	
4	.012	082	097	
5	.008	033	095	
6	.006	192	094	
0 dB		Score	+	+
1	.022	201	085	
2	.018	279	094	
3	.012	316	092	
4	.008	115	095	
5	.008	126	104	
6	.006	306	092	
-10 dB		Score	-	-
1	.030	227	094	
2	.022	282	092	
3	.018	129	091	
4	.008	139	094	
5	.008	282	102	
6	.006	028	092	

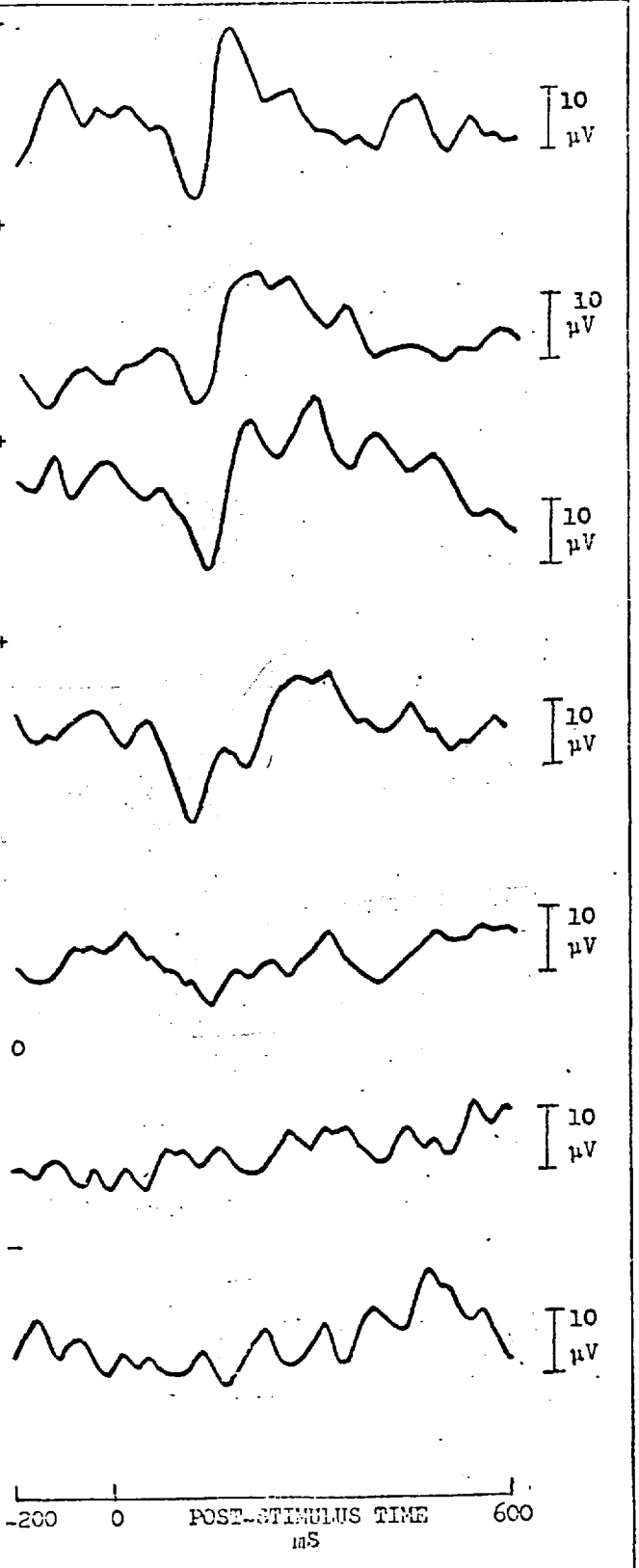


Subjective Threshold = -5 dB

Table 5.16 Subject JSN M,36 yrs.

Right Ear 500 Hz

Microprocessor Results				Ensemble Average
HH	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.072	160	094	
2	.046	194	092	
3	.034	309	084	
4	.024	357	087	
5	.018	085	087	
6	.018	095	087	
50 dB		Score	++	++
1	.062	105	088	
2	.040	270	092	
3	.030	352	092	
4	.022	019	091	
5	.018	095	082	
6	.022	085	090	
30 dB		Score	++	++
1	.062	153	084	
2	.040	201	099	
3	.034	040	094	
4	.022	074	091	
5	.018	104	084	
6	.022	237	092	
20 dB		Score	++	++
1	.060	180	085	
2	.040	300	087	
3	.034	059	087	
4	.024	354	097	
5	.022	129	098	
6	.022	098	088	
10 dB		Score	+	+
1	.066	237	098	
2	.044	233	090	
3	.030	071	102	
4	.024	004	095	
5	.018	133	095	
6	.014	030	092	
0 dB		Score	-	0
1	.063	164	101	
2	.046	251	098	
3	.038	267	094	
4	.024	195	099	
5	.024	278	102	
6	.030	087	097	
-10 dB		Score	-	- -
1	.066	216	095	
2	.050	164	097	
3	.030	033	097	
4	.022	056	095	
5	.022	312	097	
6	.022	302	101	



Subjective Threshold = -5 dB

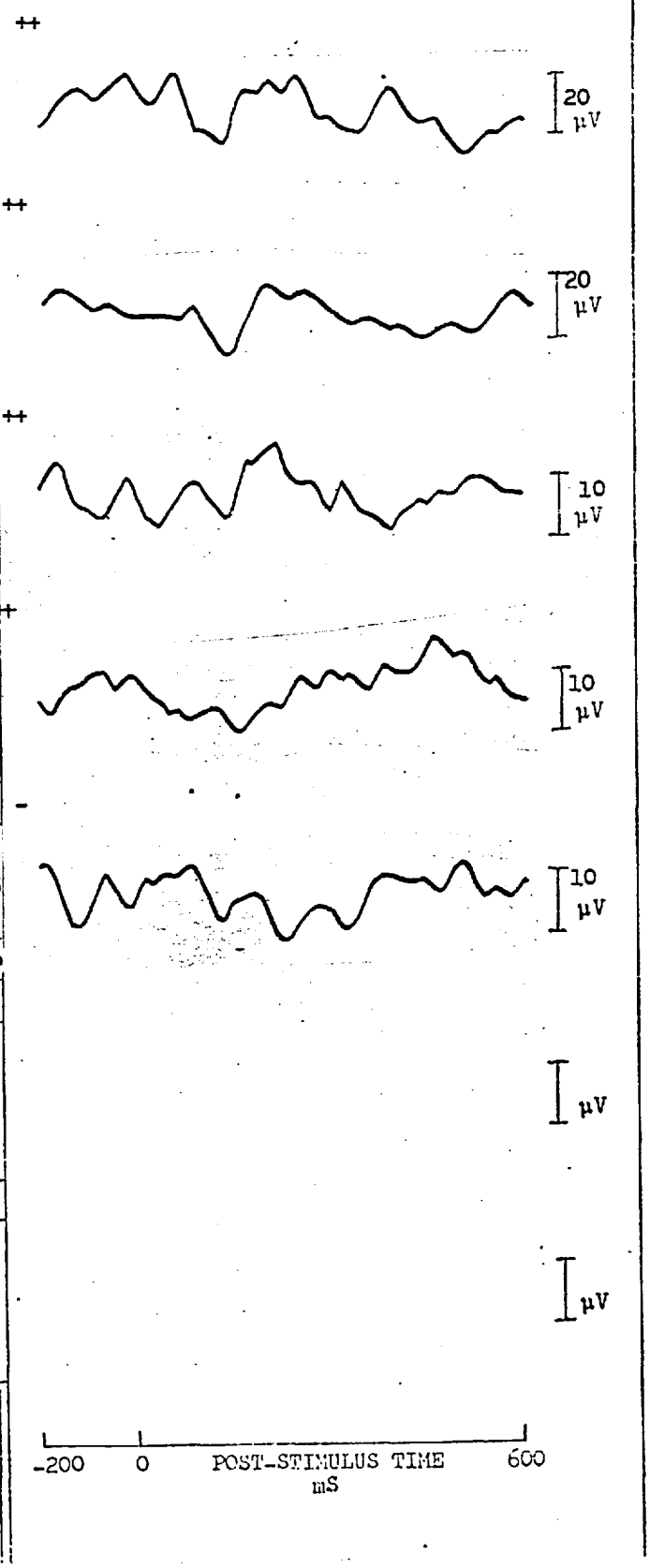
Table 5.17 Subject JSN

Left Ear 500 Hz

HW	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
70 dB		Score	+
1	.068	338	101
2	.046	158	099
3	.030	322	087
4	.024	092	095
5	.022	028	099
6	.012	147	097
50 dB		Score	++
1	.044	066	095
2	.040	264	077
3	.028	354	090
4	.024	097	092
5	.018	170	090
6	.014	151	087
40 dB		Score	-
1	.046	032	102
2	.046	203	091
3	.030	052	095
4	.024	046	101
5	.018	140	091
6	.012	278	101
30 dB		Score	+
1	.050	205	090
2	.038	292	102
3	.030	061	099
4	.018	032	099
5	.018	295	095
6	.014	357	097
20 dB		Score	-
1	.050	035	095
2	.040	149	097
3	.024	153	095
4	.022	354	091
5	.018	352	104
6	.018	075	099
dB		Score	
dB		Score	

Ensemble Average

Score



Subjective Threshold = 25 dB

Table 5.18 Subject JSN

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz × 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.050	073	090	
2	.040	202	091	
3	.030	299	081	
4	.028	021	095	
5	.018	358	092	
6	.018	126	082	
60 dB		Score	+	++
1	.050	133	094	
2	.040	226	097	
3	.030	001	090	
4	.024	022	095	
5	.018	097	095	
6	.018	090	101	
40 dB		Score	-	++
1	.066	327	091	
2	.050	268	095	
3	.038	324	094	
4	.028	068	091	
5	.022	119	091	
6	.022	253	092	
30 dB		Score	-	++
1	.066	136	095	
2	.046	348	097	
3	.034	106	093	
4	.024	194	101	
5	.018	191	101	
6	.014	337	099	
20 dB		Score	+	o
1	.060	120	097	
2	.044	140	085	
3	.030	021	095	
4	.028	101	095	
5	.018	063	097	
6	.014	074	092	
10 dB		Score	-	-
1	.060	223	102	
2	.050	074	091	
3	.030	054	099	
4	.024	168	099	
5	.022	277	099	
6	.018	302	102	
dB		Score		

10 μV

10 μV

10 μV

10 μV

10 μV

10 μV

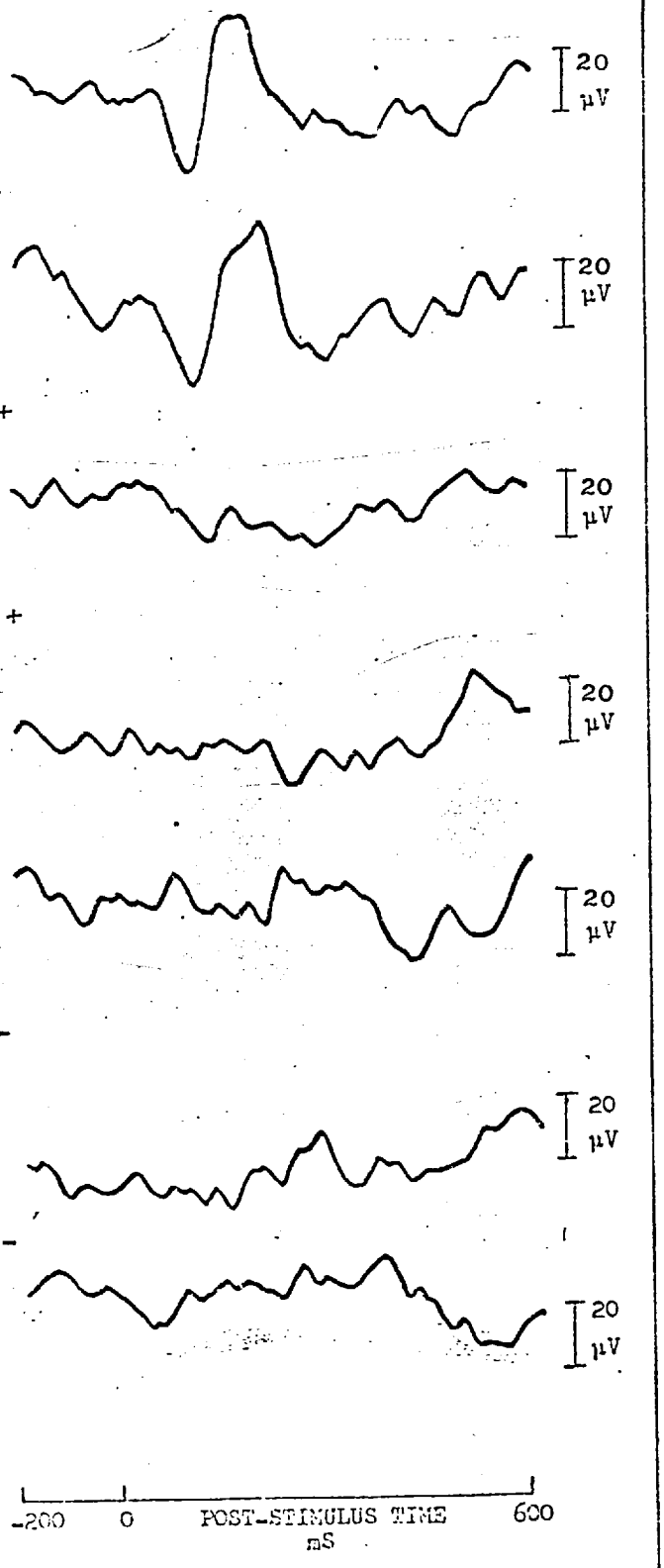
Subjective Threshold = 20 dB

-200 0 POST-STIMULUS TIME mS 600

Table 5.19 Subject MF F, 30 yrs.

Left Ear 500 Hz

HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Ensemble Average Score
70 dB		Score	++++	
1	.060	022	095	
2	.046	236	088	
3	.034	277	074	
4	.022	323	087	
5	.014	082	085	
6	.012	164	095	
50 dB		Score	++++	
1	.062	298	095	
2	.050	223	080	
3	.030	295	080	
4	.022	046	081	
5	.014	045	095	
6	.012	142	094	
30 dB		Score	+	++
1	.062	299	092	
2	.040	279	104	
3	.028	274	102	
4	.018	046	088	
5	.012	341	092	
6	.008	217	102	
20 dB		Score	-	+
1	.072	270	099	
2	.056	275	101	
3	.038	182	091	
4	.022	097	102	
5	.014	053	098	
6	.012	313	098	
10 dB		Score	+	+
1	.082	303	099	
2	.056	281	087	
3	.038	129	098	
4	.030	347	094	
5	.034	232	094	
6	.024	172	093	
0 dB		Score	+	-
1	.068	254	098	
2	.046	219	097	
3	.030	032	098	
4	.022	195	104	
5	.018	005	095	
6	.012	158	088	
-10 dB		Score	-	--
1	.072	111	098	
2	.046	035	099	
3	.030	288	091	
4	.022	250	104	
5	.014	229	099	
6	.012	097	097	

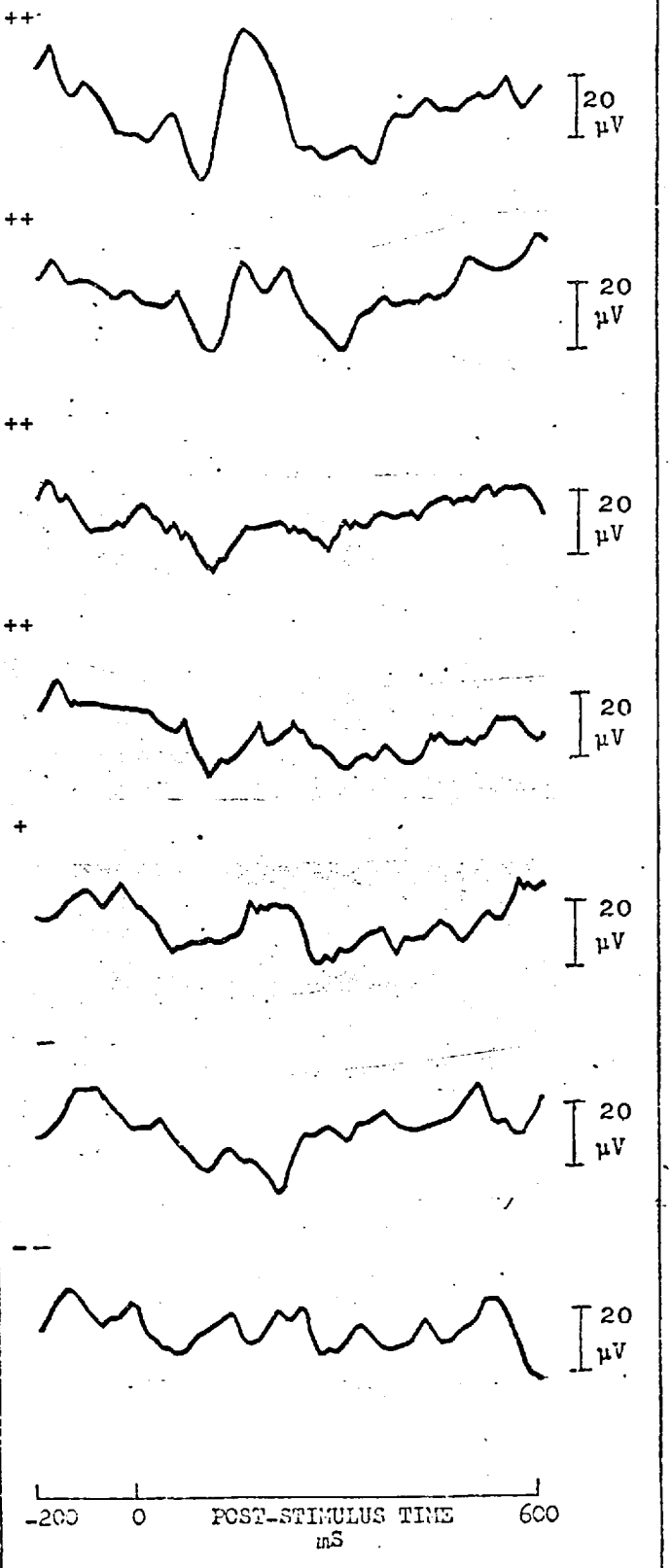


Subjective Threshold = -5dB

Table 5.20 Subject MF

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.068	320	091	
2	.056	208	081	
3	.034	275	078	
4	.022	351	080	
5	.018	064	091	
6	.012	170	091	
50 dB		Score	++	++
1	.060	299	097	
2	.040	226	087	
3	.030	284	085	
4	.022	007	088	
5	.012	334	095	
6	.008	146	101	
30 dB		Score	+	++
1	.072	223	098	
2	.052	227	087	
3	.030	059	102	
4	.022	023	098	
5	.014	037	102	
6	.012	075	099	
20 dB		Score	+	++
1	.060	205	098	
2	.046	257	091	
3	.024	323	088	
4	.018	047	099	
5	.014	337	098	
6	.008	092	091	
10 dB		Score	+	+
1	.068	226	099	
2	.056	216	092	
3	.030	324	085	
4	.022	050	101	
5	.014	187	094	
6	.012	329	094	
0 dB		Score	++	-
1	.060	226	088	
2	.044	282	094	
3	.028	292	099	
4	.030	313	099	
5	.030	327	087	
6	.024	208	098	
-10 dB		Score	+	--
1	.068	140	099	
2	.050	153	094	
3	.030	140	095	
4	.024	084	094	
5	.024	289	097	
6	.024	329	085	

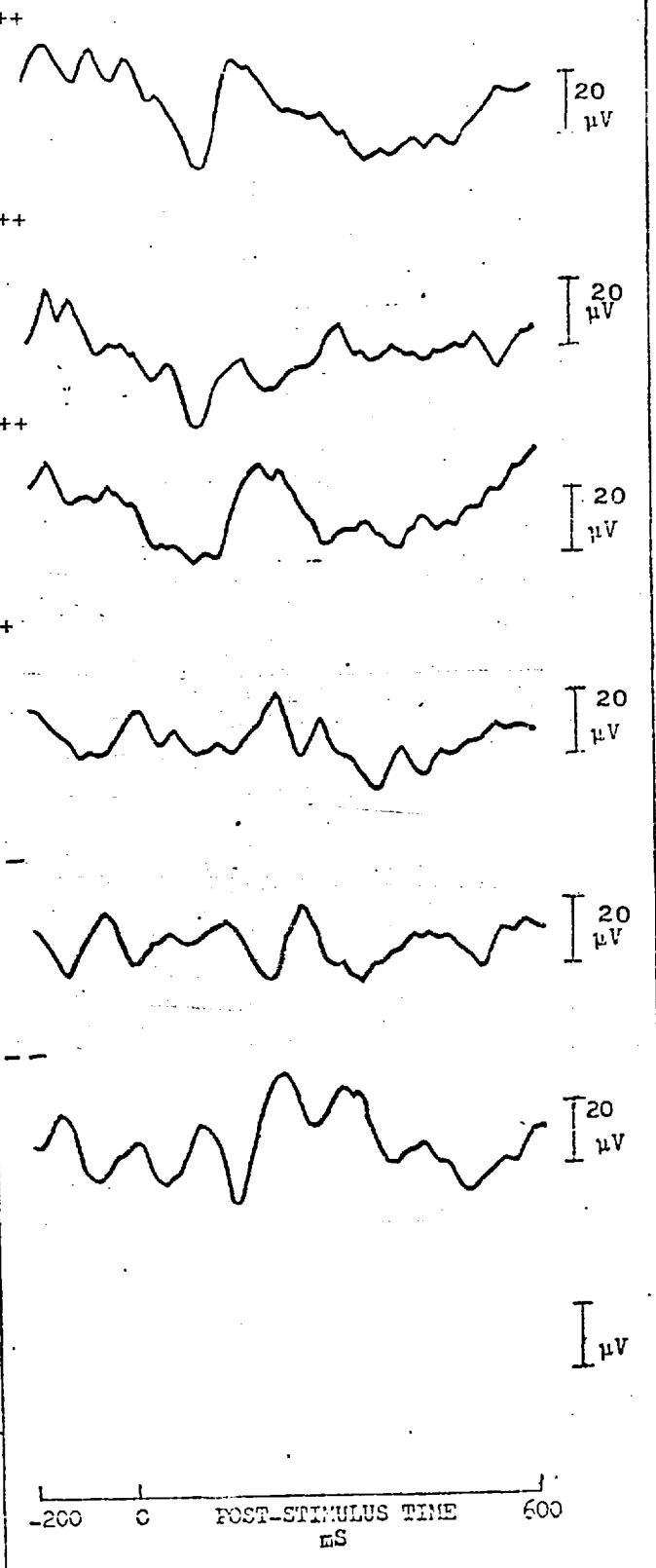


Subjective Threshold
Below -10 dB

Table 5.21 Subject MF

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
	Amplitude Mean V/Hz x 25000	Phase Mean °	Phase S.D. °	Score
70 dB		Score	++	++
1	.060	327	092	
2	.050	248	084	
3	.030	225	081	
4	.024	323	090	
5	.024	057	092	
6	.022	068	105	
50 dB		Score	++	++
1	.088	271	098	
2	.060	250	095	
3	.038	316	092	
4	.022	313	085	
5	.018	023	095	
6	.014	187	088	
30 dB		Score	-	++
1	.094	313	101	
2	.060	264	099	
3	.040	277	092	
4	.024	337	092	
5	.018	258	094	
6	.012	032	102	
10 dB		Score	+	+
1	.068	011	101	
2	.050	240	088	
3	.028	338	094	
4	.022	185	097	
5	.018	087	099	
6	.012	274	101	
0 dB		Score	-	-
1	.068	032	097	
2	.046	232	101	
3	.034	302	097	
4	.028	132	094	
5	.034	234	097	
6	.024	354	094	
-10 dB		Score	++	- -
1	.068	081	087	
2	.046	302	085	
3	.028	344	087	
4	.028	262	098	
5	.030	154	084	
6	.028	272	082	
dB		Score		



Subjective Threshold

Below -10dB

Table 5.22 Subject BE F, 21 yrs.

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
BN	Amplitude Mean V/Hz x25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.078	250	080	
2	.062	212	091	
3	.040	295	082	
4	.038	326	090	
5	.034	043	084	
6	.028	201	097	
50 dB		Score	++	++
1	.084	260	094	
2	.060	203	092	
3	.046	310	085	
4	.028	004	095	
5	.028	049	085	
6	.022	088	099	
30 dB		Score	+	++
1	.076	246	091	
2	.050	241	095	
3	.038	285	091	
4	.030	064	088	
5	.028	315	099	
6	.022	227	095	
20 dB		Score	++	++
1	.072	261	082	
2	.050	244	085	
3	.034	313	078	
4	.028	255	102	
5	.028	022	097	
6	.024	209	088	
10 dB		Score	++	++
1	.068	248	085	
2	.052	251	078	
3	.034	028	094	
4	.028	229	094	
5	.044	032	095	
6	.028	109	097	
0 dB		Score	-	+
1	.078	260	097	
2	.050	315	095	
3	.040	136	098	
4	.034	334	098	
5	.038	220	102	
6	.022	291	091	
-10 dB		Score	-	0
1	.106	105	101	
2	.066	324	092	
3	.046	317	094	
4	.040	225	102	
5	.040	061	102	
6	.034	094	094	

Subjective Threshold = 0 dB

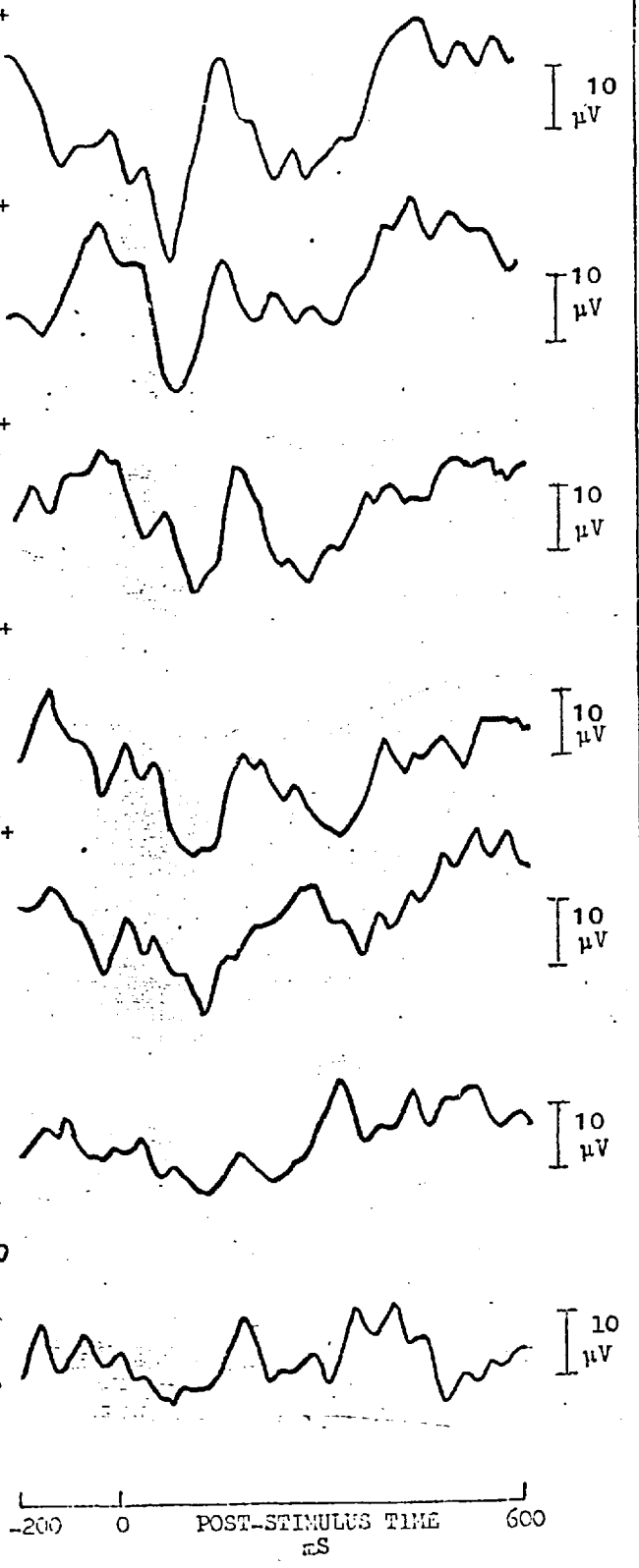
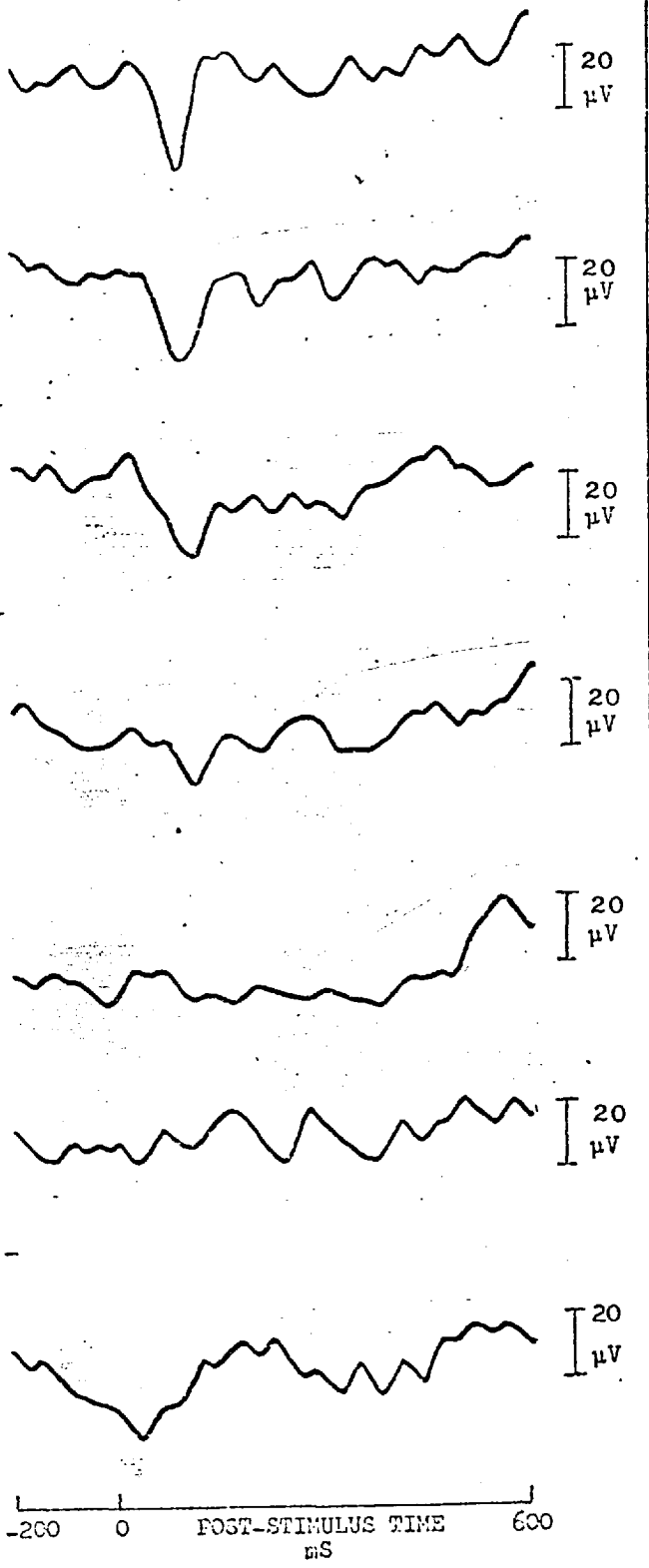


Table 5.23 Subject BE

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++++	
1	.038	305	097	
2	.030	241	092	
3	.022	302	081	
4	.018	334	080	
5	.018	323	087	
6	.014	085	092	
50 dB		Score	++++	
1	.044	254	091	
2	.030	275	088	
3	.022	285	085	
4	.018	298	094	
5	.018	042	090	
6	.012	352	105	
30 dB		Score	++++	
1	.044	253	091	
2	.028	216	095	
3	.018	344	085	
4	.014	317	088	
5	.012	354	088	
6	.012	074	098	
20 dB		Score	++	++
1	.038	288	097	
2	.028	282	088	
3	.018	015	084	
4	.014	288	094	
5	.014	187	101	
6	.012	187	097	
10 dB		Score	+	+
1	.040	315	085	
2	.024	279	092	
3	.014	279	094	
4	.014	233	097	
5	.014	105	092	
6	.012	288	101	
0 dB		Score	+	-
1	.050	160	097	
2	.030	309	101	
3	.024	184	097	
4	.018	004	095	
5	.018	049	097	
6	.014	198	090	
-10 dB		Score	+	--
1	.044	008	098	
2	.034	213	090	
3	.024	233	092	
4	.018	329	102	
5	.018	201	097	
6	.014	241	099	



Subjective Threshold = 5 dB

Table 5.24 Subject BE

Left Ear 3 KHz

Microprocessor Results

HH	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
70 dB		Score	++
1	.040	223	094
2	.028	229	088
3	.018	279	085
4	.018	316	085
5	.014	053	087
6	.012	095	088
50 dB		Score	+
1	.046	298	098
2	.034	208	092
3	.022	316	092
4	.014	357	095
5	.014	074	087
6	.012	143	091
30 dB		Score	++
1	.040	302	097
2	.028	177	095
3	.014	326	088
4	.014	331	097
5	.014	082	078
6	.012	223	099
20 dB		Score	++
1	.034	277	078
2	.022	056	099
3	.018	337	092
4	.018	233	099
5	.018	126	090
6	.014	184	088
10 dB		Score	++
1	.044	299	095
2	.028	320	090
3	.018	227	101
4	.018	334	090
5	.022	090	098
6	.014	358	099
0 dB		Score	++
1	.056	175	099
2	.040	087	097
3	.024	097	090
4	.022	337	102
5	.018	330	095
6	.014	120	087
dB		Score	

Subjective Threshold = 10 dB

Ensemble Average

Score

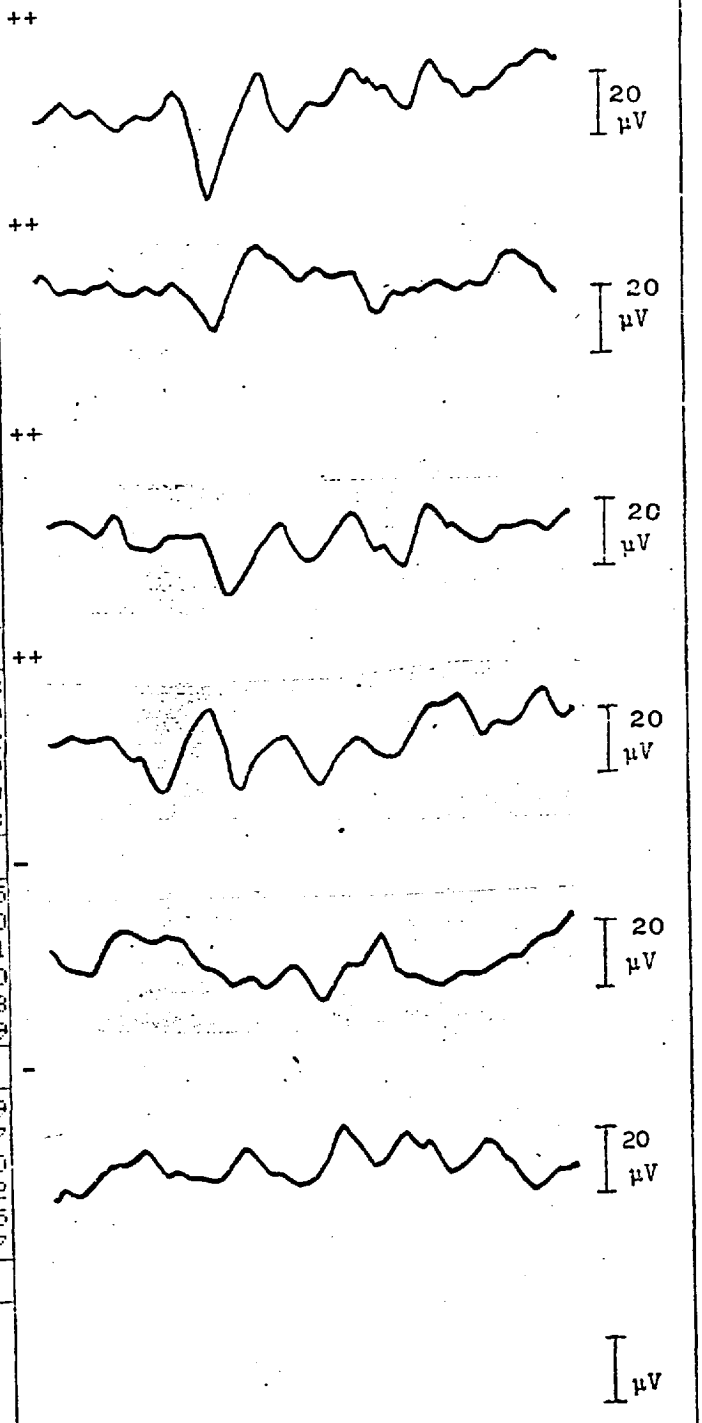


Table 5.25 Subject DW F, 19 yrs.

Left Ear 1 KHz

Microprocessor Results

HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
70 dB		Score	++
1	.044	234	084
2	.024	177	094
3	.018	322	077
4	.012	000	092
5	.008	082	087
6	.006	116	090
50 dB		Score	++
1	.040	239	094
2	.030	233	095
3	.018	309	094
4	.012	056	081
5	.008	101	087
6	.008	143	084
30 dB		Score	++
1	.040	237	094
2	.024	046	101
3	.018	315	090
4	.012	016	097
5	.008	071	091
6	.006	040	088
20 dB		Score	++
1	.034	234	091
2	.024	220	092
3	.018	036	091
4	.012	074	090
5	.008	108	088
6	.006	087	099
10 dB		Score	+
1	.030	229	087
2	.024	201	099
3	.018	327	088
4	.012	047	092
5	.008	264	102
6	.006	021	095
0 dB		Score	+
1	.038	244	090
2	.028	004	091
3	.014	220	099
4	.012	313	092
5	.008	216	098
6	.006	181	094
-10 dB		Score	-
1	.040	300	094
2	.028	267	097
3	.018	028	098
4	.012	000	094
5	.012	272	098
6	.008	005	094

Subjective Threshold = -10dB

Ensemble Average

Score

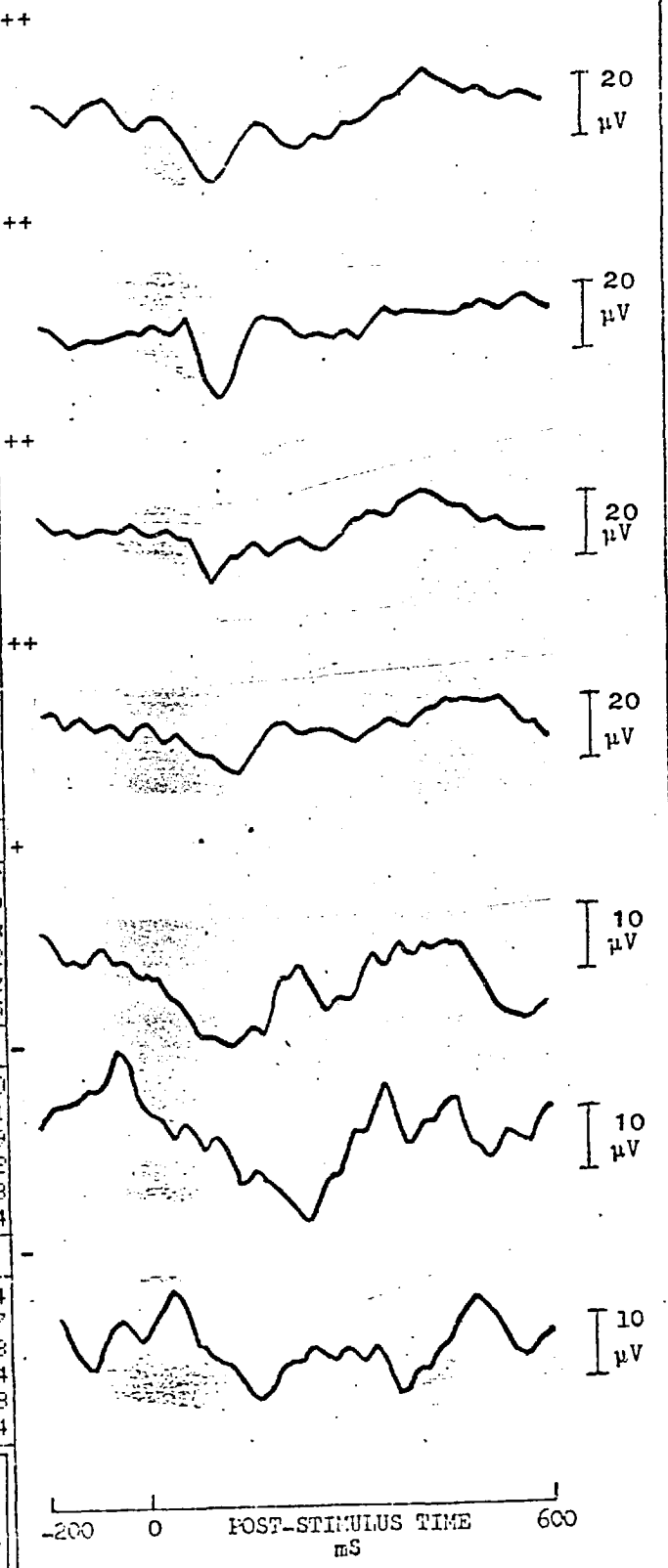
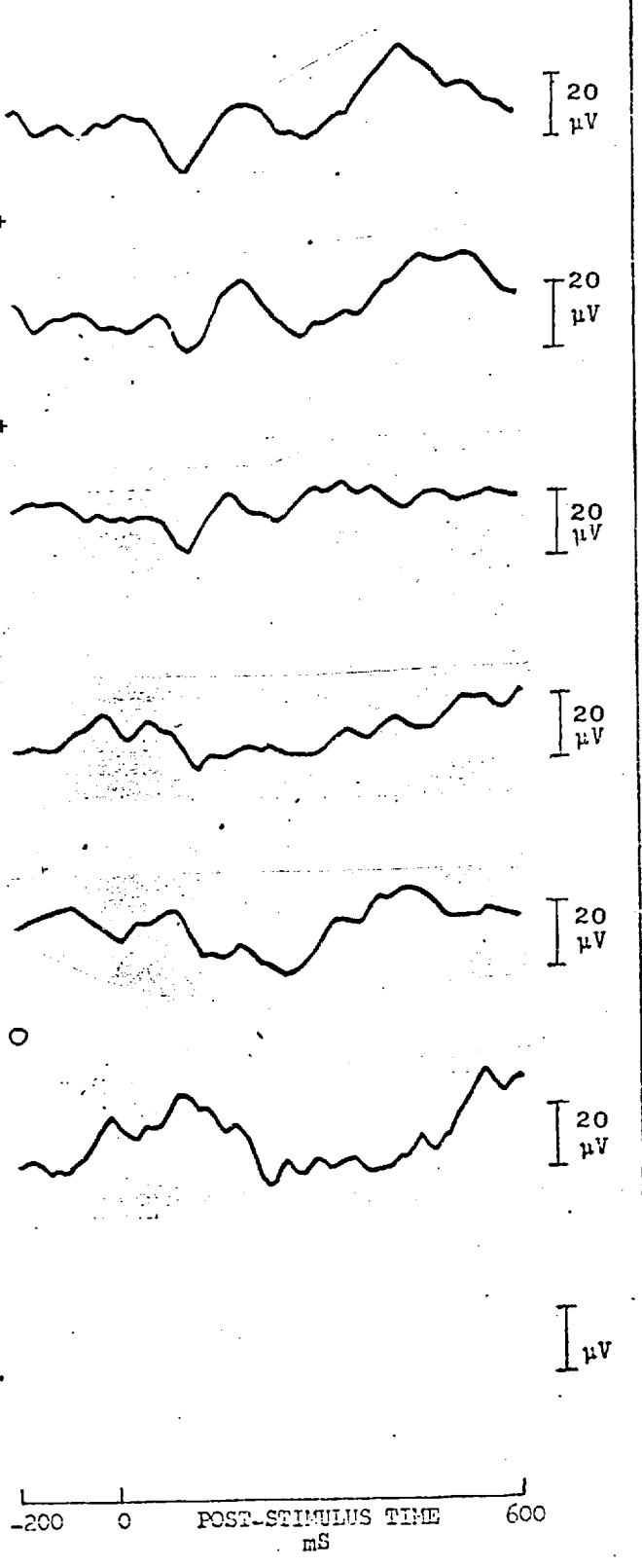


Table 5.26 Subject DW

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz × 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.038	237	090	
2	.024	154	082	
3	.018	334	082	
4	.012	037	085	
5	.008	081	098	
6	.008	067	090	
50 dB		Score	++	++
1	.040	270	091	
2	.024	175	080	
3	.018	298	094	
4	.012	046	088	
5	.008	111	088	
6	.006	087	097	
30 dB		Score	+	++
1	.046	248	097	
2	.028	302	092	
3	.018	254	094	
4	.014	329	091	
5	.008	088	091	
6	.006	126	088	
20 dB		Score	+	+
1	.040	277	090	
2	.030	286	099	
3	.014	315	095	
4	.012	040	092	
5	.008	057	094	
6	.006	324	099	
10 dB		Score	++	+
1	.038	275	084	
2	.028	060	085	
3	.018	345	090	
4	.012	279	106	
5	.012	146	087	
6	.006	261	109	
0 dB		Score	-	O
1	.044	313	094	
2	.028	354	101	
3	.014	174	094	
4	.012	209	099	
5	.008	170	095	
6	.006	060	098	
dB		Score		

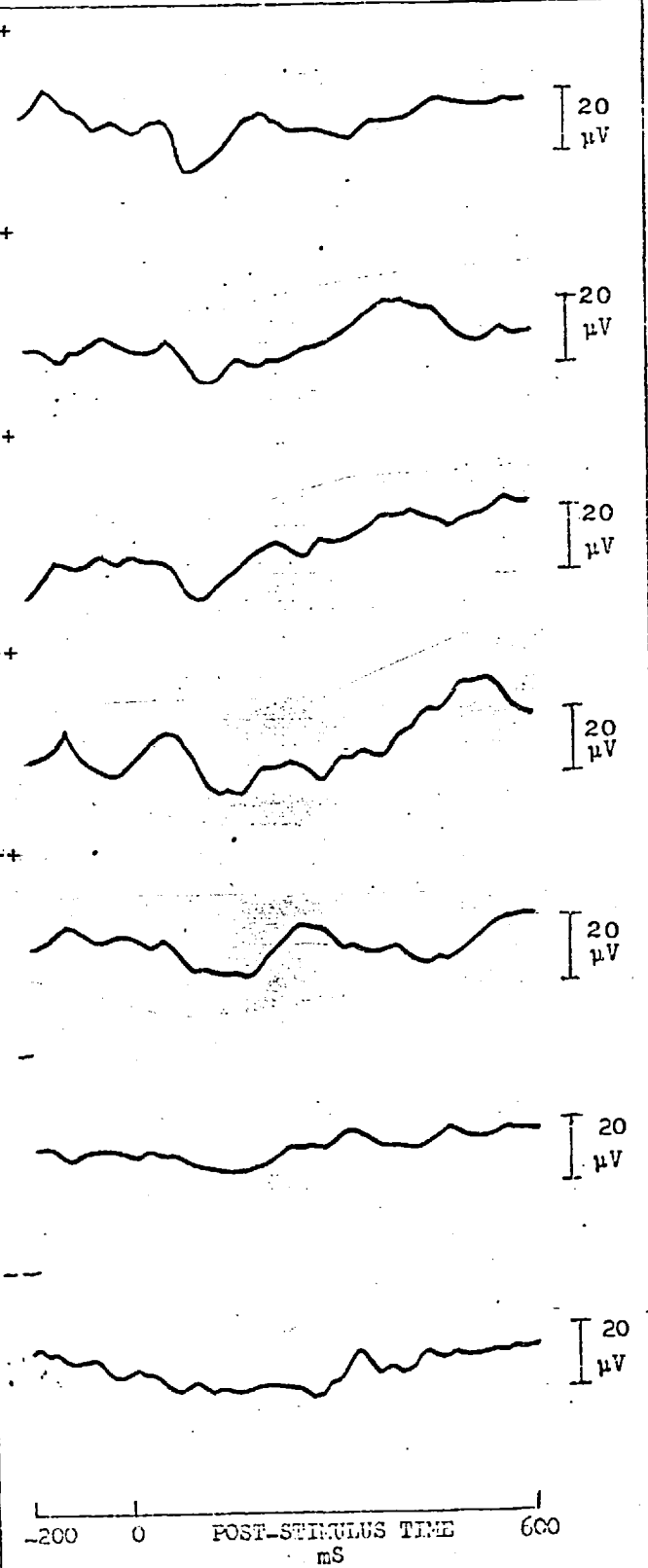


Subjective Threshold = -5 dB

Table 5.27 Subject DW

Left Ear 3 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz × 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.034	251	085	
2	.024	216	090	
3	.014	336	082	
4	.008	043	091	
5	.008	070	098	
6	.006	174	088	
50 dB		Score	+	++
1	.038	206	084	
2	.024	002	095	
3	.018	289	098	
4	.008	088	099	
5	.008	113	095	
6	.006	108	092	
30 dB		Score	-	++
1	.044	212	094	
2	.028	255	098	
3	.018	310	099	
4	.012	094	102	
5	.008	099	091	
6	.006	070	099	
20 dB		Score	+	++
1	.056	277	092	
2	.040	203	094	
3	.024	037	091	
4	.012	080	090	
5	.012	090	091	
6	.008	029	094	
10 dB		Score	++	++
1	.052	267	099	
2	.034	300	090	
3	.022	344	090	
4	.012	206	094	
5	.008	285	097	
6	.006	042	099	
0 dB		Score	-	-
1	.040	229	094	
2	.028	285	094	
3	.022	009	092	
4	.012	094	104	
5	.008	180	092	
6	.006	053	102	
-10dB		Score	+	--
1	.050	217	094	
2	.034	350	092	
3	.018	291	093	
4	.012	288	090	
5	.008	265	104	
6	.006	312	098	



Subjective Threshold = 0 dB

Table 5.28 Subject MR F, 21 yrs.

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.084	240	092	
2	.072	201	082	
3	.052	295	081	
4	.034	025	088	
5	.034	046	090	
6	.022	091	088	
50 dB		Score	++	++
1	.056	284	081	
2	.040	213	087	
3	.030	277	088	
4	.022	000	088	
5	.022	074	095	
6	.012	151	081	
30 dB		Score	+	++
1	.050	313	094	
2	.038	188	091	
3	.022	011	088	
4	.018	080	094	
5	.018	095	097	
6	.012	112	093	
20 dB		Score	-	+
1	.052	267	092	
2	.040	101	104	
3	.028	305	094	
4	.014	178	102	
5	.014	078	094	
6	.008	163	097	
10 dB		Score	++	+
1	.046	260	094	
2	.040	320	097	
3	.022	064	082	
4	.018	090	087	
5	.014	092	092	
6	.012	219	085	
0 dB		Score	+	+
1	.046	043	098	
2	.030	212	097	
3	.024	081	088	
4	.014	130	091	
5	.012	272	105	
6	.008	331	094	
-10 dB		Score	-	-
1	.046	338	097	
2	.034	330	099	
3	.022	122	094	
4	.014	043	098	
5	.014	059	097	
6	.012	025	093	

Subjective Threshold = -5 dB

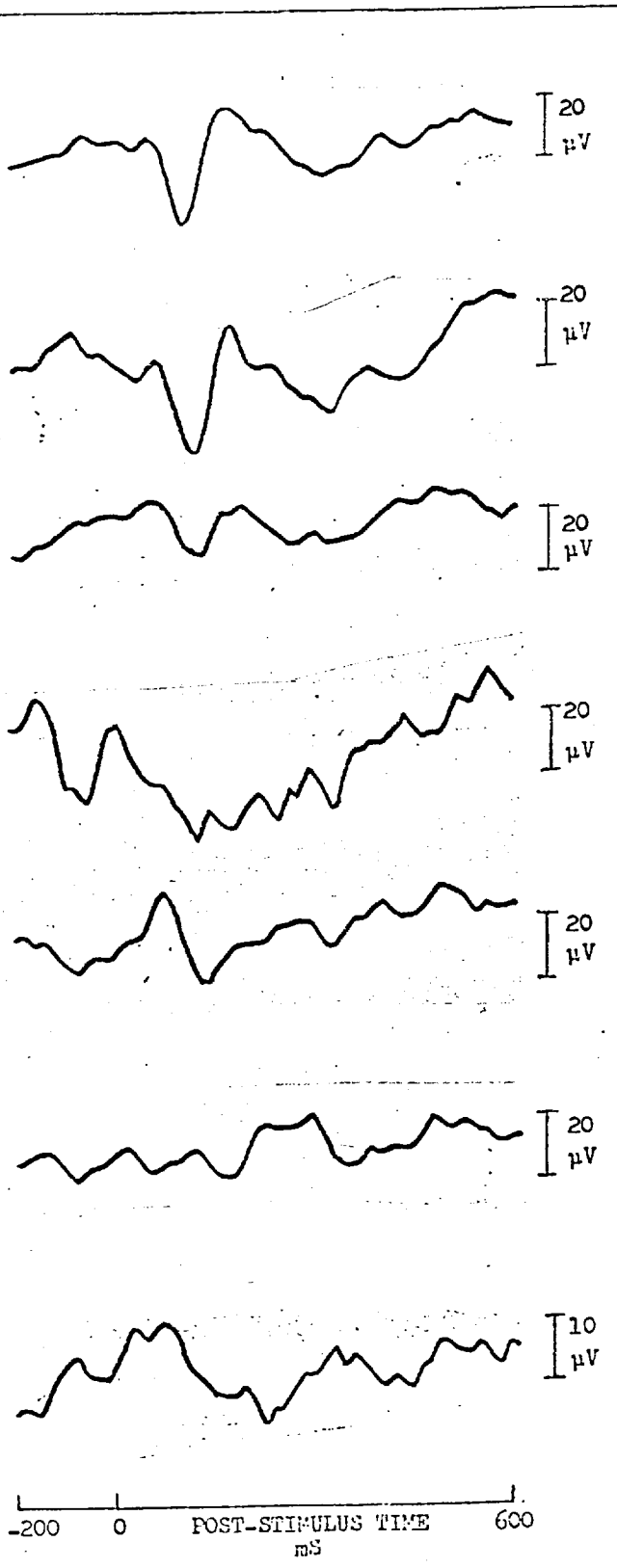


Table 5.29 Subject MR

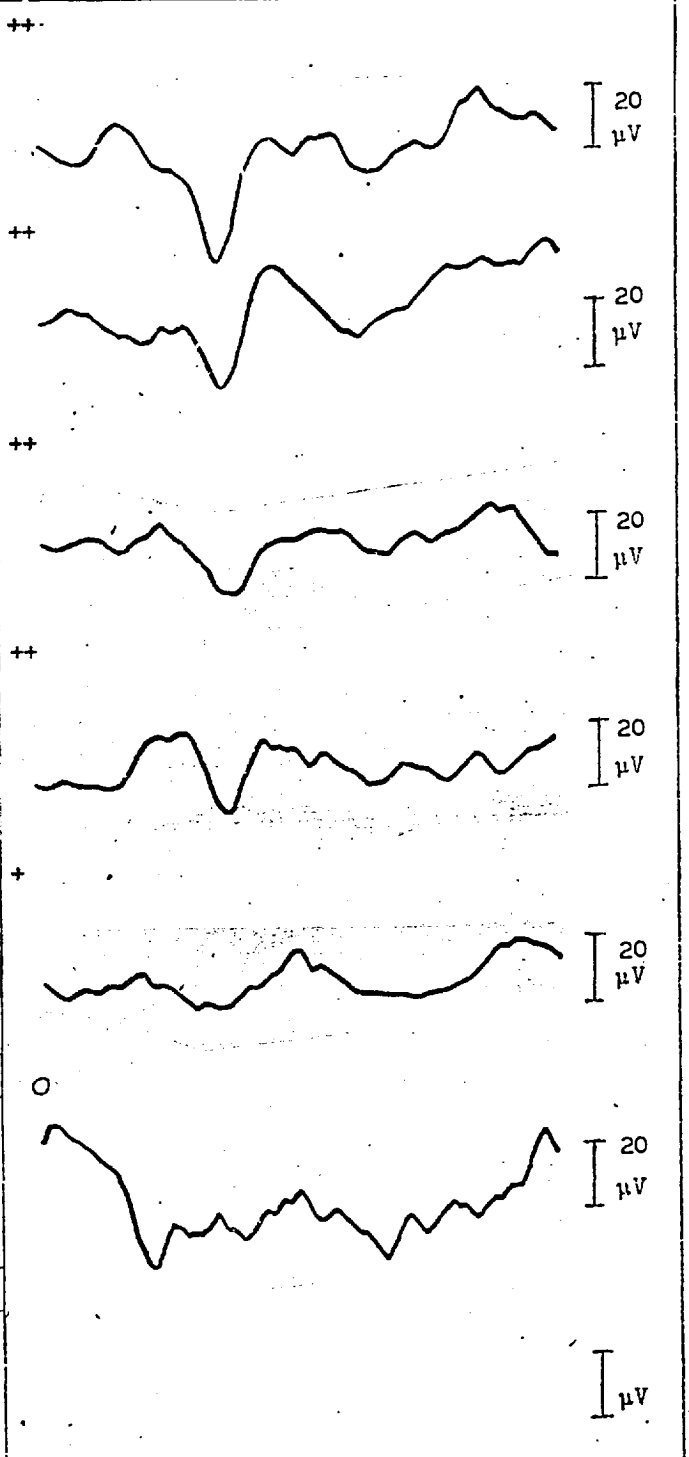
Left Ear 2 KHz

HR	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
70 dB		Score	++
1	.044	223	084
2	.034	216	074
3	.022	329	090
4	.018	344	087
5	.014	026	091
6	.012	133	081
50 dB		Score	++
1	.040	262	094
2	.034	216	078
3	.028	305	075
4	.018	016	088
5	.012	105	094
6	.008	160	091
30 dB		Score	++
1	.038	239	087
2	.034	212	092
3	.022	341	090
4	.014	056	091
5	.014	040	084
6	.008	088	099
20 dB		Score	++
1	.040	025	099
2	.038	226	097
3	.022	354	087
4	.018	035	084
5	.014	070	097
6	.008	189	094
10 dB		Score	+
1	.046	282	101
2	.038	213	084
3	.024	261	099
4	.014	264	106
5	.012	316	099
6	.008	302	098
0 dB		Score	-
1	.040	281	095
2	.038	237	092
3	.024	313	092
4	.018	208	097
5	.012	208	098
6	.008	237	095
dB		Score	

Microprocessor Results

Ensemble Average

Score



Subjective Threshold
Below -10 dB

Table 5.30 Subject MR

Left Ear 3 KHz

Microprocessor Results

HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
70 dB		Score	++
1	.044	143	099
2	.034	216	087
3	.024	277	082
4	.022	007	078
5	.014	063	090
6	.008	074	082
50 dB		Score	++
1	.040	127	095
2	.034	198	091
3	.028	315	090
4	.018	002	074
5	.012	092	092
6	.008	237	098
30 dB		Score	++
1	.046	279	092
2	.038	230	090
3	.024	000	092
4	.018	305	087
5	.014	165	091
6	.008	178	097
20 dB		Score	-
1	.046	288	095
2	.034	251	097
3	.028	279	091
4	.018	172	097
5	.014	056	095
6	.008	217	095
10 dB		Score	+
1	.034	001	098
2	.038	216	090
3	.024	004	098
4	.018	175	095
5	.014	267	099
6	.008	226	095
0 dB		Score	-
1	.044	035	104
2	.034	002	099
3	.028	136	102
4	.018	001	095
5	.018	029	091
6	.008	154	092
-10 dB		Score	+
1	.040	097	098
2	.040	001	085
3	.024	319	091
4	.022	233	095
5	.014	309	101
6	.008	257	101

Subjective Threshold = -5 dB

Ensemble Average

Score

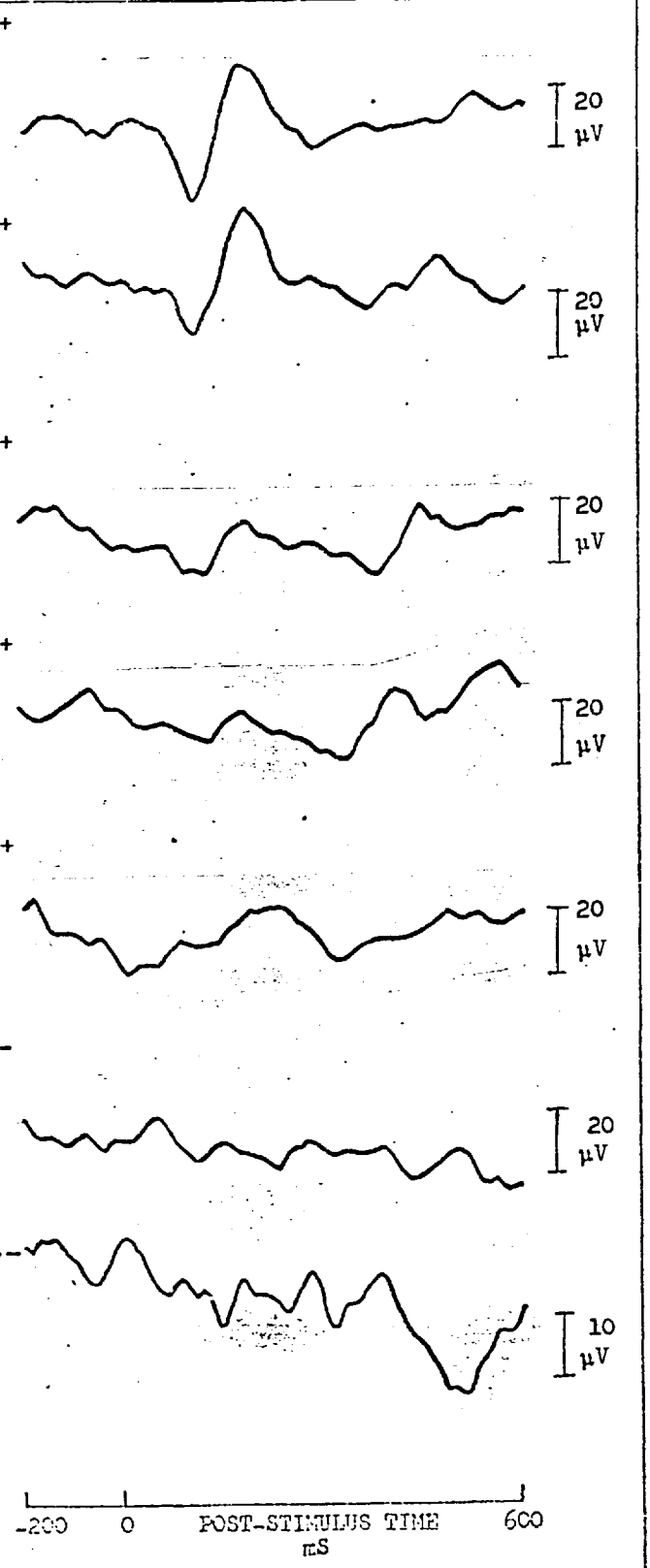
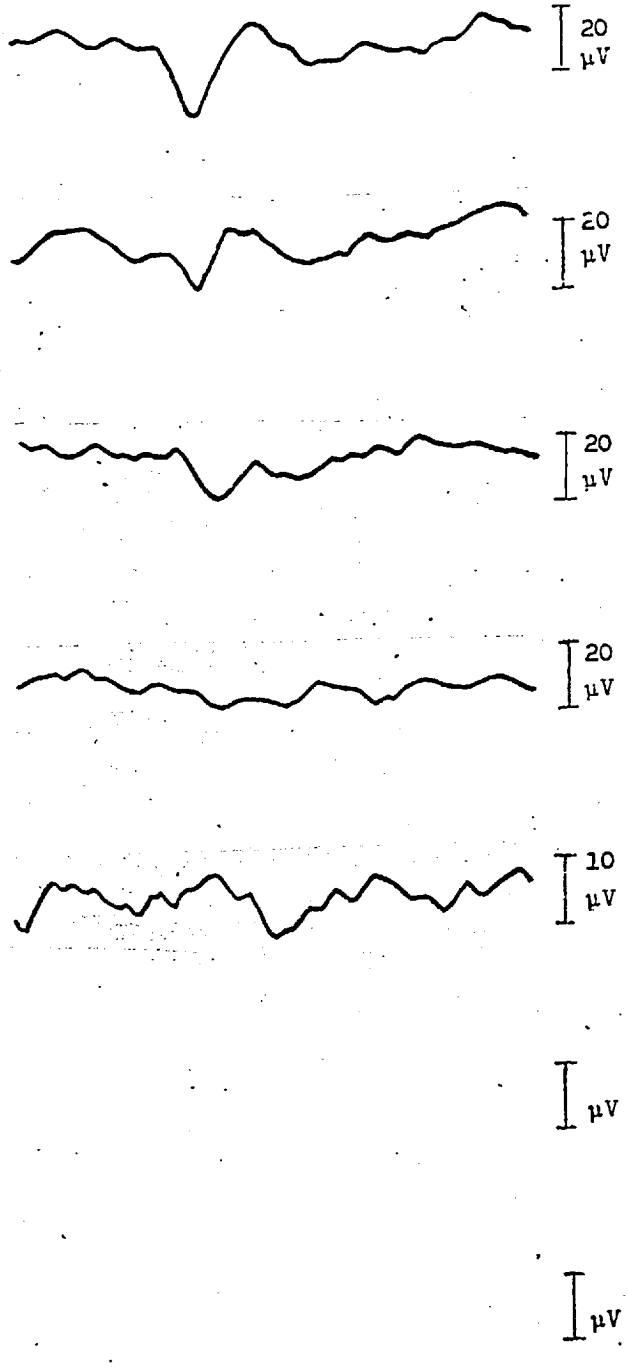


Table 5.31 Subject SW . M, 31 yrs.

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.022	281	082	
2	.018	239	087	
3	.014	288	080	
4	.012	050	084	
5	.002	097	084	
6	.006	136	081	
50 dB		Score	++	++
1	.024	254	088	
2	.014	213	091	
3	.012	274	090	
4	.008	073	099	
5	.006	140	082	
6	.006	172	081	
30 dB		Score	++	++
1	.022	232	082	
2	.018	354	095	
3	.014	028	095	
4	.012	081	087	
5	.006	118	087	
6	.006	092	102	
20 dB		Score	+	+
1	.024	264	087	
2	.014	253	104	
3	.018	136	099	
4	.012	227	102	
5	.008	087	095	
6	.002	277	113	
10 dB		Score	-	-
1	.022	282	097	
2	.018	057	095	
3	.014	216	094	
4	.014	305	095	
5	.008	306	095	
6	.006	170	099	
dB		Score		
dB		Score		

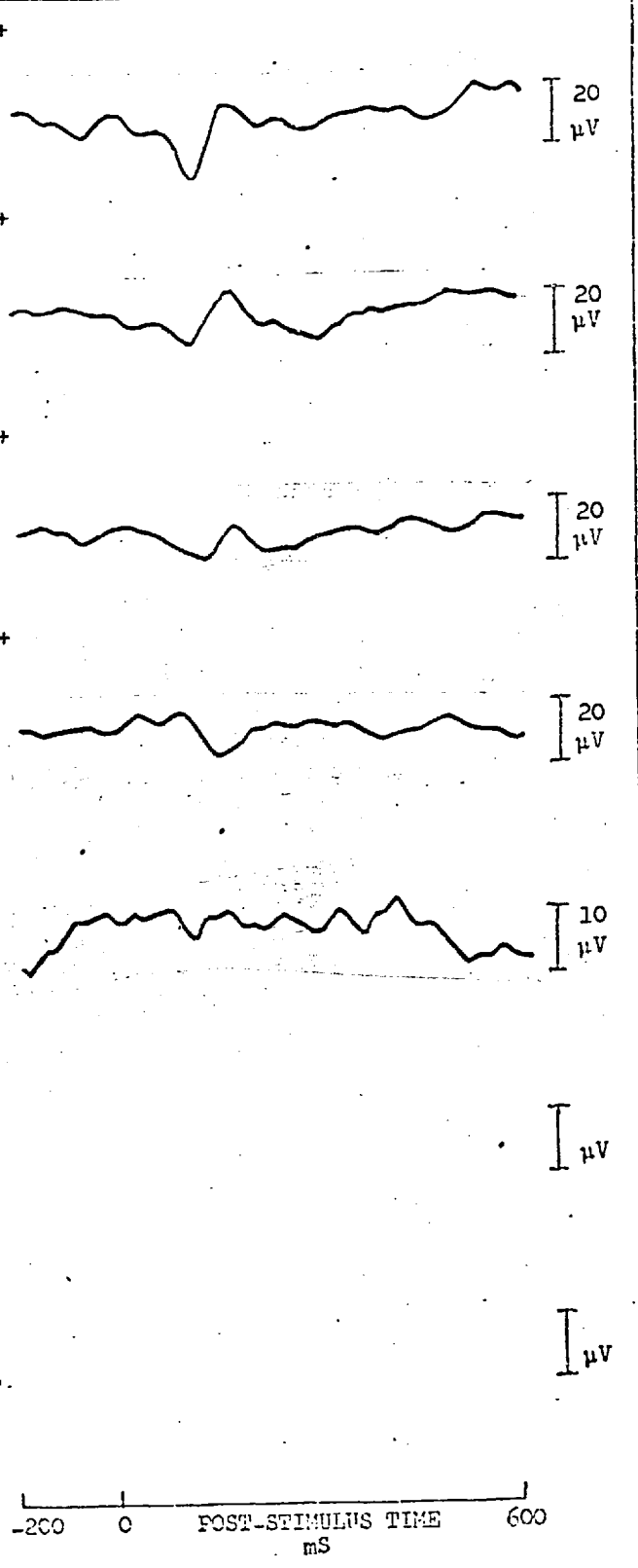


Subjective Threshold = 15 dB

Table 5.32 Subject SW

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
dB	Amplitude Mean V/Hz x 62500	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.052	230	090	
2	.046	264	084	
3	.050	275	081	
4	.030	043	101	
5	.022	071	088	
6	.012	143	084	
50 dB		Score	++	++
1	.062	257	098	
2	.044	181	090	
3	.044	271	088	
4	.038	005	094	
5	.022	015	098	
6	.012	109	087	
30 dB		Score	+	++
1	.062	253	091	
2	.050	254	098	
3	.044	298	098	
4	.030	299	092	
5	.022	075	088	
6	.012	135	092	
20 dB		Score	-	++
1	.062	244	104	
2	.060	302	101	
3	.040	054	092	
4	.034	080	098	
5	.022	154	098	
6	.014	300	098	
10 dB		Score	-	-
1	.028	139	099	
2	.014	080	095	
3	.018	348	098	
4	.014	357	102	
5	.008	036	098	
6	.006	061	092	
dB		Score		
-				
dB		Score		



Subjective Threshold = 15 dB

Table 5.33 Subject SW

Left Ear 3 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz × 62500	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.060	244	084	
2	.046	241	085	
3	.038	262	084	
4	.038	021	085	
5	.022	136	099	
6	.014	153	092	
50 dB		Score	++	++
1	.076	227	091	
2	.056	258	085	
3	.044	278	087	
4	.038	338	090	
5	.022	102	084	
6	.014	182	087	
30 dB		Score	+	++
1	.060	295	099	
2	.052	257	098	
3	.040	331	090	
4	.028	355	101	
5	.018	146	091	
6	.014	241	097	
20 dB		Score	-	++
1	.056	316	097	
2	.052	246	094	
3	.044	322	094	
4	.034	092	092	
5	.022	057	101	
6	.014	284	101	
10 dB		Score	++	+
1	.022	009	094	
2	.018	302	099	
3	.014	045	090	
4	.014	009	098	
5	.006	189	082	
6	.006	002	098	
0 dB		Score	-	+
1	.038	095	102	
2	.024	296	102	
3	.018	018	092	
4	.014	087	101	
5	.008	262	101	
6	.006	002	095	
-10 dB		Score	+	--
1	.022	209	085	
2	.018	057	097	
3	.014	022	097	
4	.012	170	095	
5	.008	143	092	
6	.006	061	101	

Subjective Threshold = 5 dB

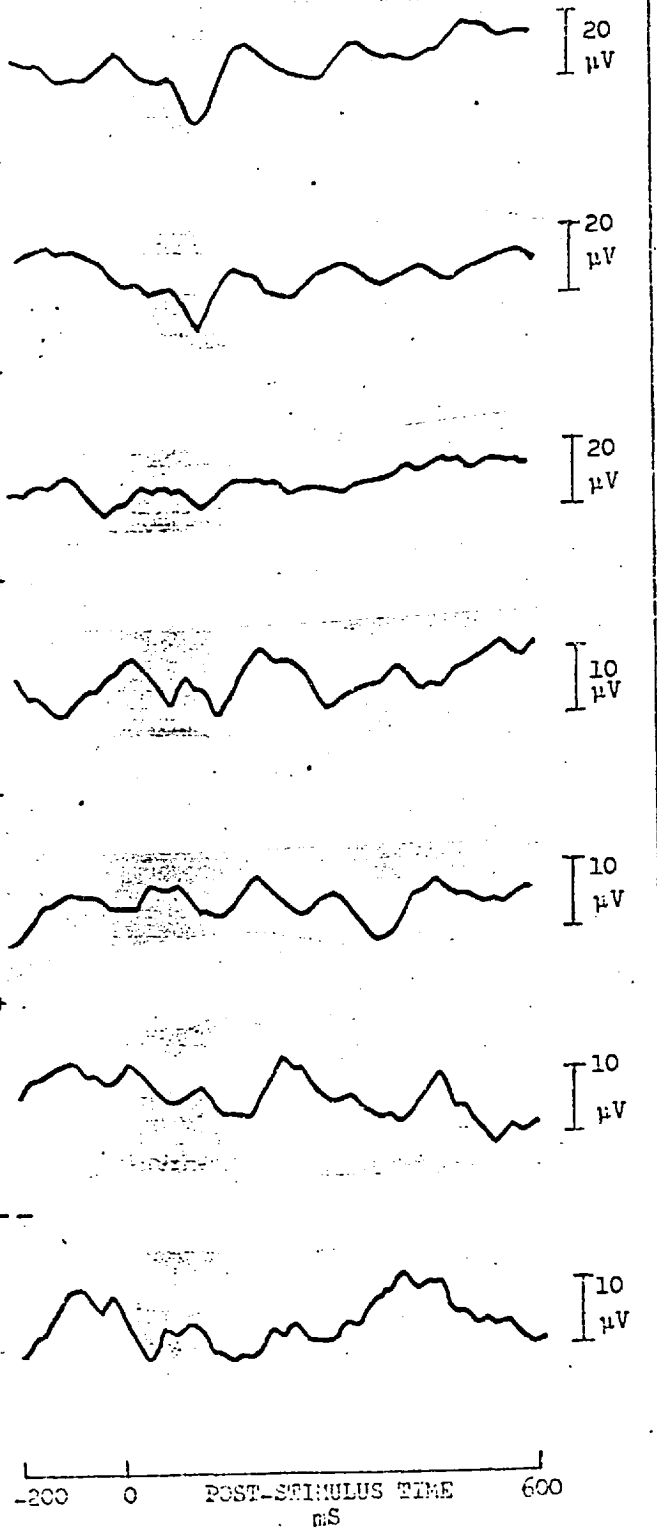
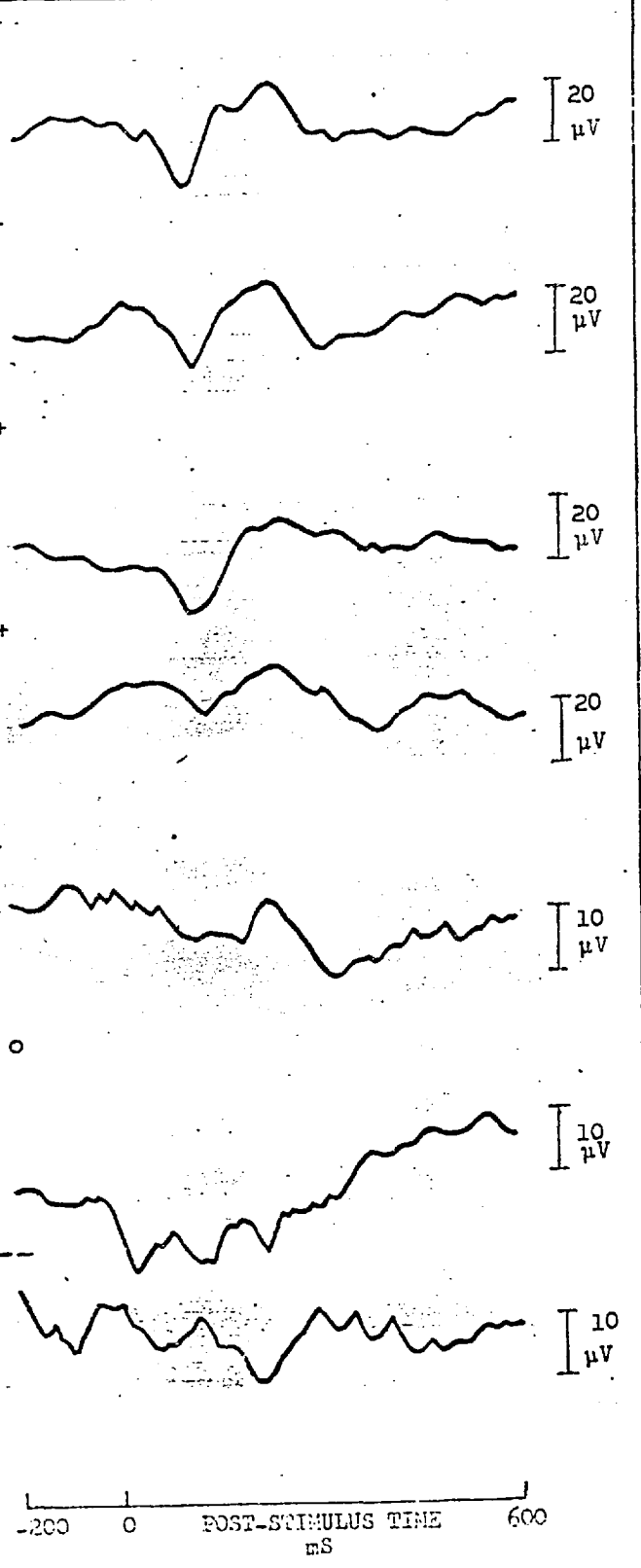


Table 5.34 Subject HW M, 41 yrs.

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.038	061	097	
2	.034	237	082	
3	.022	306	078	
4	.014	326	102	
5	.008	331	098	
6	.006	071	091	
50 dB		Score	++	++
1	.040	012	094	
2	.034	226	078	
3	.024	331	081	
4	.014	040	084	
5	.008	088	098	
6	.006	053	090	
30 dB		Score	-	++
1	.050	174	098	
2	.034	251	094	
3	.022	338	091	
4	.018	047	092	
5	.008	115	099	
6	.006	151	091	
20 dB		Score	++	++
1	.036	036	099	
2	.040	277	102	
3	.024	052	088	
4	.014	347	095	
5	.008	080	088	
6	.006	018	091	
10 dB		Score	-	+
1	.052	231	095	
2	.038	223	092	
3	.024	309	094	
4	.014	257	097	
5	.008	007	102	
6	.008	113	094	
0 dB		Score	++	o
1	.050	205	099	
2	.038	118	104	
3	.022	144	088	
4	.018	133	092	
5	.008	057	102	
6	.006	126	090	
-10 dB		Score	+	--
1	.076	175	099	
2	.046	019	098	
3	.034	254	095	
4	.022	248	091	
5	.014	341	090	
6	.008	237	095	

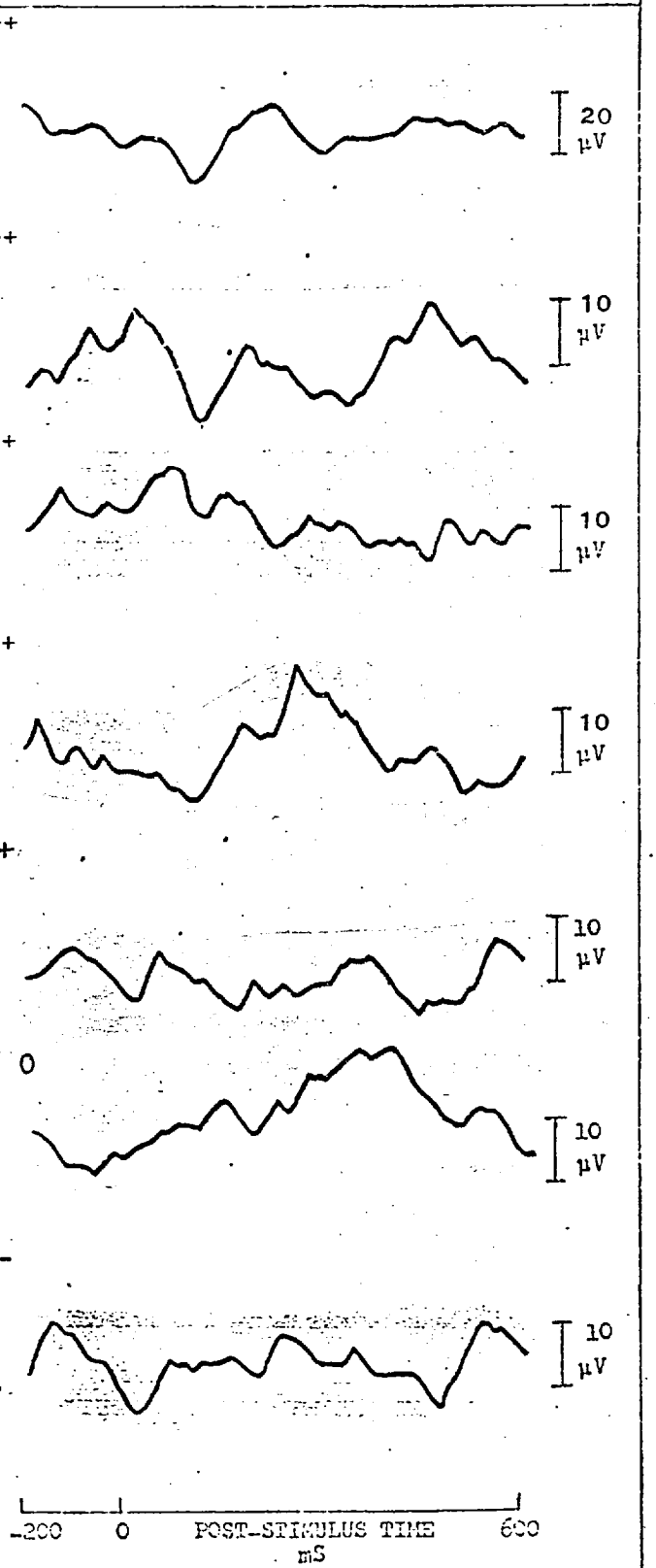


Subjective Threshold = 0 dB

Table 5.35 Subject HW

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.040	258	104	
2	.034	222	090	
3	.024	323	087	
4	.014	002	082	
5	.008	063	097	
6	.006	057	090	
50 dB		Score	++	++
1	.034	205	099	
2	.024	185	097	
3	.018	330	090	
4	.012	016	090	
5	.008	056	091	
6	.006	105	090	
30 dB		Score	+	++
1	.038	345	092	
2	.030	077	098	
3	.024	068	099	
4	.014	025	094	
5	.008	081	094	
6	.006	126	090	
20 dB		Score	-	++
1	.044	116	097	
2	.038	275	101	
3	.022	016	092	
4	.014	326	094	
5	.008	008	092	
6	.006	085	095	
10 dB		Score	+	+
1	.050	295	105	
2	.038	310	091	
3	.024	260	099	
4	.018	052	104	
5	.012	130	094	
6	.006	136	088	
0 dB		Score	++	0
1	.050	143	091	
2	.040	068	090	
3	.028	105	097	
4	.014	033	102	
5	.008	043	082	
6	.006	039	081	
-10 dB		Score	+	-
1	.068	191	098	
2	.044	270	084	
3	.028	212	099	
4	.018	192	094	
5	.008	080	101	
6	.008	307	095	

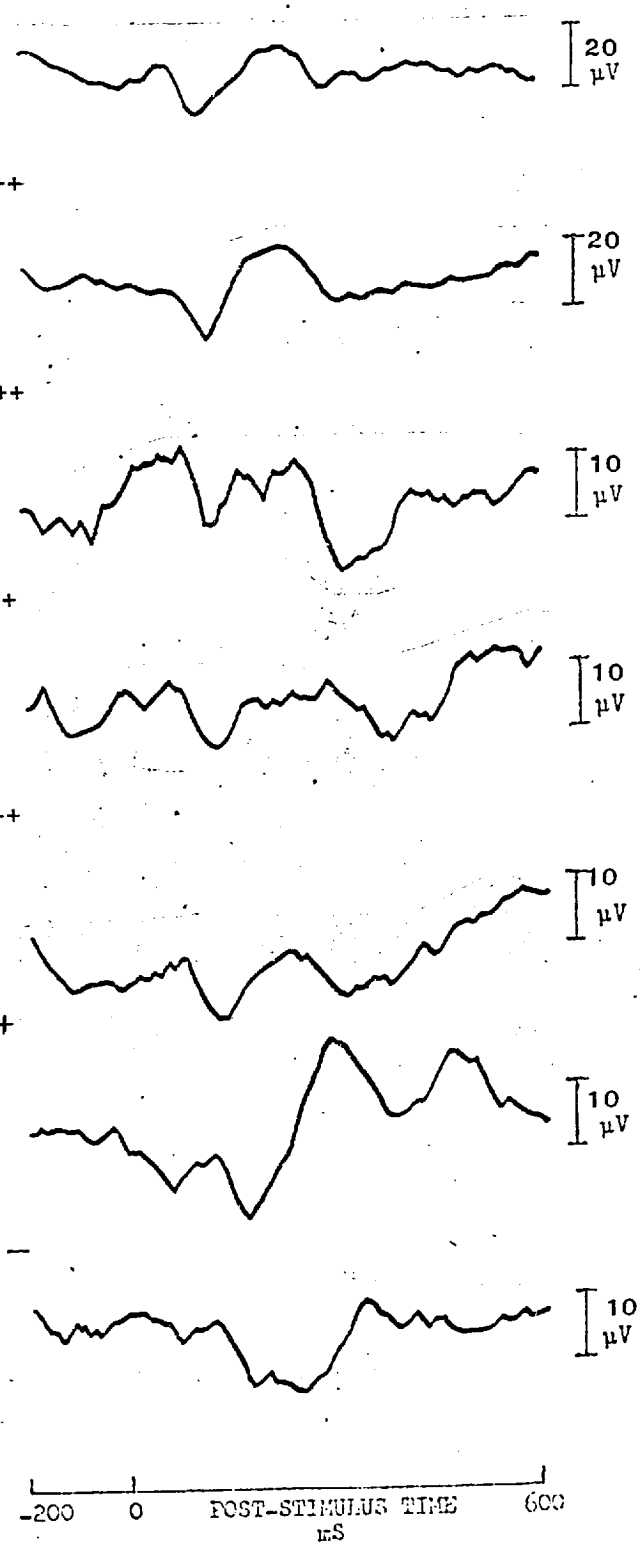


Subjective Threshold = -5 dB

Table 5.36 Subject HW

Left Ear 3 KHz

Microprocessor Results				Ensemble Average
RN	Amplitude Mean V/Hz x25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.038	168	101	
2	.030	271	098	
3	.022	338	080	
4	.012	046	088	
5	.008	085	087	
6	.006	068	085	
50 dB		Score	++	++
1	.052	309	098	
2	.034	254	085	
3	.024	317	087	
4	.014	326	098	
5	.008	270	102	
6	.006	206	102	
30 dB		Score	+	++
1	.056	350	095	
2	.038	272	095	
3	.024	341	090	
4	.014	177	101	
5	.008	323	098	
6	.008	177	092	
20 dB		Score	-	++
1	.040	312	098	
2	.030	267	091	
3	.018	054	101	
4	.014	023	094	
5	.008	105	102	
6	.006	158	094	
10 dB		Score	++	++
1	.068	285	088	
2	.044	310	095	
3	.028	001	090	
4	.022	185	092	
5	.012	185	092	
6	.008	177	091	
0 dB		Score	++	+
1	.062	168	090	
2	.038	289	088	
3	.024	094	081	
4	.014	226	101	
5	.008	187	097	
6	.006	352	099	
-10 dB		Score	+	-
1	.062	246	099	
2	.038	023	095	
3	.022	082	102	
4	.012	036	092	
5	.008	104	094	
6	.006	030	087	

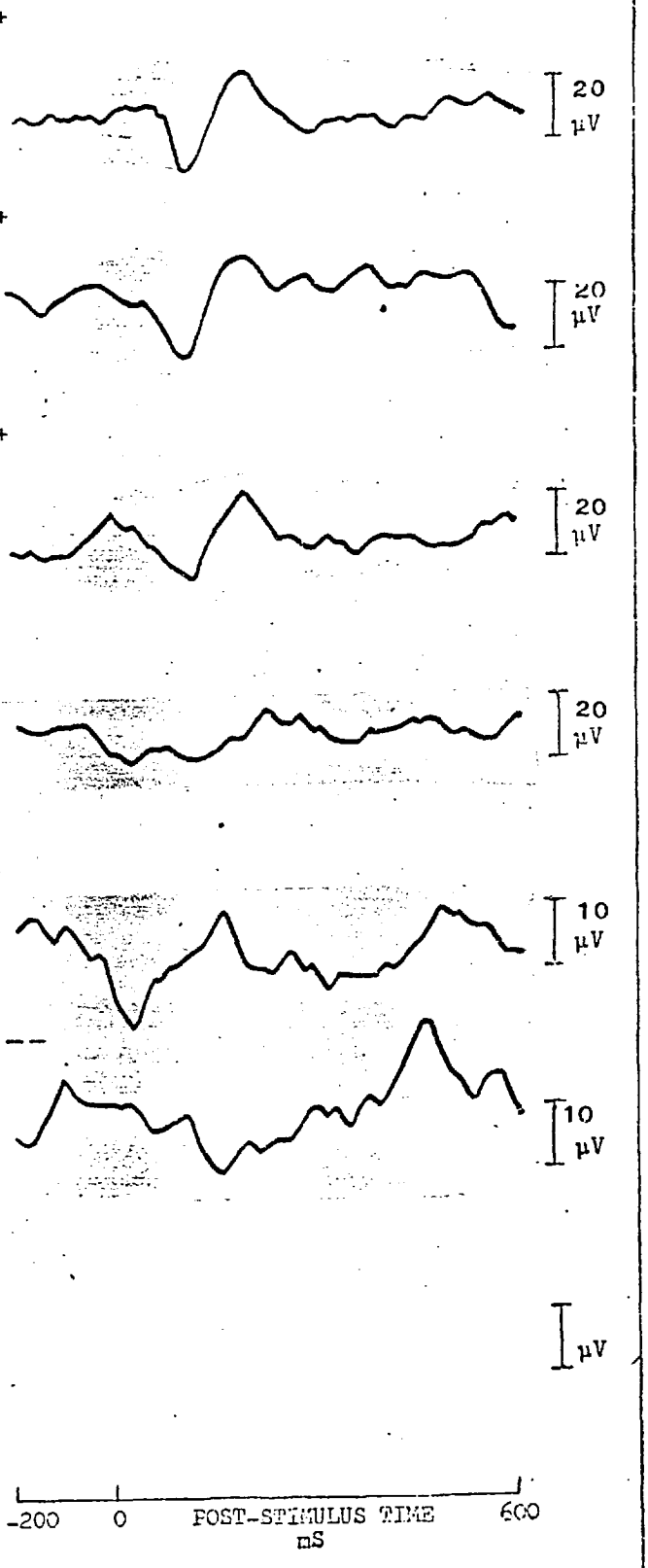


Subjective Threshold
Below -10 dB

Table 5.37 Subject RR F, 31yrs.

Left Ear 1KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean. o	Phase S.D. o	Score
70 dB		Score	++	++
1	.052	268	098	
2	.044	198	084	
3	.030	303	092	
4	.022	014	085	
5	.014	077	090	
6	.008	129	090	
50 dB		Score	++	++
1	.068	187	095	
2	.038	172	081	
3	.028	295	099	
4	.022	026	088	
5	.014	056	075	
6	.012	105	091	
30 dB		Score	+	++
1	.056	030	097	
2	.034	227	092	
3	.024	309	081	
4	.022	032	094	
5	.014	064	097	
6	.012	133	098	
20 dB		Score	+	+
1	.072	184	098	
2	.040	284	095	
3	.028	354	085	
4	.022	323	101	
5	.014	202	099	
6	.012	295	105	
10 dB		Score	+	-
1	.056	077	101	
2	.038	168	087	
3	.028	164	091	
4	.022	009	094	
5	.012	326	094	
6	.008	074	101	
0 dB		Score	+	--
1	.046	254	090	
2	.030	317	102	
3	.022	082	092	
4	.014	279	099	
5	.012	142	097	
6	.008	105	099	
dB		Score		

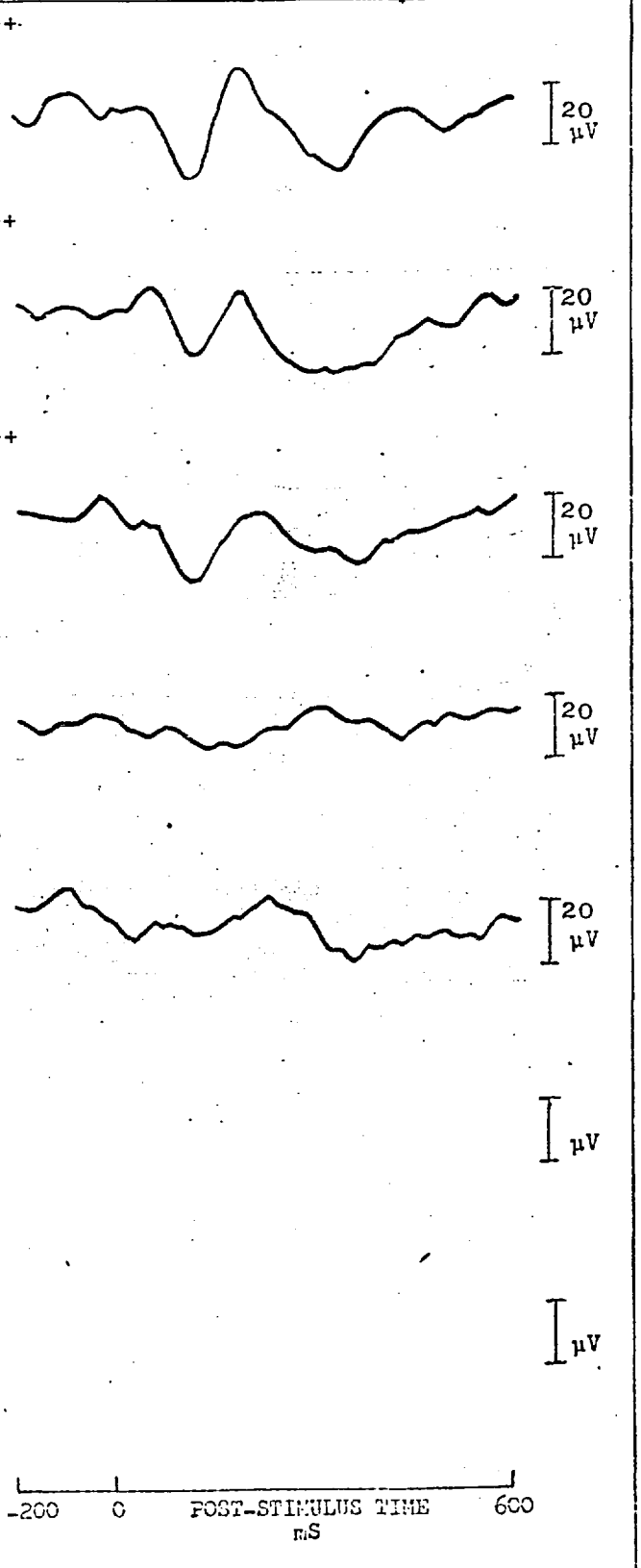


Subjective Threshold = 15 dB

Table 5.38 Subject RR

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
NN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
80 dB		Score	++	++
1	.030	334	087	
2	.028	205	091	
3	.022	300	064	
4	.018	000	092	
5	.008	081	091	
6	.006	120	091	
60 dB		Score	++	++
1	.044	319	075	
2	.024	198	095	
3	.024	327	085	
4	.018	032	088	
5	.012	095	082	
6	.012	147	091	
40 dB		Score	++	++
1	.056	317	082	
2	.044	251	088	
3	.030	317	080	
4	.018	016	085	
5	.014	323	099	
6	.014	237	104	
30 dB		Score	+	+
1	.040	298	098	
2	.024	327	087	
3	.018	080	098	
4	.012	354	095	
5	.012	192	099	
6	.008	241	105	
20 dB		Score	-	+
1	.050	036	097	
2	.034	243	094	
3	.022	344	092	
4	.018	246	101	
5	.012	260	104	
6	.008	106	097	
dB		Score		
dB		Score		



Subjective Threshold = 5 dB

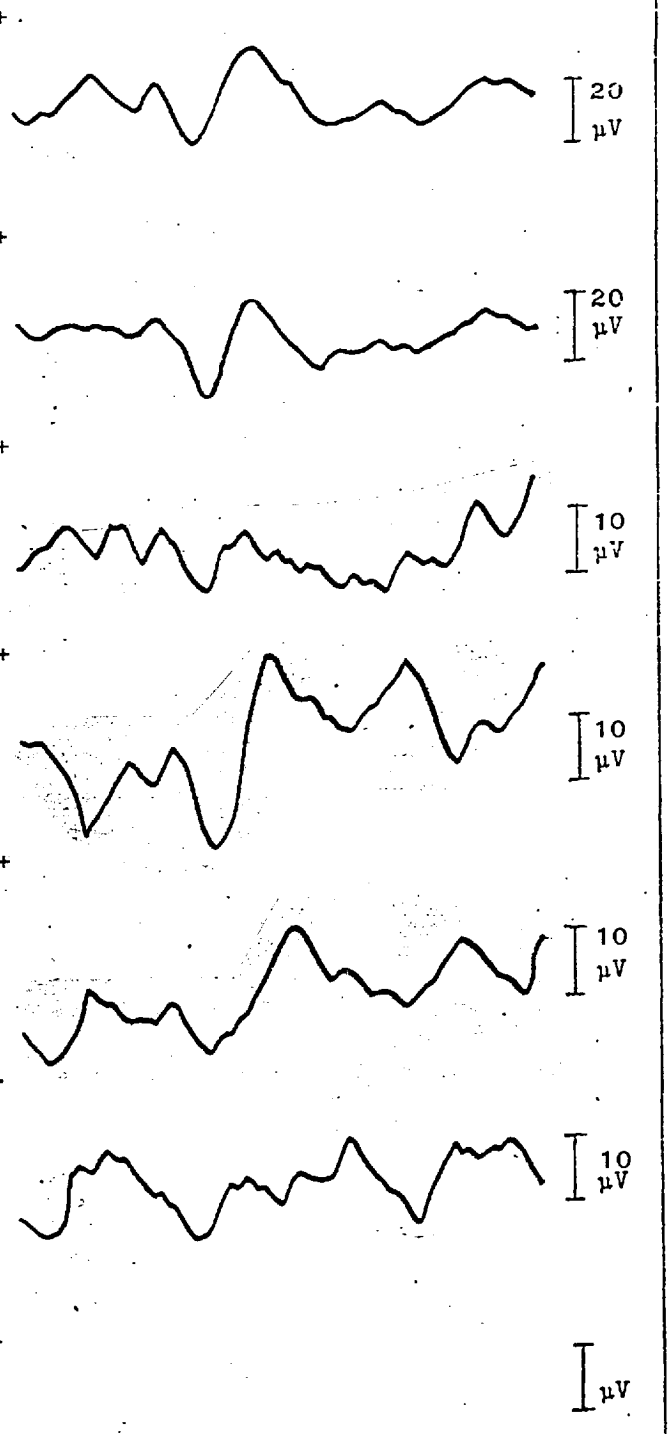
Table 5.39 Subject RR

Left Ear 3 KHz

HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
80 dB		Score	++++
1	.060	350	087
2	.044	146	094
3	.030	298	081
4	.022	053	082
5	.014	068	088
6	.012	071	091
60 dB		Score	+ ++
1	.052	293	099
2	.038	223	091
3	.022	323	090
4	.014	073	095
5	.012	112	091
6	.008	320	101
40 dB		Score	+ ++
1	.046	303	101
2	.030	247	094
3	.024	313	090
4	.014	007	092
5	.012	037	104
6	.008	244	097
30 dB		Score	++++
1	.052	161	097
2	.040	255	088
3	.024	324	078
4	.018	136	095
5	.014	189	091
6	.012	239	088
20 dB		Score	- ++
1	.106	064	095
2	.068	341	102
3	.038	035	092
4	.028	097	098
5	.018	127	098
6	.012	122	098
10 dB		Score	- -
1	.082	061	101
2	.052	261	097
3	.038	194	097
4	.022	340	098
5	.018	215	101
6	.012	104	094
	dB	Score	

Ensemble Average

Score



Subjective Threshold = 15 dB

Table 5.40 Subject JT F, 35 yrs.

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.052	126	084	
2	.038	270	085	
3	.024	354	087	
4	.018	001	090	
5	.012	061	092	
6	.008	165	088	
50 dB		Score	++	++
1	.034	080	101	
2	.030	260	081	
3	.022	319	084	
4	.018	350	084	
5	.008	057	095	
6	.008	130	085	
30 dB		Score	++	++
1	.046	223	084	
2	.034	258	082	
3	.024	341	091	
4	.018	337	104	
5	.012	118	094	
6	.006	195	084	
20 dB		Score	++	++
1	.040	074	092	
2	.030	350	090	
3	.024	045	088	
4	.018	033	095	
5	.008	132	090	
6	.008	164	095	
10 dB		Score	-	++
1	.044	172	092	
2	.038	298	099	
3	.024	036	099	
4	.014	071	099	
5	.012	075	098	
6	.008	319	097	
0 dB		Score	++	0
1	.066	043	094	
2	.044	068	097	
3	.028	039	101	
4	.018	016	099	
5	.012	338	088	
6	.008	104	090	
-10 dB		Score	+	--
1	.034	160	092	
2	.030	306	097	
3	.022	136	097	
4	.018	025	102	
5	.008	070	085	
6	.008	036	091	

Subjective Threshold = 5 dB

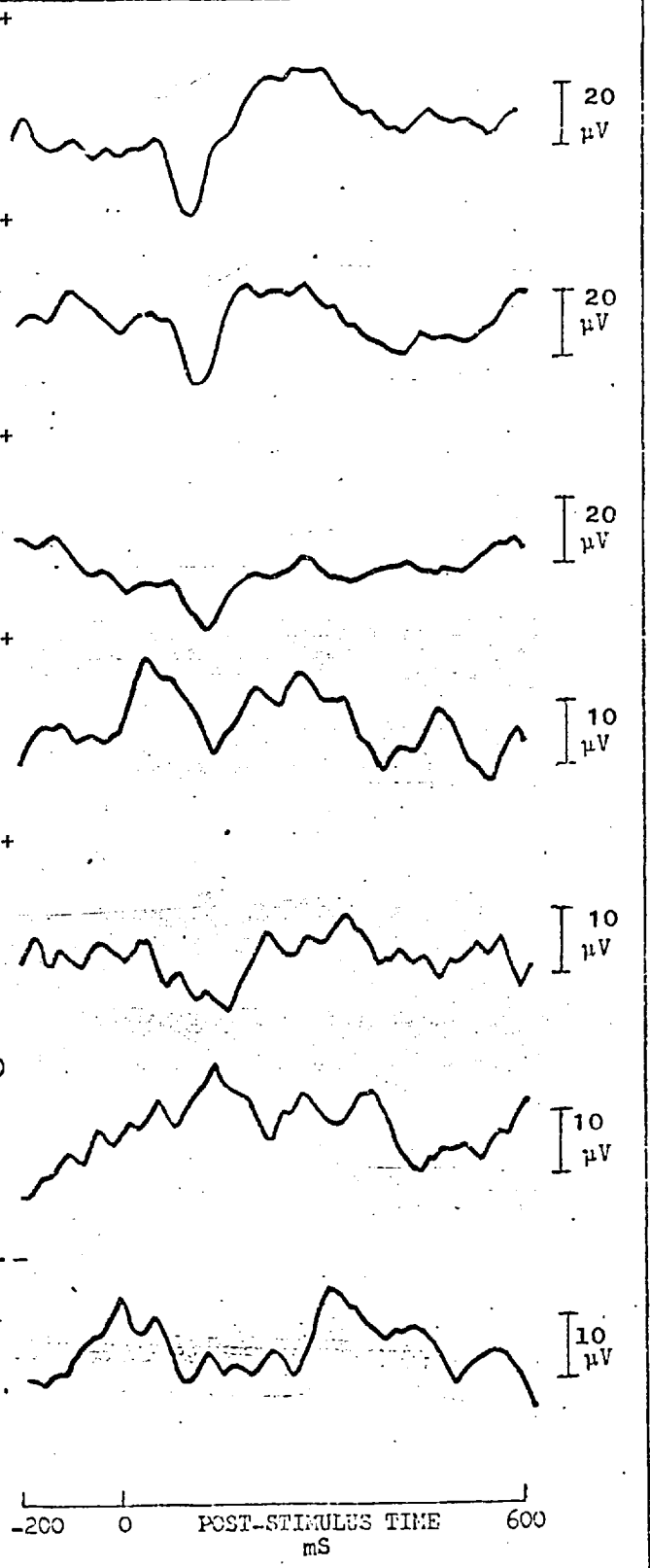


Table 5.41 Subject JT

Left Ear 2 KHz

Microprocessor Results | Ensemble Average

HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
70 dB		Score	++
1	.062	201	094
2	.038	272	091
3	.030	323	085
4	.022	337	088
5	.014	057	090
6	.008	095	090
50 dB		Score	++
1	.052	227	095
2	.034	284	081
3	.024	001	084
4	.014	071	097
5	.012	153	092
6	.008	285	104
30 dB		Score	-
1	.038	109	094
2	.028	354	102
3	.024	329	099
4	.012	182	095
5	.012	226	102
6	.008	278	101
20 dB		Score	-
1	.050	244	098
2	.040	239	091
3	.024	320	095
4	.014	026	097
5	.012	299	095
6	.008	108	101
10 dB		Score	++
1	.056	091	087
2	.034	319	091
3	.030	054	092
4	.018	113	095
5	.012	073	102
6	.008	081	090
0 dB		Score	++
1	.040	289	098
2	.030	227	094
3	.024	032	092
4	.018	226	087
5	.012	340	087
6	.008	251	104
-10 dB		Score	++
1	.046	061	088
2	.034	078	099
3	.028	018	081
4	.022	216	094
5	.012	182	094
6	.008	323	095

Score

++ ++ 20 µV

++ ++ 20 µV

++ ++ 10 µV

++ ++ 10 µV

+ ++ 10 µV

- ++ 10 µV

-- ++ 10 µV

-200 0 POST-STIMULUS TIME 600 mS

Subjective Threshold = 5 dB

Table 5.42 Subject JT

Left Ear 3 KHz

Microprocessor Results | Ensemble Average

HN	Amplitude Mean V/Hz x	Phase Mean o	Phase S.D. o
70 dB		Score	++
1	.073	206	098
2	.046	291	085
3	.028	080	094
4	.018	323	087
5	.012	101	101
6	.008	275	108
50 dB		Score	-
1	.044	143	098
2	.030	158	095
3	.024	078	092
4	.018	045	099
5	.012	198	094
6	.008	223	105
30 dB		Score	+
1	.052	355	090
2	.034	274	098
3	.028	042	094
4	.018	182	094
5	.012	309	102
6	.008	068	098
20 dB		Score	-
1	.044	309	095
2	.034	251	102
3	.024	182	097
4	.022	090	094
5	.012	036	098
6	.008	122	092
10 dB		Score	-
1	.044	172	101
2	.034	001	098
3	.030	341	095
4	.018	322	091
5	.014	320	095
6	.008	007	094
dB		Score	
dB		Score	

Subjective Threshold = 15 dB

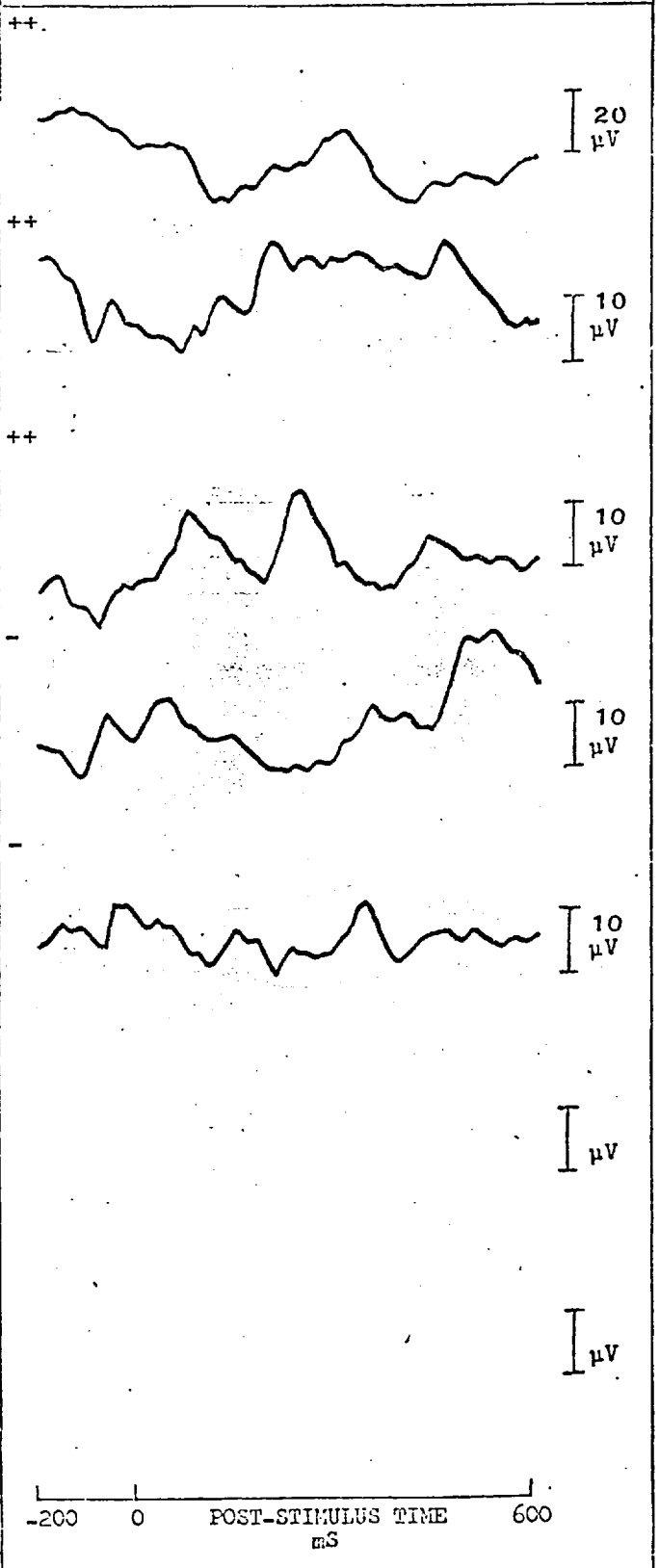
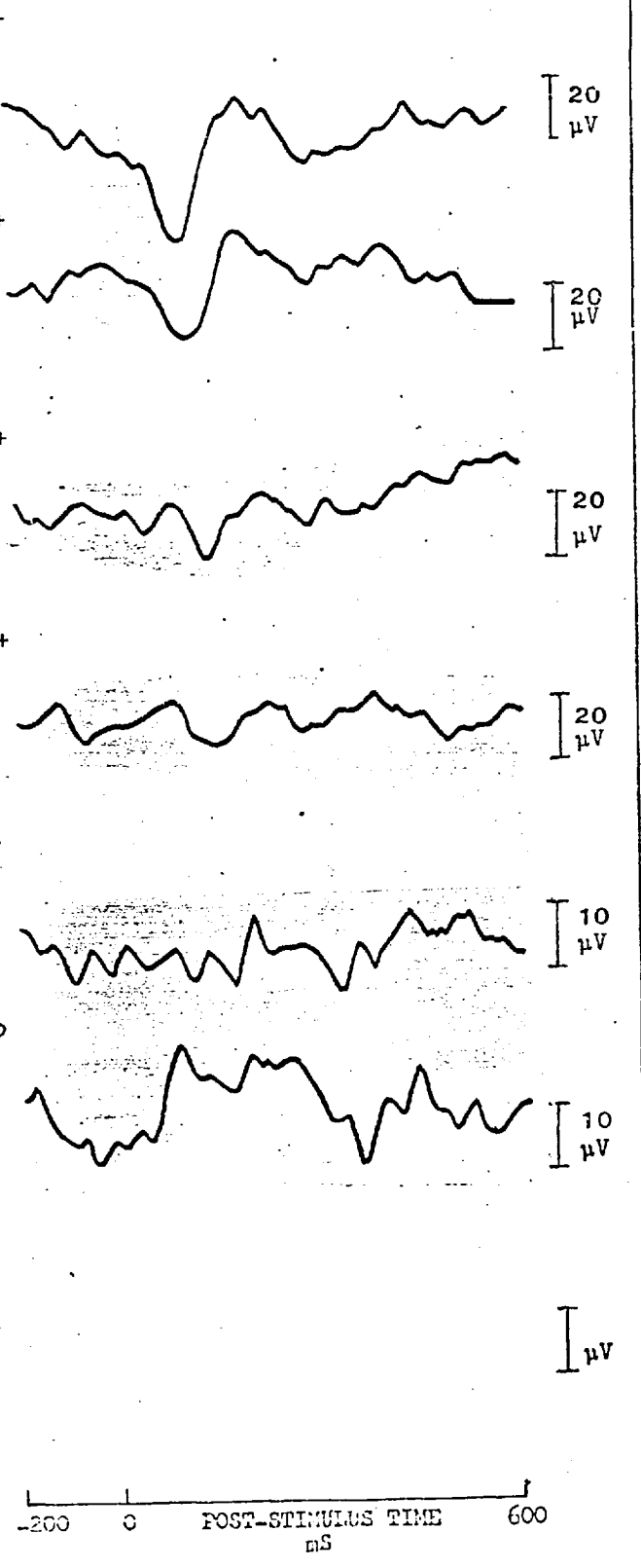


Table 5.43 Subject ML F, 22 yrs.

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.040	223	099	
2	.030	216	084	
3	.022	288	067	
4	.014	343	081	
5	.012	021	084	
6	.008	045	087	
50 dB		Score	++	++
1	.050	174	087	
2	.038	185	098	
3	.024	315	078	
4	.014	011	082	
5	.012	042	078	
6	.006	108	094	
30 dB		Score	++	++
1	.056	230	102	
2	.034	250	085	
3	.022	354	095	
4	.018	061	104	
5	.012	182	087	
6	.008	243	101	
20 dB		Score	++	++
1	.038	130	099	
2	.028	347	091	
3	.022	348	088	
4	.012	092	097	
5	.012	161	087	
6	.006	146	092	
10 dB		Score	-	+
1	.040	313	099	
2	.034	147	094	
3	.018	012	098	
4	.012	146	091	
5	.012	199	105	
6	.008	253	104	
0 dB		Score	-	o
1	.046	078	097	
2	.028	139	101	
3	.018	030	092	
4	.014	167	095	
5	.012	168	095	
6	.006	306	098	
dB		Score		



Subjective Threshold = 0 dB

Table 5.44 Subject ML

Left Ear 2 KHz

HR	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
70 dB		Score	++
1	.040	158	092
2	.034	302	085
3	.022	343	098
4	.014	336	082
5	.012	073	092
6	.008	084	085
50 dB		Score	++
1	.044	146	098
2	.028	240	090
3	.024	323	082
4	.014	032	088
5	.008	075	093
6	.008	120	091
30 dB		Score	++
1	.060	279	088
2	.034	236	097
3	.024	331	084
4	.014	054	097
5	.012	106	094
6	.008	129	095
20 dB		Score	+
1	.056	267	099
2	.040	358	101
3	.028	323	095
4	.014	039	088
5	.012	306	097
6	.008	286	106
10 dB		Score	+
1	.052	011	097
2	.034	154	097
3	.022	338	092
4	.014	135	087
5	.012	087	098
6	.008	323	092
0 dB		Score	+
1	.050	071	104
2	.030	331	099
3	.018	090	101
4	.014	043	090
5	.012	358	091
6	.008	094	092
-10 dB		Score	+
1	.050	035	101
2	.030	350	099
3	.024	331	090
4	.014	277	094
5	.012	265	091
6	.008	215	094

Subjective Threshold = 0 dB

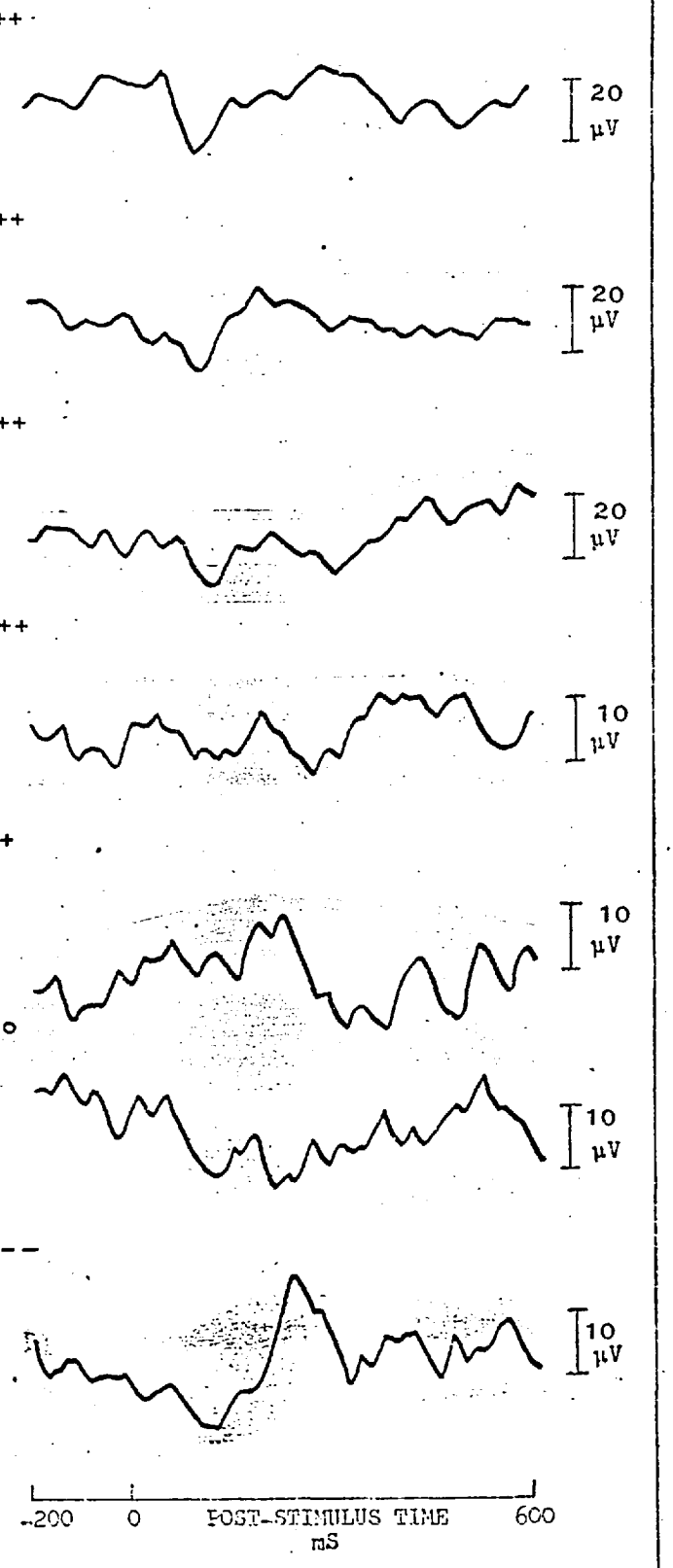
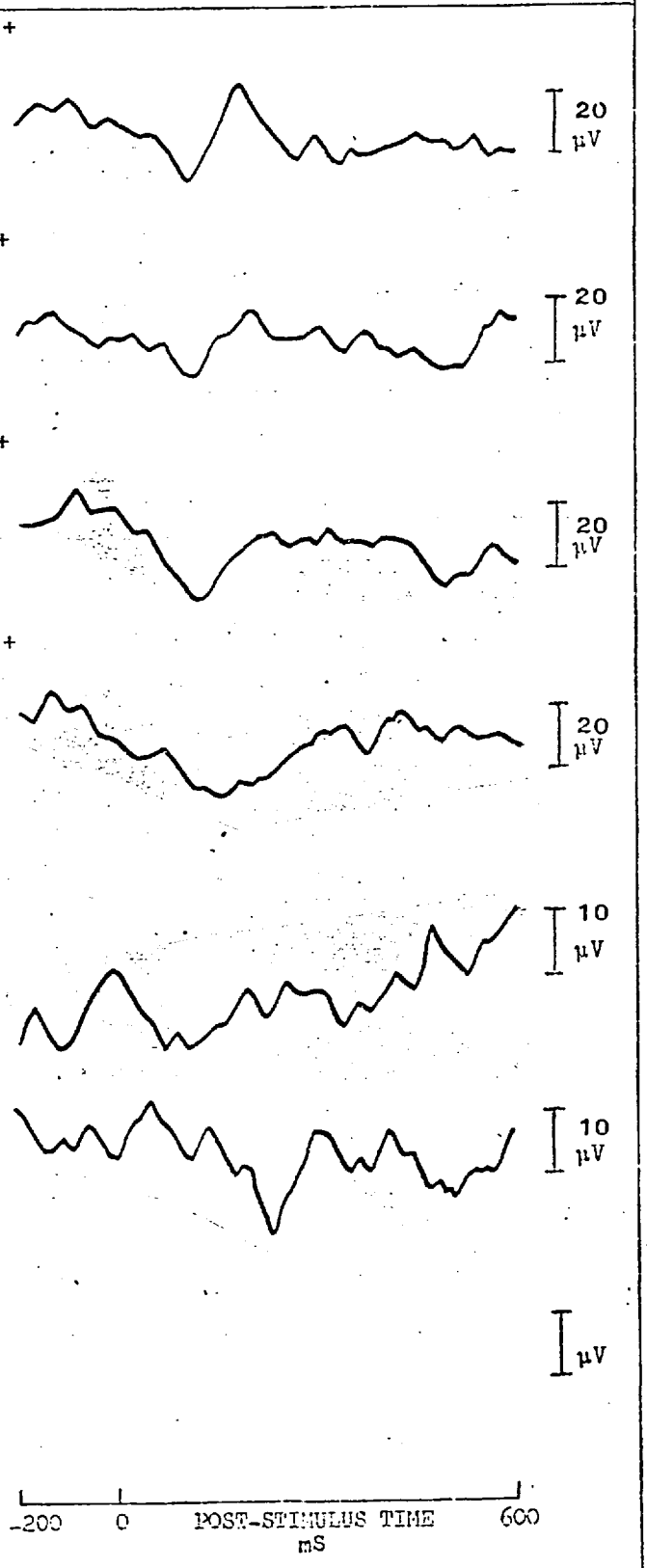


Table 5.45 Subject ML

Left Ear 3 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.040	074	099	
2	.030	174	088	
3	.018	303	088	
4	.014	350	084	
5	.012	082	087	
6	.006	244	102	
50 dB		Score	+	++
1	.050	106	101	
2	.038	279	091	
3	.022	306	087	
4	.012	326	099	
5	.012	091	092	
6	.008	115	094	
30 dB		Score	++	++
1	.066	226	094	
2	.040	238	094	
3	.024	316	087	
4	.012	026	090	
5	.008	133	085	
6	.006	021	094	
20 dB		Score	++	++
1	.044	239	080	
2	.030	258	098	
3	.018	039	098	
4	.012	241	102	
5	.008	113	087	
6	.006	334	098	
10 dB		Score	-	+
1	.044	292	099	
2	.038	265	098	
3	.018	355	099	
4	.014	298	098	
5	.008	348	094	
6	.006	208	097	
0 dB		Score	-	-
1	.072	277	101	
2	.040	011	091	
3	.024	002	093	
4	.014	329	095	
5	.012	070	095	
6	.008	291	101	
dB		Score		

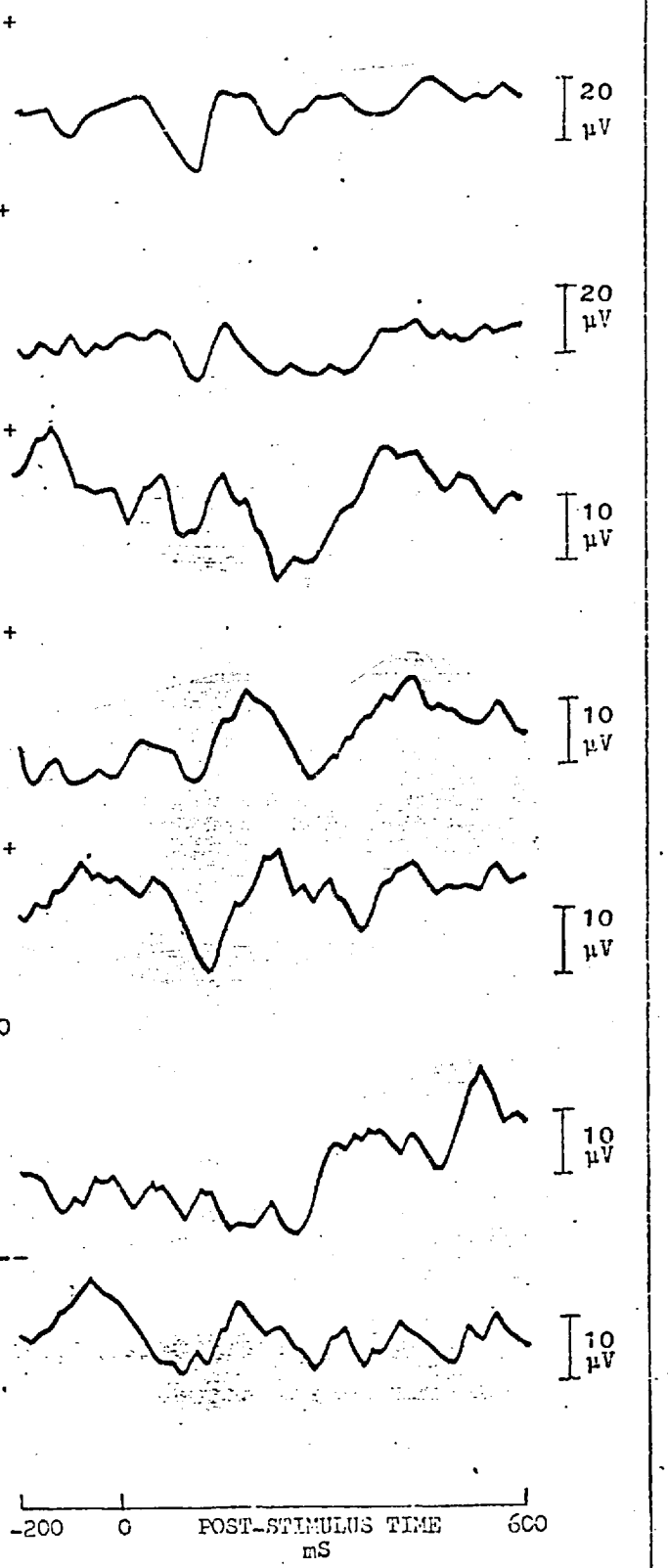


Subjective Threshold = 5 dB

Table 5.46 Subject CM F, 18 yrs.

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70dB		Score	++	++
1	.034	246	098	
2	.024	202	098	
3	.018	295	092	
4	.012	341	074	
5	.008	080	080	
6	.006	113	075	
50dB		Score	++	++
1	.030	293	085	
2	.024	097	098	
3	.022	319	095	
4	.014	323	097	
5	.012	037	087	
6	.008	105	087	
30dB		Score	++	++
1	.034	270	088	
2	.022	122	088	
3	.014	277	092	
4	.012	023	098	
5	.008	080	082	
6	.006	130	094	
20dB		Score	++	++
1	.034	217	092	
2	.028	130	087	
3	.022	295	092	
4	.014	063	098	
5	.008	094	090	
6	.006	068	092	
10dB		Score	++	++
1	.030	260	098	
2	.024	241	087	
3	.014	347	088	
4	.012	135	095	
5	.008	111	087	
6	.006	032	099	
0dB		Score	++	0
1	.046	226	092	
2	.030	344	098	
3	.024	188	092	
4	.014	111	097	
5	.012	050	088	
6	.006	012	090	
-10dB		Score	+	--
1	.030	172	099	
2	.024	202	094	
3	.018	285	095	
4	.012	313	099	
5	.008	095	098	
6	.006	043	088	

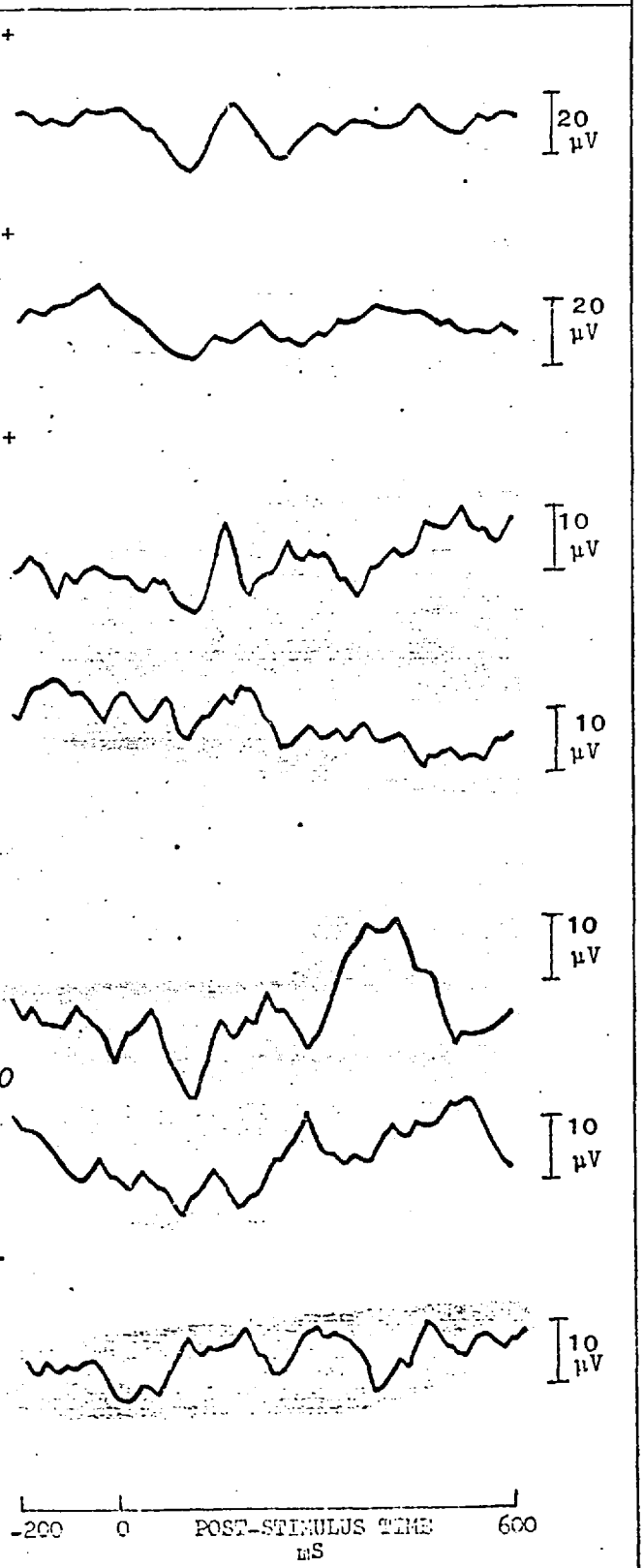


Subjective Threshold = 5 dB

Table 5.47 Subject CM

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HH	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.030	230	091	
2	.024	198	098	
3	.018	257	081	
4	.014	383	078	
5	.008	057	092	
6	.006	115	092	
50 dB		Score	+	++
1	.028	230	087	
2	.022	172	097	
3	.014	279	097	
4	.014	312	101	
5	.012	004	101	
6	.006	352	095	
30 dB		Score	+	++
1	.030	237	104	
2	.028	220	094	
3	.018	057	104	
4	.012	305	098	
5	.012	043	084	
6	.006	098	097	
20 dB		Score	-	+
1	.028	064	099	
2	.024	025	097	
3	.018	277	101	
4	.012	348	091	
5	.012	279	104	
6	.006	198	099	
10 dB		Score	++	+
1	.030	194	091	
2	.022	061	084	
3	.018	331	075	
4	.014	043	095	
5	.008	057	099	
6	.008	087	091	
0 dB		Score	+	0
1	.034	223	087	
2	.024	244	095	
3	.022	140	095	
4	.012	239	099	
5	.008	023	091	
6	.006	032	097	
-10 dB		Score	-	-
1	.030	101	098	
2	.024	331	106	
3	.018	095	101	
4	.014	291	094	
5	.008	216	099	
6	.008	158	097	

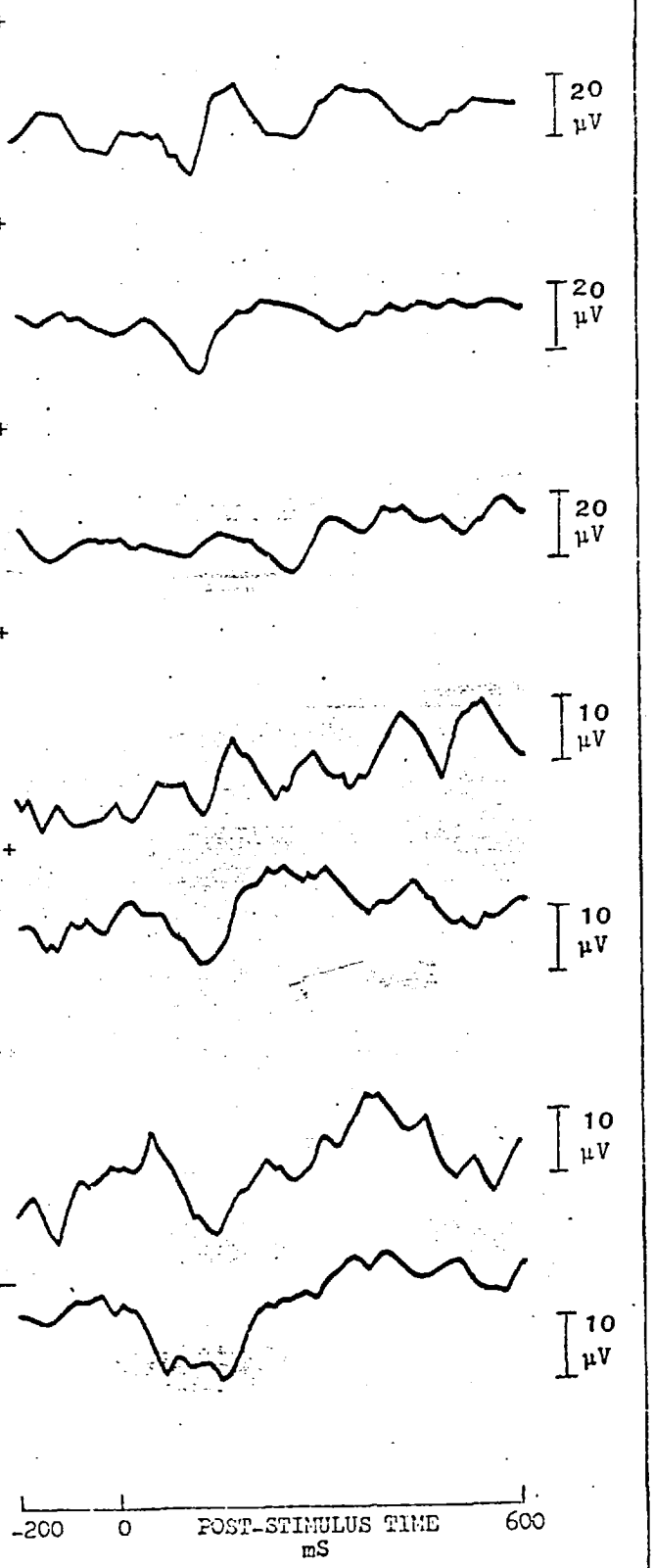


Subjective Threshold = -5dB

Table 5.48 Subject CM

Left Ear 3 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.038	139	098	
2	.028	336	096	
3	.018	247	090	
4	.014	004	085	
5	.008	080	084	
6	.006	111	088	
50 dB		Score	++	++
1	.040	241	098	
2	.030	255	095	
3	.018	030	085	
4	.014	018	095	
5	.012	049	090	
6	.008	126	099	
30 dB		Score	-	++
1	.038	270	091	
2	.028	045	099	
3	.018	254	097	
4	.012	261	105	
5	.008	091	095	
6	.006	009	102	
20 dB		Score	+	++
1	.038	246	091	
2	.024	084	102	
3	.018	070	099	
4	.012	142	097	
5	.008	090	082	
6	.006	142	092	
10 dB		Score	++	++
1	.040	135	094	
2	.030	299	102	
3	.018	001	090	
4	.012	340	097	
5	.008	104	090	
6	.006	028	099	
0 dB		Score	++	+
1	.034	184	092	
2	.028	018	091	
3	.014	357	085	
4	.012	080	090	
5	.008	108	102	
6	.006	161	098	
-10 dB		Score	++	-
1	.044	222	092	
2	.028	267	088	
3	.018	279	099	
4	.014	000	099	
5	.012	292	090	
6	.006	295	095	



Subjective Threshold

Below -10 dB

Table 5.49 Subject LM F, 34 yrs.

Left Ear 1 KHz

Microprocessor Results

HN	Amplitude Mean V/Hz x 25000	Phase Mean °	Phase S.D. °
70 dB		Score	++
1	.050	213	085
2	.040	281	094
3	.030	295	078
4	.022	022	077
5	.018	088	085
6	.012	123	094
50 dB		Score	++
1	.072	330	099
2	.050	241	102
3	.034	279	098
4	.024	011	090
5	.018	056	094
6	.014	122	078
30 dB		Score	-
1	.060	201	091
2	.040	271	095
3	.040	327	105
4	.038	046	097
5	.018	140	099
6	.012	067	102
20 dB		Score	-
1	.066	115	104
2	.040	279	095
3	.030	054	095
4	.030	070	098
5	.014	187	098
6	.012	053	094
10 dB		Score	+
1	.050	002	097
2	.034	310	094
3	.030	237	099
4	.024	285	097
5	.012	015	091
6	.012	154	090
0 dB		Score	+
1	.062	157	090
2	.038	233	102
3	.030	241	098
4	.024	323	091
5	.014	046	088
6	.008	108	094
-10 dB		Score	+
1	.056	129	094
2	.044	175	091
3	.038	043	097
4	.028	326	087
5	.018	264	101
6	.012	004	101

Subjective Threshold = 5 dB

Ensemble Average

Score

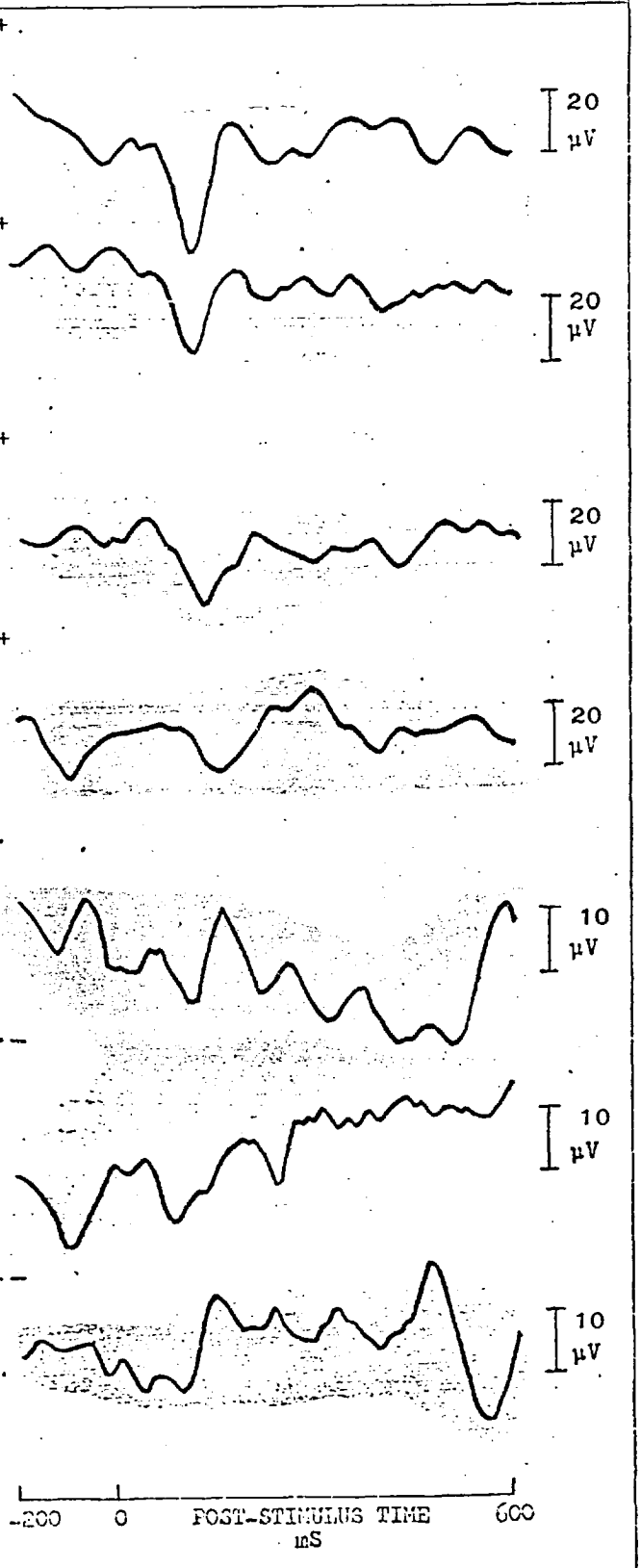
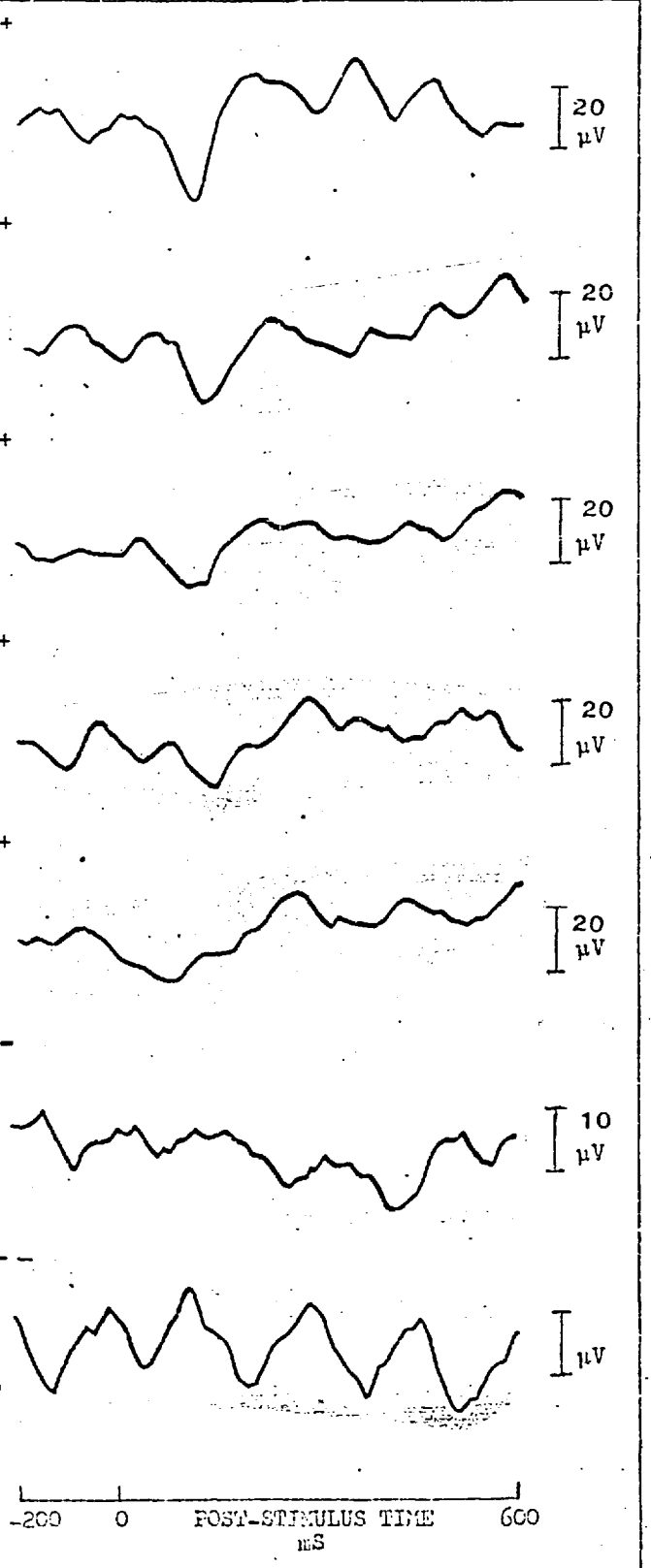


Table 5.50 Subject LM

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz × 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.046	161	088	
2	.040	222	092	
3	.038	331	085	
4	.030	012	082	
5	.014	199	101	
6	.012	122	085	
50 dB		Score	+	++
1	.038	236	094	
2	.030	233	084	
3	.028	344	094	
4	.034	021	095	
5	.012	130	098	
6	.012	133	091	
30 dB		Score	+	++
1	.046	199	092	
2	.038	274	092	
3	.030	333	090	
4	.030	268	104	
5	.014	167	095	
6	.012	077	099	
20 dB		Score	++	++
1	.046	240	094	
2	.034	281	092	
3	.030	091	085	
4	.028	146	090	
5	.012	085	091	
6	.008	161	085	
10 dB		Score	+	+
1	.050	192	092	
2	.038	237	091	
3	.030	327	092	
4	.024	239	090	
5	.014	268	099	
6	.012	278	099	
0 dB		Score	+	-
1	.052	343	088	
2	.034	354	094	
3	.034	153	102	
4	.024	340	098	
5	.014	322	106	
6	.012	201	091	
-10 dB		Score	++	- -
1	.050	305	098	
2	.034	071	094	
3	.034	136	099	
4	.034	279	088	
5	.014	164	090	
6	.012	327	097	

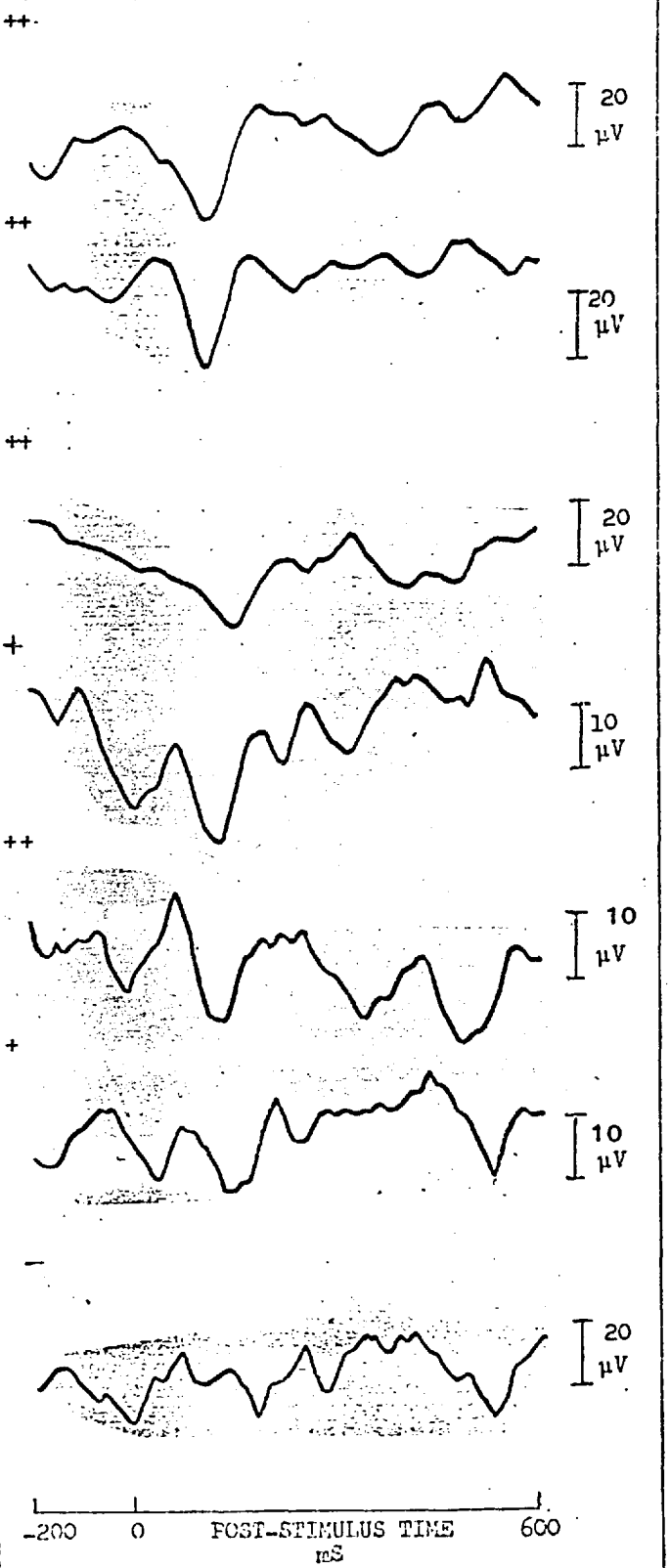


Subjective Threshold = 0 dB

Table 5.51 Subject LM

Left Ear 3 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.044	198	094	
2	.038	212	075	
3	.028	291	095	
4	.034	327	101	
5	.014	071	080	
6	.008	064	085	
50 dB		Score	++	++
1	.044	195	094	
2	.030	232	102	
3	.034	007	098	
4	.038	357	087	
5	.014	045	087	
6	.012	154	091	
30 dB		Score	+	++
1	.052	209	105	
2	.038	316	090	
3	.030	088	101	
4	.034	047	102	
5	.014	170	094	
6	.012	275	099	
20 dB		Score	++	+
1	.052	217	091	
2	.038	239	095	
3	.030	198	104	
4	.028	064	092	
5	.018	070	098	
6	.012	181	090	
10 dB		Score	++	++
1	.040	091	101	
2	.028	271	090	
3	.024	350	090	
4	.038	099	095	
5	.018	098	092	
6	.014	112	099	
0 dB		Score	+	+
1	.044	118	095	
2	.020	082	090	
3	.030	087	095	
4	.022	154	094	
5	.012	146	092	
6	.008	323	091	
-10 dB		Score	-	-
1	.046	019	102	
2	.034	002	094	
3	.038	064	102	
4	.030	334	098	
5	.014	216	101	
6	.012	029	095	



Subjective Threshold

Below -10 dB

Table 5.52 Subject KC F, 27 yrs.

Left Ear 1 KHz

HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
70 dB		Score	++
1	.056	113	092
2	.046	216	091
3	.024	289	094
4	.018	352	084
5	.014	046	082
6	.012	122	091
50 dB		Score	+
1	.060	108	094
2	.038	196	094
3	.024	292	091
4	.018	331	088
5	.014	064	095
6	.012	068	099
30 dB		Score	++
1	.066	157	092
2	.044	090	099
3	.028	326	091
4	.022	144	088
5	.014	053	090
6	.012	090	104
20 dB		Score	++
1	.052	164	082
2	.038	337	094
3	.024	306	094
4	.014	036	097
5	.014	142	084
6	.008	185	094
10 dB		Score	++
1	.050	132	090
2	.040	282	085
3	.030	036	098
4	.018	081	090
5	.014	059	099
6	.008	351	098
0 dB		Score	-
1	.050	329	099
2	.034	265	098
3	.022	080	098
4	.018	009	101
5	.014	047	101
6	.008	092	101
-10 dB		Score	+
1	.038	036	095
2	.030	296	088
3	.022	226	094
4	.018	217	097
5	.018	246	091
6	.008	344	095

Subjective Threshold = 5 dB

Microprocessor Results

Ensemble Average

Score

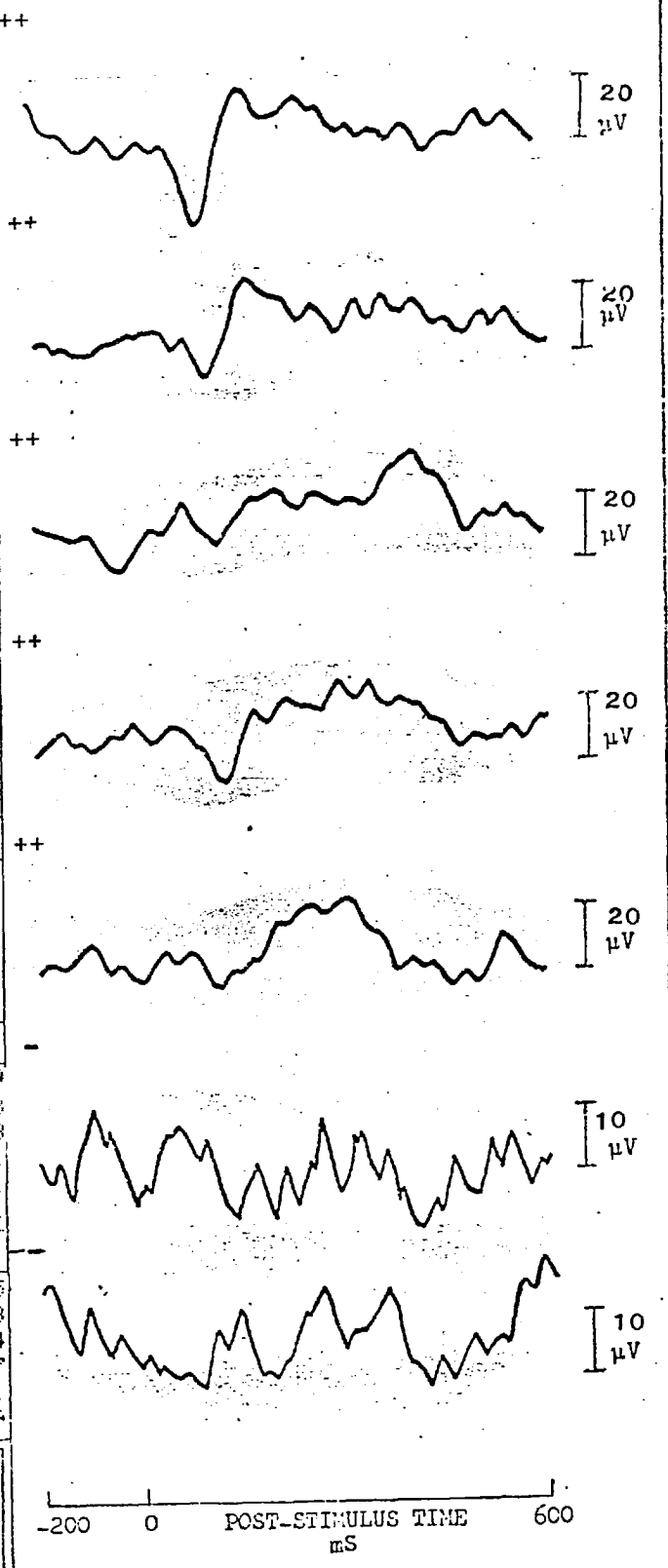


Table 5.53 Subject KC

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HR	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.038	146	087	
2	.030	258	087	
3	.024	330	091	
4	.018	333	082	
5	.018	012	097	
6	.008	067	095	
50 dB		Score	++	++
1	.028	191	097	
2	.030	184	097	
3	.022	267	091	
4	.014	340	085	
5	.012	056	085	
6	.008	115	095	
30 dB		Score	+	++
1	.040	151	090	
2	.028	258	092	
3	.018	303	101	
4	.014	350	097	
5	.012	113	098	
6	.008	344	091	
20 dB		Score	++	++
1	.044	327	088	
2	.030	225	090	
3	.024	326	091	
4	.018	057	094	
5	.014	070	087	
6	.008	150	091	
10 dB		Score	-	+
1	.060	142	102	
2	.038	324	095	
3	.024	135	099	
4	.018	042	088	
5	.014	105	091	
6	.012	127	092	
0 dB		Score	-	-
1	.060	127	092	
2	.034	021	091	
3	.022	095	094	
4	.022	219	104	
5	.018	172	097	
6	.012	132	102	
-10 dB		Score	-	-
1	.056	295	088	
2	.044	236	091	
3	.024	192	102	
4	.018	037	095	
5	.014	189	099	
6	.008	111	101	

Subjective Threshold = 0 dB

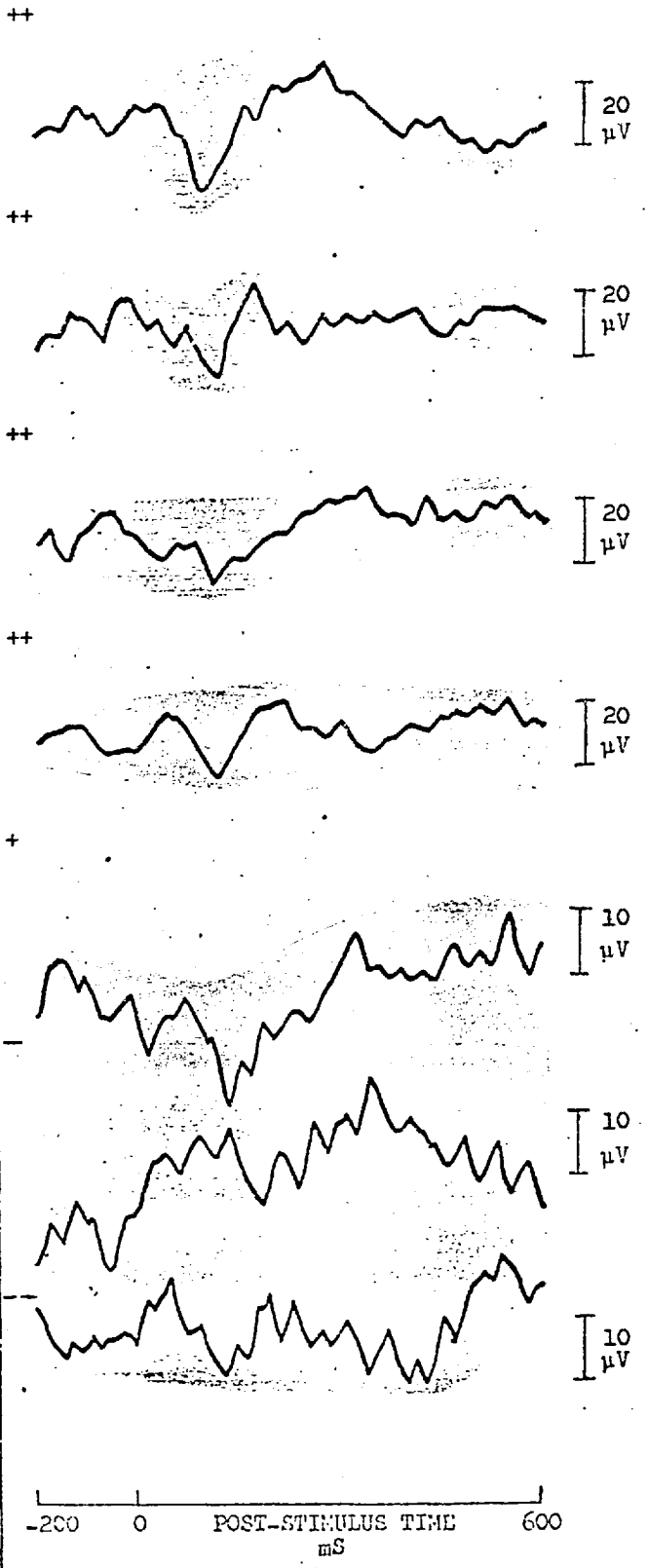
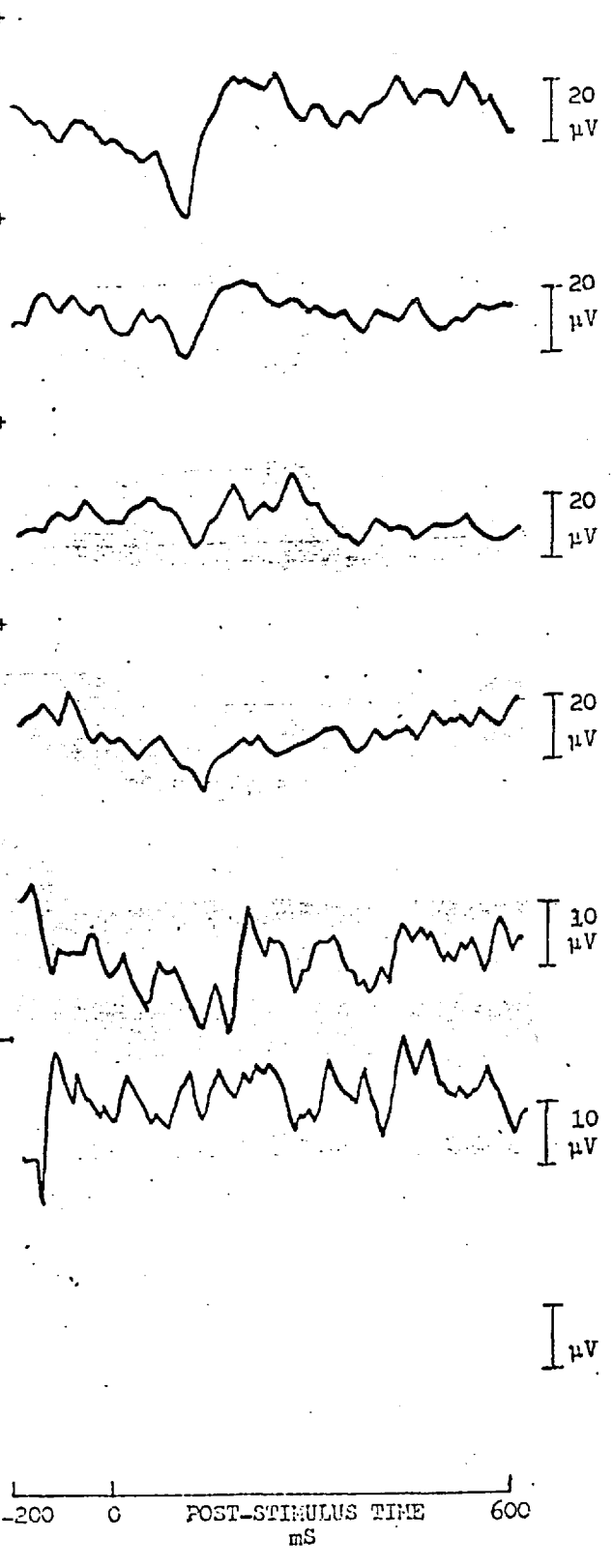


Table 5.54 Subject KC

Lett Ear 3 KHz

Microprocessor Results				Ensemble Average
HH	Amplitude Mean V/Hz × 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.040	122	092	
2	.040	208	075	
3	.024	323	092	
4	.018	007	090	
5	.014	066	085	
6	.012	037	084	
50 dB		Score	++	++
1	.056	092	095	
2	.038	165	098	
3	.024	307	095	
4	.014	000	088	
5	.014	063	092	
6	.012	092	087	
30 dB		Score	+	++
1	.050	057	098	
2	.034	241	094	
3	.022	053	098	
4	.014	043	095	
5	.012	049	075	
6	.008	120	092	
20 dB		Score	-	++
1	.052	243	102	
2	.034	264	094	
3	.022	326	098	
4	.018	009	095	
5	.014	151	094	
6	.008	310	098	
10 dB		Score	-	+
1	.044	229	102	
2	.038	216	095	
3	.022	355	097	
4	.018	315	101	
5	.014	140	091	
6	.008	289	105	
0 dB		Score	-	--
1	.050	180	095	
2	.038	154	098	
3	.022	087	104	
4	.018	337	094	
5	.014	116	095	
6	.008	043	099	
dB		Score		



Subjective Threshold = 5 dB

Table 5.55 Subject SA M, 20 yrs.

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.022	234	098	
2	.014	222	092	
3	.008	302	081	
4	.006	012	092	
5	.002	143	099	
6	.002	071	088	
50 dB		Score	++	++
1	.024	254	091	
2	.022	043	099	
3	.012	354	080	
4	.006	355	092	
5	.006	029	088	
6	.002	109	098	
30 dB		Score	++	++
1	.022	212	082	
2	.018	272	087	
3	.008	080	102	
4	.006	005	091	
5	.002	112	095	
6	.002	177	098	
20 dB		Score	++	+
1	.022	229	092	
2	.012	293	097	
3	.008	054	094	
4	.006	123	101	
5	.002	023	085	
6	.002	074	090	
10 dB		Score	-	+
1	.022	077	101	
2	.014	247	101	
3	.008	345	098	
4	.006	009	099	
5	.002	180	092	
6	.002	195	097	
0 dB		Score	+	--
1	.014	293	099	
2	.012	285	101	
3	.008	004	097	
4	.006	291	102	
5	.002	082	087	
6	.002	064	102	
-10 dB		Score	+	--
1	.024	125	094	
2	.018	308	094	
3	.008	334	094	
4	.006	336	094	
5	.006	078	098	
6	.002	043	087	

Subjective Threshold = 5 dB

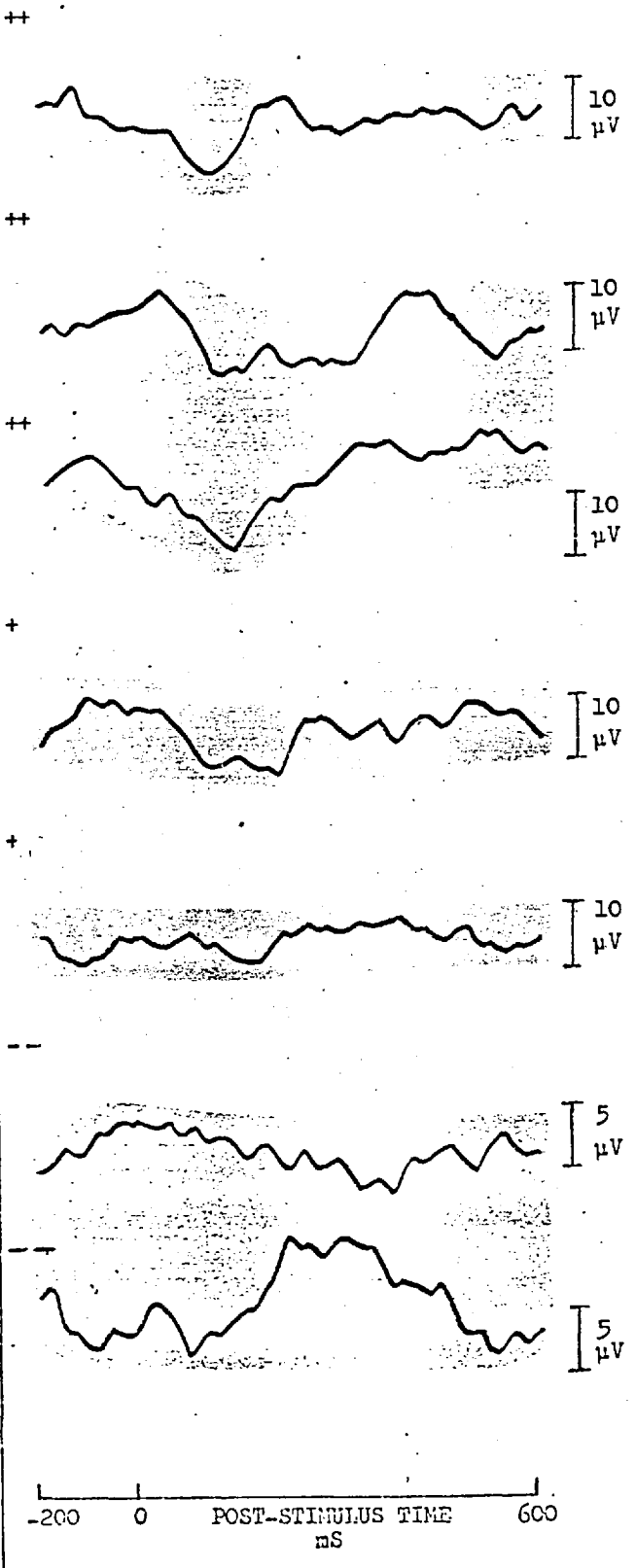
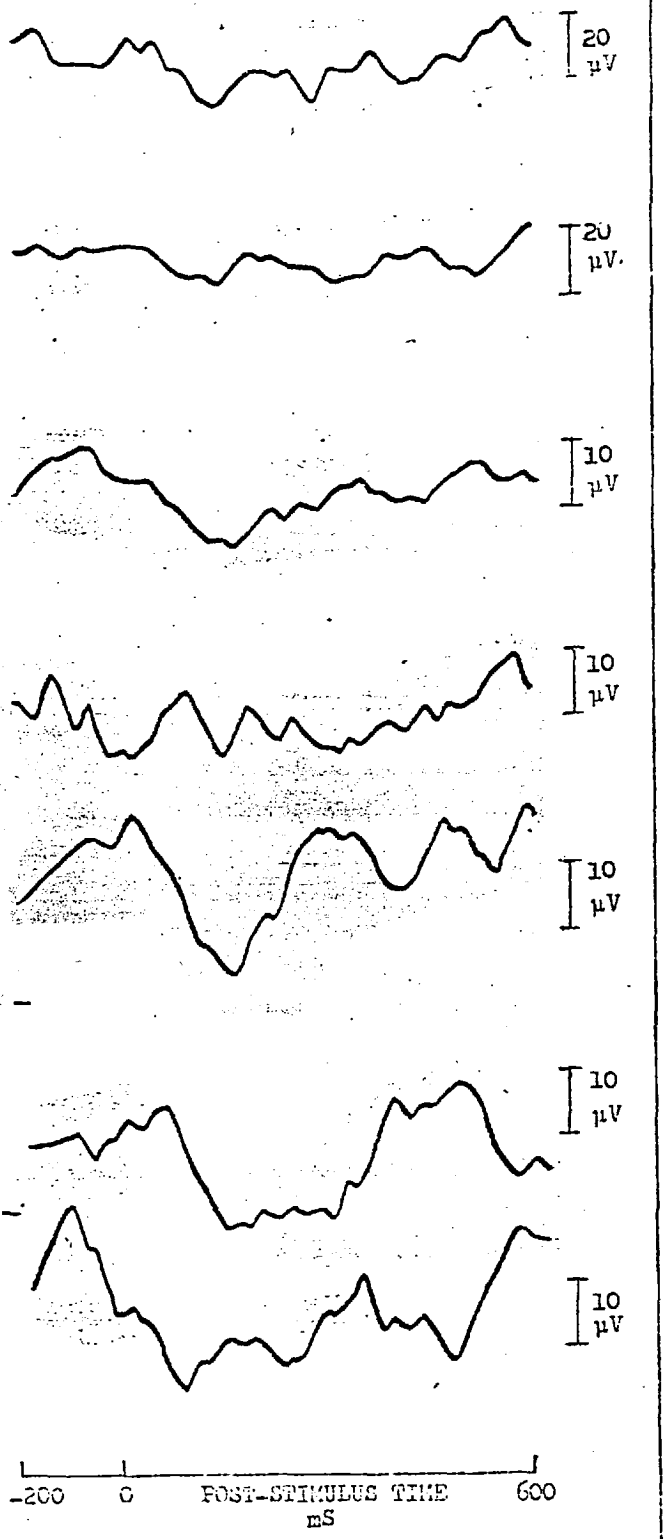


Table 5.56 Subject SA

Left Ear 2 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB (x 62500)		Score	++	++
1	.056	275	090	
2	.044	260	088	
3	.028	268	098	
4	.022	094	091	
5	.014	115	094	
6	.008	085	098	
50 dB (x 62500)		Score	+	+
1	.056	278	098	
2	.052	255	098	
3	.030	317	091	
4	.022	277	088	
5	.014	109	099	
6	.012	157	101	
30 dB		Score	++	+
1	.040	255	084	
2	.038	327	090	
3	.022	348	099	
4	.012	050	092	
5	.008	102	104	
6	.008	302	097	
20 dB		Score	-	+
1	.040	313	098	
2	.034	247	095	
3	.022	073	102	
4	.012	157	091	
5	.012	165	092	
6	.008	154	094	
10 dB		Score	+	+
1	.056	275	094	
2	.040	316	088	
3	.018	033	092	
4	.014	011	091	
5	.008	286	108	
6	.006	123	099	
0 dB		Score	-	-
1	.046	241	092	
2	.028	039	099	
3	.022	023	095	
4	.014	050	091	
5	.012	118	101	
6	.006	095	094	
-10 dB		Score	+	-
1	.050	261	094	
2	.046	303	097	
3	.024	203	090	
4	.014	265	102	
5	.012	032	098	
6	.008	334	095	

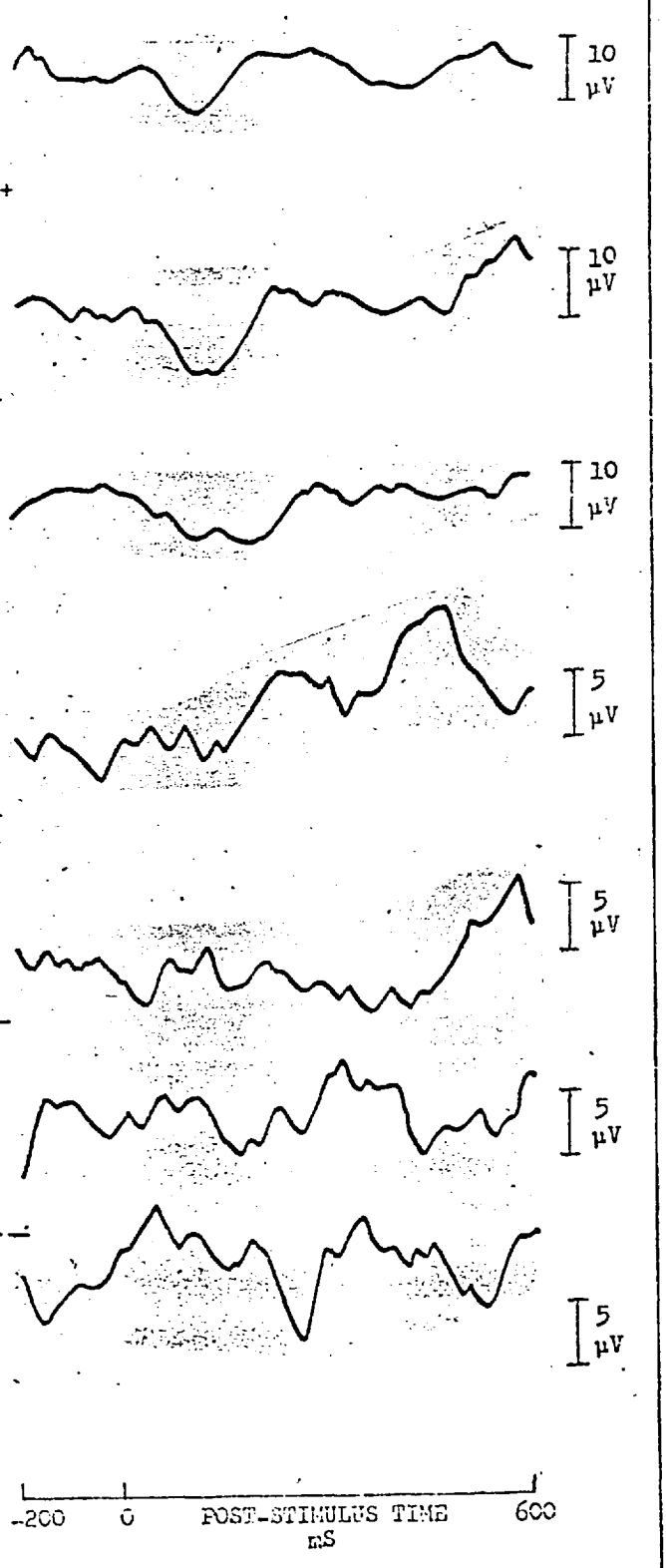


Subjective Threshold
Below -10 dB

Table 5.57 Subject SA

Left Ear 3 KHz

Microprocessor Results				Ensemble Average
HH	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.044	165	098	
2	.034	255	090	
3	.022	028	098	
4	.012	019	090	
5	.012	071	102	
6	.008	105	099	
50 dB		Score	++	++
1	.050	229	097	
2	.038	284	077	
3	.022	302	088	
4	.014	113	097	
5	.012	180	082	
6	.008	322	102	
30 dB		Score	-	+
1	.040	226	091	
2	.030	300	094	
3	.022	023	098	
4	.014	248	091	
5	.012	028	094	
6	.006	192	094	
20 dB		Score	+	+
1	.050	196	102	
2	.040	185	097	
3	.024	032	085	
4	.014	322	095	
5	.012	216	098	
6	.008	040	093	
10 dB		Score	+	+
1	.044	302	090	
2	.038	244	097	
3	.022	185	094	
4	.012	118	095	
5	.012	158	092	
6	.006	226	092	
0 dB		Score	-	-
1	.050	254	095	
2	.038	326	097	
3	.022	147	095	
4	.014	257	102	
5	.012	220	097	
6	.006	306	097	
-10 dB		Score	++	--
1	.050	025	101	
2	.044	053	097	
3	.028	240	097	
4	.018	345	090	
5	.014	135	087	
6	.008	223	102	



Subjective Threshold = 5dB

Table 5.58 Subject TR M, 34 yrs.

Left Ear 1 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.034	160	082	
2	.030	257	084	
3	.018	298	090	
4	.014	327	074	
5	.008	043	084	
6	.006	102	074	
50 dB		Score	++	++
1	.028	118	091	
2	.030	237	090	
3	.022	267	088	
4	.014	018	078	
5	.008	060	081	
6	.006	111	080	
30 dB		Score	++	++
1	.038	143	091	
2	.030	300	101	
3	.022	327	080	
4	.012	046	075	
5	.008	075	081	
6	.006	143	084	
20 dB		Score	++	++
1	.028	168	092	
2	.024	237	082	
3	.018	336	071	
4	.012	005	081	
5	.008	050	094	
6	.006	116	087	
10 dB		Score	++	++
1	.034	157	099	
2	.034	257	090	
3	.024	330	092	
4	.014	097	101	
5	.008	170	087	
6	.006	248	099	
0 dB		Score	++	+
1	.038	317	099	
2	.030	282	080	
3	.022	030	091	
4	.014	105	090	
5	.008	126	098	
6	.002	331	097	
-10 dB		Score	-	-
1	.038	351	088	
2	.028	331	097	
3	.018	227	091	
4	.012	343	095	
5	.008	246	101	
6	.006	070	099	

Subjective Threshold = -5 dB

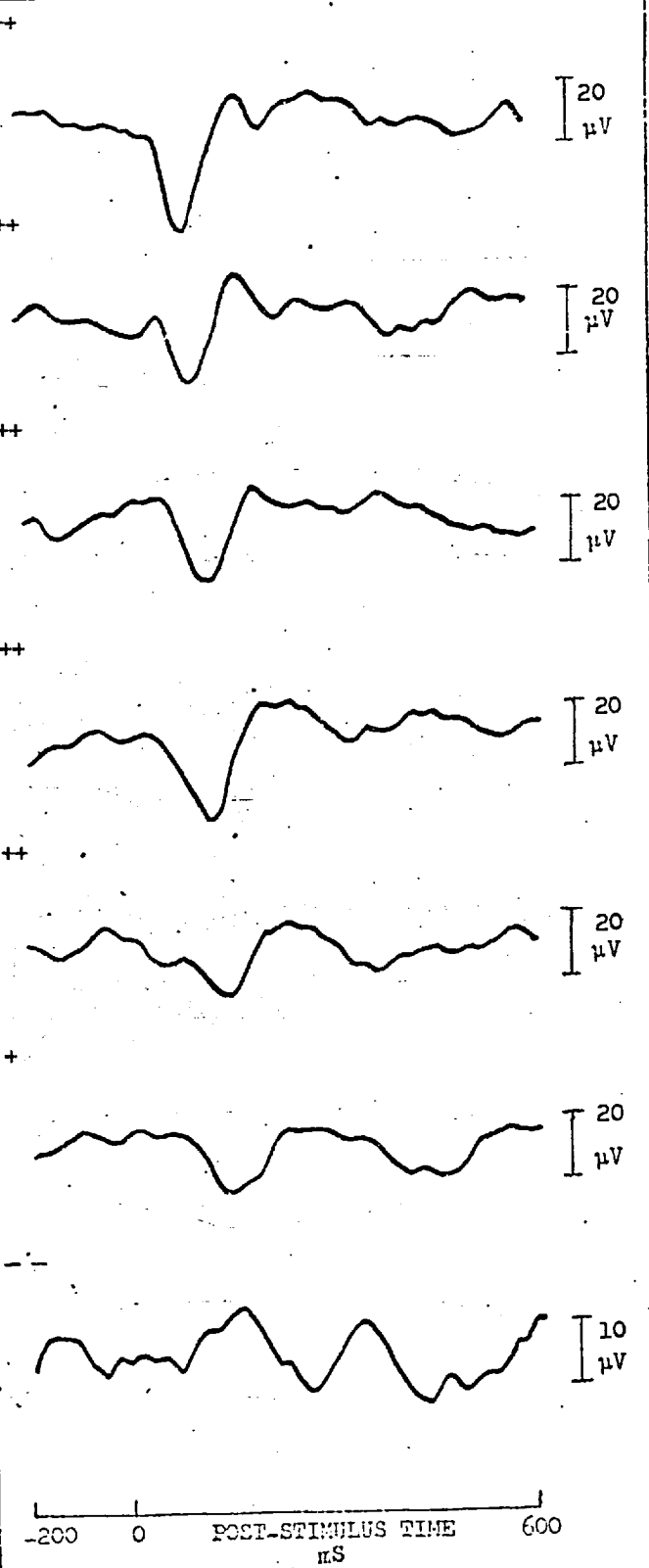


Table 5.59 Subject TR

Left Ear 2 KHz

BN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o
70 dB		Score	++
1	.040	132	090
2	.034	248	081
3	.028	282	074
4	.014	323	077
5	.008	043	070
6	.006	113	068
50 dB		Score	++
1	.034	124	091
2	.038	244	102
3	.022	265	082
4	.014	350	074
5	.008	032	085
6	.006	082	088
30 dB		Score	++
1	.034	142	090
2	.034	237	087
3	.030	310	102
4	.014	347	080
5	.008	059	081
6	.006	136	095
20 dB		Score	++
1	.040	120	097
2	.034	260	087
3	.028	302	095
4	.014	025	088
5	.008	115	092
6	.008	180	095
10 dB		Score	++
1	.038	174	091
2	.030	261	082
3	.024	025	084
4	.014	324	095
5	.008	056	094
6	.006	180	092
0 dB		Score	+
1	.030	130	081
2	.034	253	084
3	.028	057	094
4	.014	030	104
5	.008	187	102
6	.006	334	095
-10 dB		Score	+
1	.040	171	092
2	.030	291	090
3	.022	018	098
4	.014	248	099
5	.008	188	099
6	.006	257	097

Subjective Threshold = -5 dB

Ensemble Average

Score

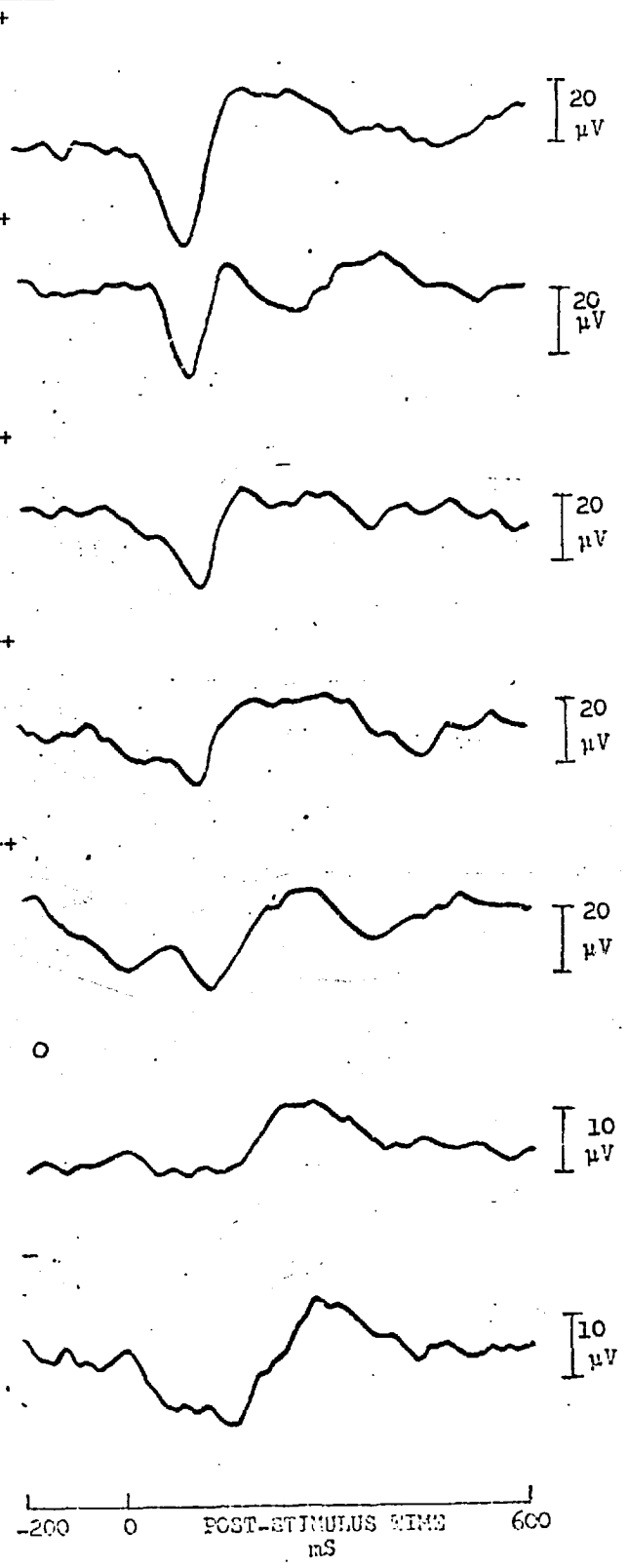
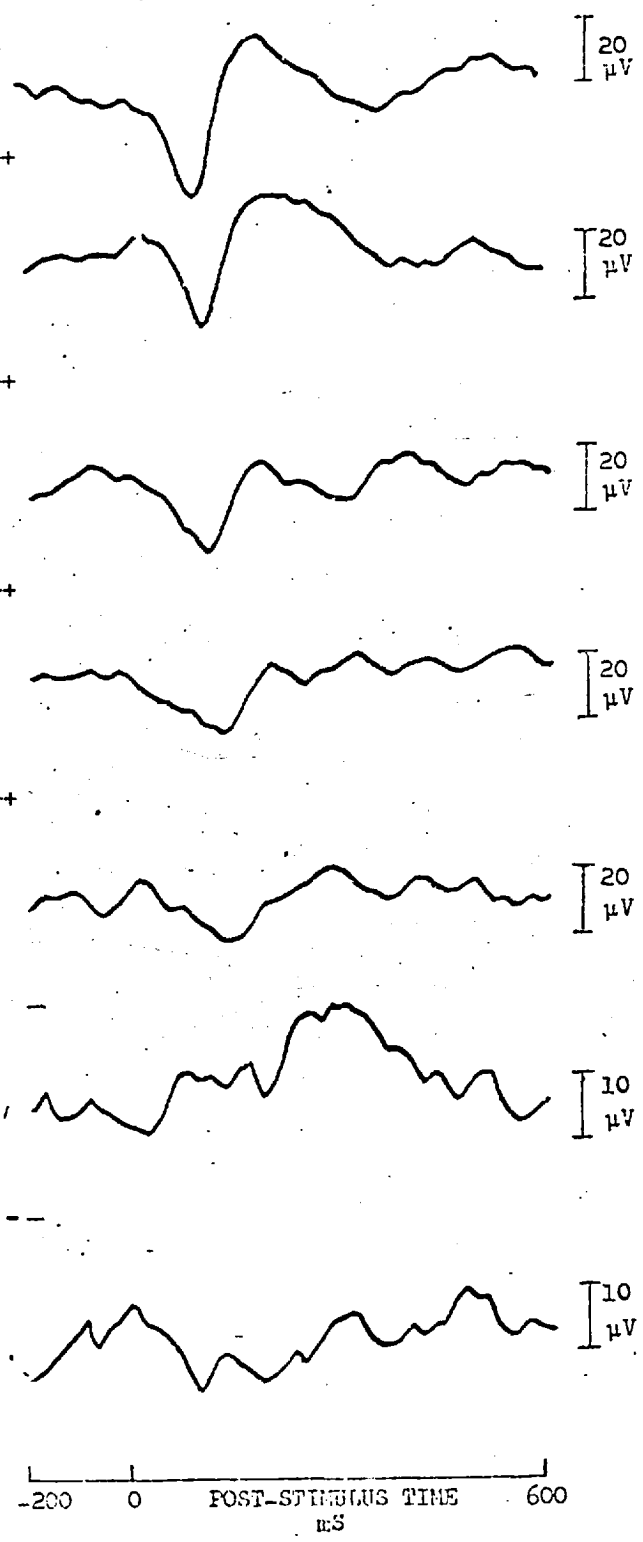


Table 5.60 Subject TR

Left Ear 3 KHz

Microprocessor Results				Ensemble Average
HN	Amplitude Mean V/Hz x 25000	Phase Mean o	Phase S.D. o	Score
70 dB		Score	++	++
1	.030	156	092	
2	.030	216	068	
3	.022	302	082	
4	.012	341	080	
5	.008	032	082	
6	.006	061	090	
50 dB		Score	++	++
1	.040	104	091	
2	.030	220	085	
3	.028	009	087	
4	.014	032	072	
5	.012	064	071	
6	.006	092	091	
30 dB		Score	++	++
1	.034	216	085	
2	.028	241	098	
3	.024	295	081	
4	.014	050	092	
5	.012	032	091	
6	.006	106	092	
20 dB		Score	++	++
1	.034	199	084	
2	.028	260	085	
3	.022	293	101	
4	.014	030	098	
5	.012	118	092	
6	.006	341	094	
10 dB		Score	+	++
1	.034	185	097	
2	.028	319	092	
3	.028	025	085	
4	.012	004	095	
5	.008	071	094	
6	.006	244	101	
0 dB		Score	+	-
1	.040	147	090	
2	.028	012	092	
3	.022	102	097	
4	.014	054	098	
5	.008	007	099	
6	.006	219	102	
-10 dB		Score	-	- -
1	.040	188	094	
2	.034	247	101	
3	.024	032	087	
4	.014	270	105	
5	.008	007	097	
6	.006	208	098	

Subjective Threshold = -5 dB



5.2 Summary of results.

It may be seen from the preceding tables that the microprocessor results were generally in fair agreement with the visually-scored ensemble averages and with the subjective thresholds.

The method of scoring the microprocessor results was simple but rather arbitrary, and some of the results did not show a uniform progression from ++ → (+) → - with decreasing stimulus level. For example, in table 5.10 (subject DA-K, left ear, 500 Hz), the scores in order of decreasing stimulus level were ++, ++, ++, ++, -, +, -. This could be due to statistical variability. If such a result occurred in clinical practice, the test would probably be repeated at one or more stimulus levels.

This type of result did not occur with the visually scored ensemble averages. It transpired that the uniform nature of these results was partly an artificial phenomenon due to the method of scoring. Scorers did not look at each trial individually, but at the complete set of trials for each frequency. As the main purpose of the tests was to determine hearing thresholds, scorers tended to ascribe +(+) to all trials above threshold, and -(-) to all trials below threshold.

Thresholds for the microprocessor results and for the visually scored ensemble averages were determined in the following way. When the score at one stimulus level was - or --, and the score at the next higher level was + or ++, the threshold was taken as halfway between the two levels. If a visually scored trace scored 0, this was taken as the threshold.

When a unique threshold existed for the microprocessor scores, it was compared with the threshold obtained from the visual scores and with the subjective threshold. 33 of the tests had unique thresholds for the microprocessor results. Of these, 14 were above the subjective threshold for the respective test (i.e. higher in intensity). 8 agreed with the subjective threshold and 11 were below it.

12 of the thresholds obtained from the microprocessor results were above those obtained by visual scoring: 6 agreed and 15 were below.

The visually scored averages for these tests were also compared with the subjective thresholds. 15 of the thresholds obtained from the visual scores were above the subjective threshold, 14 agreed and 4 were below.

It can thus be seen that when a threshold could be uniquely identified from the microprocessor results, it was generally comparable with the subjective threshold. The visually scored ensemble averages gave somewhat fewer false positives with respect to the subjective threshold.

Many of the atypical results obtained in this study could be eliminated by suitable design of the testing protocol. For example, it has been pointed out above that it is sometimes advantageous to repeat a trial: this is also true for the ensemble average method. The scoring method, while simple, has its limitations. A result in which the phase SD's of all the harmonics were 91° would be scored as -, when it would perhaps be more appropriate to assign a higher score.

Child (personal communication) has used the phase spectral method with patients with a hearing loss, as well as with normal hearing subjects. He notes that the thresholds obtained by the phase spectral method from hearing-loss patients are in better agreement with the subjective thresholds than is the case with normal hearing subjects.

The above trials were all carried out using analogue magnetic tape records. Table 5.61 below shows the results obtained when a subject was tested on-line. These trials are not strictly comparable with those of Tables 5.1 - 5.60 , as the length of the stimulus was 50 mS rather than 100 mS. No ensemble averages are available for comparison: however, it can be seen that the phase constraint at high stimulus levels was most pronounced with this subject.

Table 5.61

On-line operation.

Subject IG , female, 18 years. Right ear.

1000 Hz tone bursts. 1.25s repetition rate. 64 stimuli per trial.

50 mS total burst width, 10 mS rise time, 10 mS fall time.

Amplifier gain 50,000. Stimulus level 80 dB.

HN	AMP MEAN VOLTS/HZ	PHASE MEAN DEGREES:	S.D.:
1	.110	254	084
2	.076	267	087
3	.076	323	082
4	.056	049	061
5	.038	129	073
6	.024	171	074

Same as above but with amplifier gain 25,000 (Three trials)

HN	AMP MEAN VOLTS/HZ	PHASE MEAN DEGREES:	S.D.:
1	.056	059	102
2	.038	265	087
3	.034	316	073
4	.022	035	073
5	.012	143	078
6	.012	180	081

HN	AMP MEAN VOLTS/HZ	PHASE MEAN DEGREES:	S.D.:
1	.052	196	094
2	.030	251	073
3	.034	336	059
4	.022	053	070
5	.014	111	073
6	.008	201	081

HN	AMP MEAN VOLTS/HZ	PHASE MEAN DEGREES:	S.D.:
1	.066	174	097
2	.040	246	077
3	.040	309	059
4	.028	052	066
5	.018	126	075
6	.012	191	082

On-line operation.

Subject IG, 1000 Hz tone bursts (continued).

Amplifier gain 25,000 . Stimulus level 60 dB.

HN	AMP MEAN VOLTS/HZ	PHASE MEAN DEGREES:	S.D.:
1	.072	295	094
2	.046	253	092
3	.028	316	087
4	.024	046	078
5	.018	112	074
6	.012	158	088

Stimulus level 40 dB.

HN	AMP MEAN VOLTS/HZ	PHASE MEAN DEGREES:	S.D.:
1	.050	291	094
2	.038	327	090
3	.030	324	088
4	.024	046	075
5	.018	130	073
6	.012	158	074

Stimulus level 20 dB.

HN	AMP MEAN VOLTS/HZ	PHASE MEAN DEGREES:	S.D.:
1	.076	316	087
2	.050	277	101
3	.030	357	090
4	.022	095	095
5	.018	126	099
6	.012	215	088

Stimulus level -10 dB.

HN	AMP MEAN VOLTS/HZ	PHASE MEAN DEGREES:	S.D.:
1	.088	313	094
2	.052	158	098
3	.034	233	099
4	.022	327	101
5	.018	292	102
6	.012	239	099

The results of the four trials at 80 dB with subject IG at 1000 Hz (above) were pooled and the following statistics were calculated:

Harmonic Number	Mean of four 'phase S.D.' results (°)	Standard deviation of four 'phase S.D.' results (°)
1	94.25	6.6
2	81	6.15
3	68.25	9.8
4	67.5	4.5
5	74.75	2.04
6	79.5	3.2

This gives some indication as to the repeatability of the phase spectral method. While harmonic 3 gave rather variable results, the higher harmonics (4,5,6) showed good repeatability, harmonic 5 particularly so.

5.3 Testing the additive hypothesis

Two subjects (AMcK and LL) were selected for further study, with a view to testing the additive hypothesis for the generation of evoked potentials.

The method used to test the hypothesis was essentially as follows. The average response from each trial was added to an ensemble of pre-stimulus EEG records. The pre-stimulus records began 640 mS before the stimulus, and ended at the beginning of the stimulus. As the stimulus repetition period was 1.25 S, they began late enough for the response to the previous stimulus to have decayed. Only trials in which the statistics of the pre-stimulus records were reasonably stationary were used.

The ensemble produced by this addition process was subjected to the same statistical procedure as the post-stimulus records, to find the phase standard deviation of the first six harmonics. The results were compared. If the additive hypothesis were to be accepted, then the standard deviations obtained would be similar to those obtained from the post-stimulus records.

As the hypothesis was being tested for the first six harmonics only, it was convenient to work in the frequency domain and to ignore harmonics higher than the sixth. This meant that the amount of data to be collected at each trial was much reduced. Thus, in a trial of 64 stimuli, with 64 samples of each response collected, there would have been a total of 4096 points to be recorded. Instead, the Fourier transform routine was employed, giving 64 amplitude and phase values for 6 harmonics, a total of only 768 points.

It was arranged that the microprocessor would print out this transformed data when the phase analysis programme was run. This was done by adding a short routine for this purpose. As the data was printed out, it was also recorded on a digital cassette at the data terminal. The data recorded on the cassette could then be transferred to the CDC computer for further analysis.

It may be noted in passing that this is a good example of how computing tasks might be shared between microprocessors and larger machines. The CDC computer is versatile and fast, and better suited to lengthy mathematical procedures. The microprocessor reduces the amount of data to be handled, thus making more efficient use of the mainframe machine.

By changing the contents of one address in the analogue magnetic tape reading routine, it was possible to trigger the microprocessor so that the 640 mS pre-stimulus period of each record was analysed instead of the 640 mS post-stimulus period.

The two subjects selected for further study were chosen because their phase analysis results appeared to be typical and their subjective thresholds were close to 0 dB. The transformed pre-stimulus and post-stimulus records, at three different frequencies and at a number of supra-threshold levels were recorded on digital cassettes and transferred to the CDC computer.

5.4 Analysis of the transformed data.

The transformed data as collected above was first examined to determine whether the post-stimulus amplitude records for each harmonic were significantly greater than the pre-stimulus records. If this had been the case, then it would have lent support to the additive hypothesis.

The test employed for this purpose was the Kolmogorov-Smirnov two-sample test (Lindgren,1968: Massey, 1951: Siegel, 1956). This is a nonparametric test which exists in two forms; a two-tailed test, which tests whether two samples are significantly different from each other: and a one-tailed test, which tests whether a particular sample is significantly larger in mean than the other sample. The computational details of the two tests are very similar, so a programme was written which would compute both test statistics.

This test was applied to the pre-stimulus and post-stimulus amplitude levels for each of six harmonics for 27 different trials, that is 162 pairs of samples each containing 64 points. Significance at 5% was obtained in only two cases. The conclusion to be drawn was that the post-stimulus amplitudes were not significantly different from the pre-stimulus amplitudes.

As the differences between pre- and post-stimulus records were subtle, it was essential that pre-stimulus records selected as examples of unstimulated EEG were stationary over the length of a trial. Suitable pre-stimulus records were selected according to two criteria:

1) Uniformity in the distribution of phases for all six harmonics in each ensemble of 64 records. This was decided on the basis of the phase standard deviations computed by the microprocessor. Trials in which any harmonic showed significant phase aggregation at 5% were excluded.

2) Stationarity of the amplitude spectrum. This was tested by means of a run test for each of the six harmonics. If the run test indicated that any harmonic of a trial was significantly non-stationary at 5%, the trial was excluded. (Bendat and Piersol, 1971)

6 out of 12 of the pre-stimulus ensembles from subject AMcK passed both these tests, while 9 out of 15 of those from subject LL did so.

Table 5.62

Results of tests on pre-stimulus records.

Subject / Stimulus frequency	Stimulus level, dB	Phase uniformity test passed	Run test passed	Both tests passed
AMcK				
500 Hz	80		*	
	60	*	*	*
	40		*	
	20	*	*	*
1 KHz	80	*	*	*
	60	*		
	40	*	*	*
	20		*	
2 KHz	80	*	*	*
	60	*	*	*
	40	*		
	20		*	
LL				
500 Hz	80	*	*	*
	60	*	*	*
	40	*	*	*
	20	*	*	*
	10	*	*	*
1 KHz	80		*	
	60	*		
	40			
	20	*	*	*
	10		*	
2 KHz	80	*	*	*
	60		*	
	40			
	20	*	*	*
	10	*	*	*

To each record of the selected pre-stimulus ensembles was added the averaged response of the post-stimulus ensemble from the same trial. The addition was done in the frequency domain, as explained above. This method is valid because of the additivity property of Fourier transforms. The mean amplitude, mean phase, and phase standard deviation of the six harmonics of the resultant ensemble were then computed.

The computation was performed on the CDC machine using a FORTRAN programme. The pre-stimulus ensemble was converted from phase and amplitude form to a complex array. The standard response to be added to each record was formed as follows. The amplitude mean of each harmonic of the post-stimulus ensemble, computed by the microprocessor programme, was multiplied by a constant scaling factor of 1/8. This was then combined with the phase mean and converted to complex number form. As all the transformed quantities were now in real and imaginary form, the addition of the standard response was a simple matter.

The constant scaling factor needs some explanation. To construct an accurate model using the additive hypothesis, the standard response must be added to the unstimulated records with the correct signal-to-noise ratio. The signal-to-noise ratio is increased by a factor of $\sqrt{N}$ by ensemble averaging, where N is the number of members in the ensemble. This factor must

be allowed for in scaling the standard response.

The results from this reconstruction procedure are given in Tables 5.63, 5.64 . The results from the real post-stimulus data are repeated in these tables for comparison. Phase S.D. values which show significant constraint at 5% are underlined.

It may be seen at a glance that the reconstructed data does not appear to have the phase constraint of the post-stimulus data. A formal statistical test may be invoked to test the confidence of this statement. The data to be tested is in matched pairs, and its distribution is non-normal. A suitable test in this case is the Wilcoxon matched-pairs signed-rank test (Siegel, 1956: Haber and Runyon, 1977).

This test was applied to each of the 15 trials separately (i.e. to six pairs of phase standard deviation values). In four trials, the phase SD for the reconstructed data was significantly higher than that for the post-stimulus data, at 2.5 % . (These trials were: LL, 500 Hz, 80 dB and 40 dB; 2 KHz, 80 dB and 10 dB). In two trials, the significance level was 5% (AMcK, 2KHz, 80 dB; LL, 1 KHz, 20 dB). The remaining trials did not reach the 5% significance level.

It is hazardous to apply a test to such a small sample, as one atypical member of the sample can make a vast difference to the result of the test. In a matched pairs test, it is permissible to create a larger sample by merging two or more smaller samples. Thus, the two trials from subject AMcK at 80 dB (1 KHz and 2 KHz)

were combined. The significance obtained on testing this sample of 12 pairs was 5%. Similarly, with

2	trials	from	AMcK	at	60 dB	the	significance	was	2.5%
2	"	"	LL	"	10 dB	"	"	"	5%
3	"	"	LL	"	20 dB	"	"	"	0.5%
2	"	"	LL	"	80 dB	"	"	"	0.5%

When all the trials for a subject were combined, the phase S.D.s for the reconstructed data were found to be higher than those for the post-stimulus data, at significance levels much better than 0.5 % .

5.5 Effect of increasing the amplitude of the added signal

The results so far have indicated that a model which uses the additive hypothesis for the generation of evoked potentials does not produce the amount of phase constraint observed in practice. If the amplitude of the added standard signal in the model was increased, the phase constraint would be expected to increase, possibly to the extent observed in real subjects. Under these conditions it might be thought that the additive hypothesis could still be tenable. To consider this possibility, another experiment was designed, dual in nature to the previous one. In this, the amplitude of the standard signal was increased until significant phase constraint was beginning to appear. The values of amplitude mean for each harmonic were compared. If it could be shown that the amplitude means in the reconstruction were significantly greater than those from the original data, then this would indicate that the model was invalid.

The amplitude of the standard signal was increased by changing the scaling factor described above. It was found that by increasing this factor from 0.125 to 0.2 , significant phase constraint could be observed in most trials. The results obtained using this figure are given in Tables 5.65, 5.66.

It will be seen that the amplitude means for the reconstructed data appear to be generally greater than those for the original data. This was tested using the Wilcoxon matched-pairs signed-rank test for each trial. In four trials there was a significant difference at 2.5%, and in a further six trials there was significance at 5% .

The Wilcoxon test was also applied to the phase standard deviations, as before. This was necessary in order to check that the phase S.D.s of the reconstructed data were similar to those from the original data. If they had been significantly smaller, then it would not have been possible to draw any conclusions from the experiment. If both the phase S.D. and the amplitude mean values for the reconstructed data were significantly greater than the corresponding values for the original data, then there would be particularly strong grounds for rejecting the additive hypothesis.

In no trial were the phase S.D.s of the reconstructed data significantly less than those of the original data. In four trials they were significantly larger (three at 2.5%, one at 5%), and in the remaining 11 trials there was no significant difference between them. (See table 5.67)

Table 5.63 Subject AMcK Left ear

	Results from post-stimulus data			Results from reconstructed data (scaling factor .125)		
HN	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o
500 Hz 60 dB						
1	.046	234	084	.048	213	92
2	.030	106	088	.040	162	92
3	.030	007	097	.028	14	89
4	.014	012	087	.019	342	94
5	.014	078	087	.015	48	100
6	.008	111	088	.010	76	100
500 Hz 20 dB						
1	.050	262	092	.052	209	100
2	.038	071	099	.038	354	98
3	.024	030	095	.029	34	94
4	.018	036	099	.018	32	90
5	.012	104	099	.015	337	93
6	.008	250	101	.011	246	96
1 KHz 80 dB						
1	.084	164	097	.082	177	87
2	.060	243	098	.061	224	92
3	.056	247	092	.054	247	101
4	.038	005	082	.035	47	96
5	.030	061	081	.032	163	94
6	.018	115	073	.021	358	102
1 KHz 40 dB						
1	.040	208	098	.040	213	92
2	.030	057	101	.034	82	98
3	.024	247	097	.024	267	97
4	.014	007	081	.017	51	96
5	.012	036	092	.016	86	98
6	.008	105	080	.010	51	100
2 KHz 80 dB						
1	.034	043	091	.043	30	89
2	.030	156	092	.029	251	98
3	.024	241	095	.024	176	97
4	.014	296	080	.017	224	92
5	.012	049	094	.017	225	99
6	.008	053	094	.010	29	97
2 KHz 60 dB						
1	.040	241	085	.049	273	98
2	.030	118	098	.033	115	91
3	.028	260	087	.029	350	94
4	.018	313	078	.019	222	97
5	.012	054	095	.014	354	94
6	.008	105	084	.011	160	101

Table 5.64 Subject LL Left ear

	Results from post-stimulus data			Results from reconstructed data (scaling factor .125)		
HN	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o
500 Hz 80 dB						
1	.030	144	090	.033	254	96
2	.038	212	075	.032	194	100
3	.024	262	071	.023	257	93
4	.018	312	070	.018	307	98
5	.018	014	081	.019	74	101
6	.008	091	080	.011	148	94
500 Hz 60 dB						
1	.056	195	099	.060	268	94
2	.040	239	094	.039	272	90
3	.024	291	074	.033	110	97
4	.018	306	084	.020	51	101
5	.014	007	087	.017	15	90
6	.012	084	091	.013	50	94
500 Hz 40 dB						
1	.056	184	090	.052	124	96
2	.044	232	087	.042	273	99
3	.030	270	084	.029	231	94
4	.018	309	080	.019	3	99
5	.012	005	070	.014	22	101
6	.008	118	087	.012	297	105
500 Hz 20 dB						
1	.044	161	090	.050	200	95
2	.040	222	090	.038	232	94
3	.024	316	090	.028	271	99
4	.018	009	087	.020	24	82
5	.014	045	088	.019	35	97
6	.012	146	082	.012	187	96
500 Hz 10 dB						
1	.030	127	095	.034	40	98
2	.028	284	082	.028	267	92
3	.018	043	084	.022	57	86
4	.012	125	099	.016	96	95
5	.014	129	094	.018	102	98
6	.008	094	104	.011	152	95
1 KHz 20 dB						
1	.034	174	098	.046	196	93
2	.028	241	091	.039	287	98
3	.018	008	091	.020	107	105
4	.012	021	075	.015	36	97
5	.008	118	081	.013	58	96
6	.006	187	090	.009	301	102

Table 5.64 (contd.) Subject LL Left ear

	Results from post-stimulus data			Results from reconstructed data (scaling factor .125)		
HN	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o
2 KHz 80 dB						
1	.038	123	097	.043	50	101
2	.028	225	094	.038	260	98
3	.028	270	082	.027	288	93
4	.014	319	074	.018	311	99
5	.012	032	082	.014	95	94
6	.008	122	080	.011	126	96
2 KHz 20 dB						
1	.034	026	102	.038	336	85
2	.028	194	091	.035	189	99
3	.024	293	090	.022	27	103
4	.012	019	077	.015	31	91
5	.008	302	101	.012	316	102
6	.006	154	095	.010	88	102
2 KHz 10 dB						
1	.046	101	094	.051	37	101
2	.038	182	091	.032	215	102
3	.024	009	085	.022	203	101
4	.014	022	091	.018	182	99
5	.014	043	094	.016	30	96
6	.008	097	101	.013	268	102

Table 5.65 Subject AMcK Left ear

	Results from post-stimulus data			Results from reconstructed data (scaling factor 0.2)		
HN	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o
500 Hz 60 dB						
1	.046	234	084	.049	215	88
2	.030	106	088	.040	153	91
3	.030	007	097	.028	9	84
4	.014	012	087	.020	352	90
5	.014	078	087	.015	51	96
6	.008	111	088	.010	88	98
500 Hz 20 dB						
1	.050	262	092	.052	234	98
2	.038	071	099	.038	26	96
3	.024	030	095	.029	30	91
4	.018	036	099	.018	34	87
5	.012	104	099	.015	351	95
6	.008	250	101	.011	245	93
1 KHz 80 dB						
1	.084	164	097	.084	175	84
2	.060	243	098	.062	228	87
3	.056	247	092	.054	245	97
4	.038	005	082	.036	33	91
5	.030	061	081	.032	140	94
6	.018	115	073	.021	78	103
1 KHz 40 dB						
1	.040	208	098	.041	214	89
2	.030	057	101	.034	72	95
3	.024	247	097	.025	265	93
4	.014	007	081	.018	38	93
5	.012	036	092	.016	68	97
6	.008	105	080	.011	63	99
2 KHz 80 dB						
1	.034	043	091	.043	31	87
2	.030	156	092	.029	208	100
3	.024	241	095	.024	202	96
4	.014	296	080	.017	235	92
5	.012	049	094	.017	225	101
6	.008	053	094	.011	32	95
2 KHz 60 dB						
1	.040	241	085	.049	266	95
2	.030	118	098	.033	117	87
3	.028	260	087	.029	327	96
4	.018	313	078	.019	251	94
5	.012	054	095	.014	7	91
6	.008	105	084	.011	143	101

Table 5.66 Subject LL Left ear

	Results from post-stimulus data			Results from reconstructed data (scaling factor 0.2)		
HN	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o
500 Hz 80 dB						
1	.030	144	090	.033	231	93
2	.038	212	075	.033	202	93
3	.024	262	071	.023	264	87
4	.018	312	070	.018	306	94
5	.018	014	081	.020	43	102
6	.008	091	080	.011	139	94
500 Hz 60 dB						
1	.056	195	099	.060	252	92
2	.040	239	094	.039	268	87
3	.024	291	074	.033	110	100
4	.018	306	084	.020	18	97
5	.014	007	087	.017	15	87
6	.012	084	091	.013	52	91
500 Hz 40 dB						
1	.056	184	090	.052	145	94
2	.044	232	087	.042	258	94
3	.030	270	084	.029	242	89
4	.018	309	080	.019	335	95
5	.012	005	070	.015	17	97
6	.008	118	087	.012	172	104
500 Hz 20 dB						
1	.044	161	090	.051	188	91
2	.040	222	090	.038	230	90
3	.024	316	090	.028	291	94
4	.018	009	087	.020	23	77
5	.014	045	088	.019	36	93
6	.012	146	082	.012	173	92
500 Hz 10 dB						
1	.030	127	095	.034	70	102
2	.028	284	082	.029	269	89
3	.018	043	084	.022	55	83
4	.012	125	099	.016	105	91
5	.014	129	094	.018	112	96
6	.008	094	104	.011	142	94
1 KHz 20 dB						
1	.034	174	098	.047	188	88
2	.028	241	091	.039	277	96
3	.018	008	091	.020	24	100
4	.012	021	075	.015	31	94
5	.008	118	081	.013	71	97
6	.006	187	090	.009	242	103

Table 5.66 (contd.) Subject LL Left ear

	Results from post-stimulus data			Results from reconstructed data (scaling factor 0.2)		
HN	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o	Amplitude mean, V/Hz x 25000	Phase mean o	Phase S.D. o
2 KHz 80 dB						
1	.038	123	097	.043	91	98
2	.028	225	094	.038	251	96
3	.028	270	082	.027	282	89
4	.014	319	074	.018	312	96
5	.012	032	082	.014	83	91
6	.008	122	080	.012	128	93
2 KHz 20 dB						
1	.034	026	102	.039	343	82
2	.028	194	091	.035	191	96
3	.024	293	090	.022	318	98
4	.012	019	077	.015	29	89
5	.008	302	101	.012	316	100
6	.006	154	095	.010	104	99
2 KHz 10 dB						
1	.046	101	094	.051	63	97
2	.038	182	091	.033	199	98
3	.024	009	085	.022	299	105
4	.014	022	091	.018	174	100
5	.014	043	094	.016	35	91
6	.008	097	101	.013	253	105

Table 5.67

Significance tests on the results using scaling factor 0.2

Subject / Stimulus frequency	Stimulus level dB	Amplitude mean test	Phase mean test
AMcK			
500 Hz	60	NS	NS
	20	RSG 5%	NS
1 KHz	80	NS	NS
	40	RSG 2.5%	NS
2 KHz	80	RSG 5%	NS
	60	RSG 2.5%	NS
LL			
500 Hz	80	NS	RSG 2.5%
	60	RSG 5%	NS
	40	NS	RSG 2.5%
	20	RSG 5%	NS
	10	RSG 2.5%	NS
1 KHz	20	RSG 2.5%	NS
2 KHz	80	RSG 2.5%	RSG 2.5%
	20	RSG 5%	NS
	10	NS	RSG 5%

RSG Reconstructed data significantly greater than original data (followed by significance value).

NS No significant difference.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

The design, construction and testing of a microprocessor system for audiological work has been described. The system was used in fundamental studies concerning the generation of auditory evoked potentials in man.

The purpose of the system was to generate auditory stimuli and to analyze the vertex potentials so evoked, using the phase spectral method. The phase spectra of an ensemble of post-stimulus records are compared with each other to test whether there is evidence of phase aggregation. This is indicative of a response, and offers the prospect of a completely objective method of threshold measurement, in which respect it is unique.

Phase aggregation could be caused in one of two different ways. It could be due to synchronization between a multiplicity of neural units which together integrate to produce the electroencephalogram. On the other hand, the auditory evoked potentials could be generated by the addition of a response to normal unstimulated EEG. Phase aggregation would then be expected as an epiphenomenon.

The experimental work described in this thesis points very strongly to the conclusion that this 'additive hypothesis' is not sufficient to account for the amount of phase aggregation observed in practice, and that an alternative hypothesis should be proposed. This result has great significance in the study of brain function, as has been indicated by Stuart et al. (1979).

The requirements for a stimulus generator, specified in section 3.2 , and for a phase spectrum analyzer, have been completely satisfied. The stimulus generator has been in general use in a clinical setting for a range of audiometric tests. The phase spectral analysis technique for AEP detection has been demonstrated with a sample of twenty normal hearing subjects. The results obtained by this technique compare favourably with results obtained by the traditional visually-scored ensemble average method. It was not the purpose of this thesis to compare the two methods at very great length, as extensive clinical trials are at present in progress to investigate this matter (R. Child, personal communication). Rather, it was the intention to indicate that the phase spectral analyzer was capable of producing clinically useful results, before embarking upon the experimental work to test the additive hypothesis.

EEG records from two subjects were used in the additive hypothesis study. Out of 27 trials at a variety of stimulus levels and three different frequencies, 15 were selected for further consideration. These trials had produced pre-stimulus records which satisfied certain statistical tests for stationarity. To each pre-stimulus record was added the averaged post-stimulus record from the same trial. It was then shown that this procedure, which takes the additive hypothesis as the model for auditory evoked potential generation, produced significantly less phase aggregation than was observed in the post-stimulus records from the trial.

As a result of experience gained while using the system over a period of about a year, it is possible to make some suggestions for incorporation into any future design of the instrument. For example, it would be feasible to make it more self-contained. The 'Medelec' signal averager is used in conjunction with the present system purely in order to amplify and filter the EEG signal. This function could be performed by a physiological amplifier included as part of the phase analysis system. The data terminal at present employed to control the operation of the system, has more facilities than are strictly necessary. The cassette drives were needed during the development of the software, but as the software now resides in PROM they are seldom used. Only a small selection of the keys on the keyboard are used, so the data terminal could be replaced by a keypad with some twenty keys, and a cheap printer with a carriage width of perhaps 30 characters.

One point that remains somewhat unsettled is how to combine the 'phase standard deviation' results from each of six harmonics in order to arrive at a score for each trial, and inevitably to determine a threshold for the patient at a particular frequency. One method is indicated in this thesis. While this is a simple method, it is likely that it could be improved upon. The microprocessor could be programmed to carry out this procedure and to print the threshold at the end of a test.

The question remains as to which model should be postulated in place of the additive hypothesis. As Sayers and Beagley (1974) have pointed out, phase constraint in the frequency domain is perhaps more realistically envisaged as a synchronization process in the time domain. Elul (1968) has studied this type of synchronization model, and notes that if the number of generators is large, then a small increase in synchronization will result in a large increase in the EEG amplitude. The nature of the generators involved in the production of the EEG remains a matter for debate.

There is certainly scope for further studies in system identification to describe more precisely the nature of evoked potentials, and perhaps to arrive at a suitable model. In this respect the work of Reddy and Kirlin (1979) deserves mention. They used pseudorandom noise as a stimulus. They computed the power spectral density of the responses, and also the transfer function between stimulus and response. They observed frequency following responses similar to those described by Davis (1976). However, no unique transfer functions, either with respect to subject or to stimulus level, were obtained.

In the studies described in this thesis, as in the work of Reddy and Kirlin, the brain and ear have been regarded as a 'black box'. Further studies of this type will inevitably involve the processing of large masses of data. It has been shown how the microprocessor can be used as a valuable tool in pre-processing and reducing the data from such experimental work.

APPENDICES

Appendix A - Circuit diagrams and hardware details.

Appendix B - Flow charts.

Appendix C - Programmes.

Figure A1 - Microprocessor board

POWER SUPPLY PINS					
TYPE	VOLTS	-12	0V	-5	+12
8T15		8	7	–	14
8T16		–	7	14	–
8T96		–	8	16	–
8T97		–	8	16	–
8T98		–	8	16	–
4011		–	7	14	–
4030		–	7	14	–
8T26		–	8	16	–

STIMULUS GENERATOR
MICROPROCESSOR BOARD

Figure A.2

Data acquisition and display board.

DATA ACQUISITION AND DISPLAY BOARD

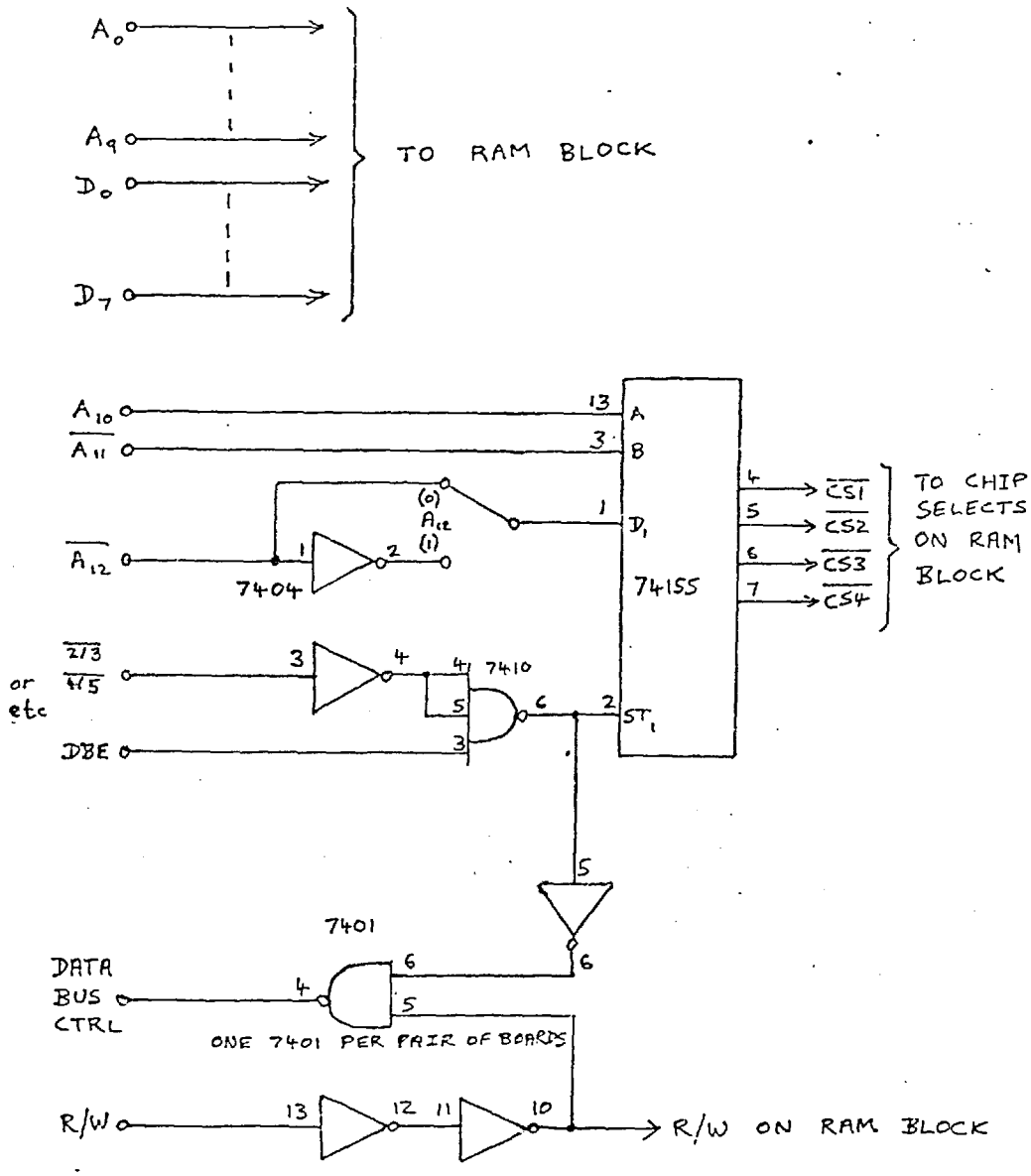


Figure A.3 4K byte memory board.

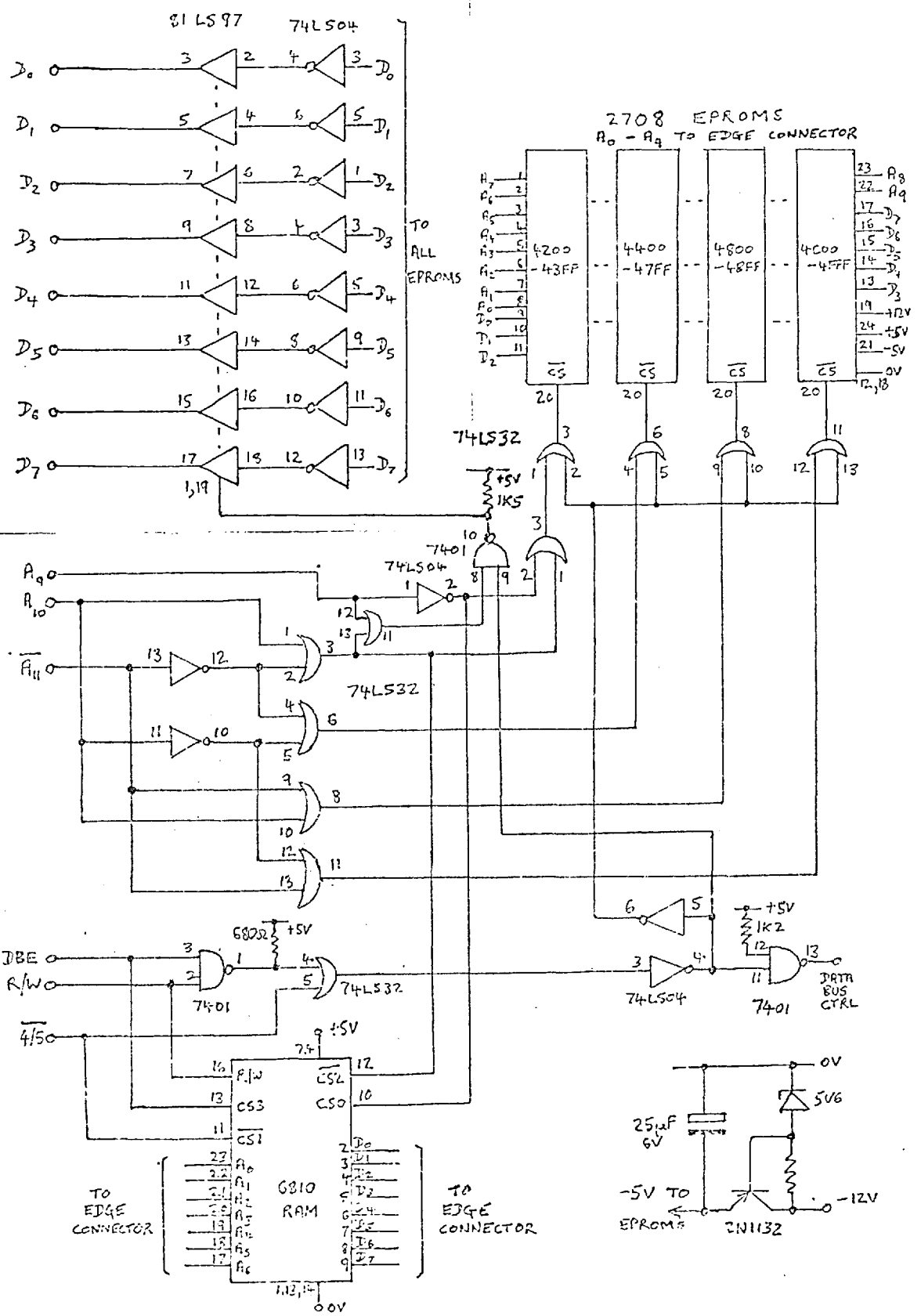


Figure A.4 Electrically programmable read-only memory (EPROM) board.

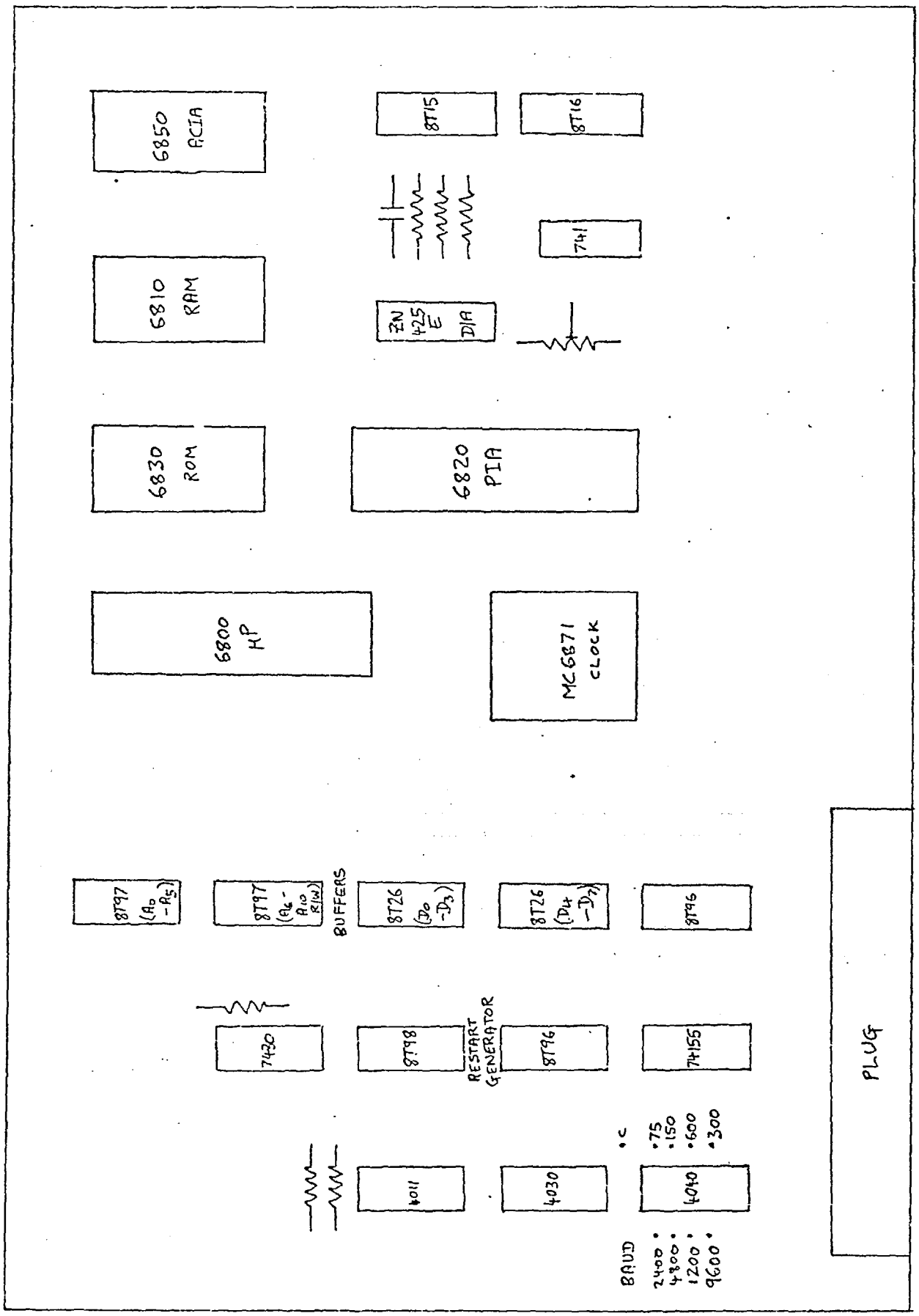


Figure A.5 - Microprocessor board layout.

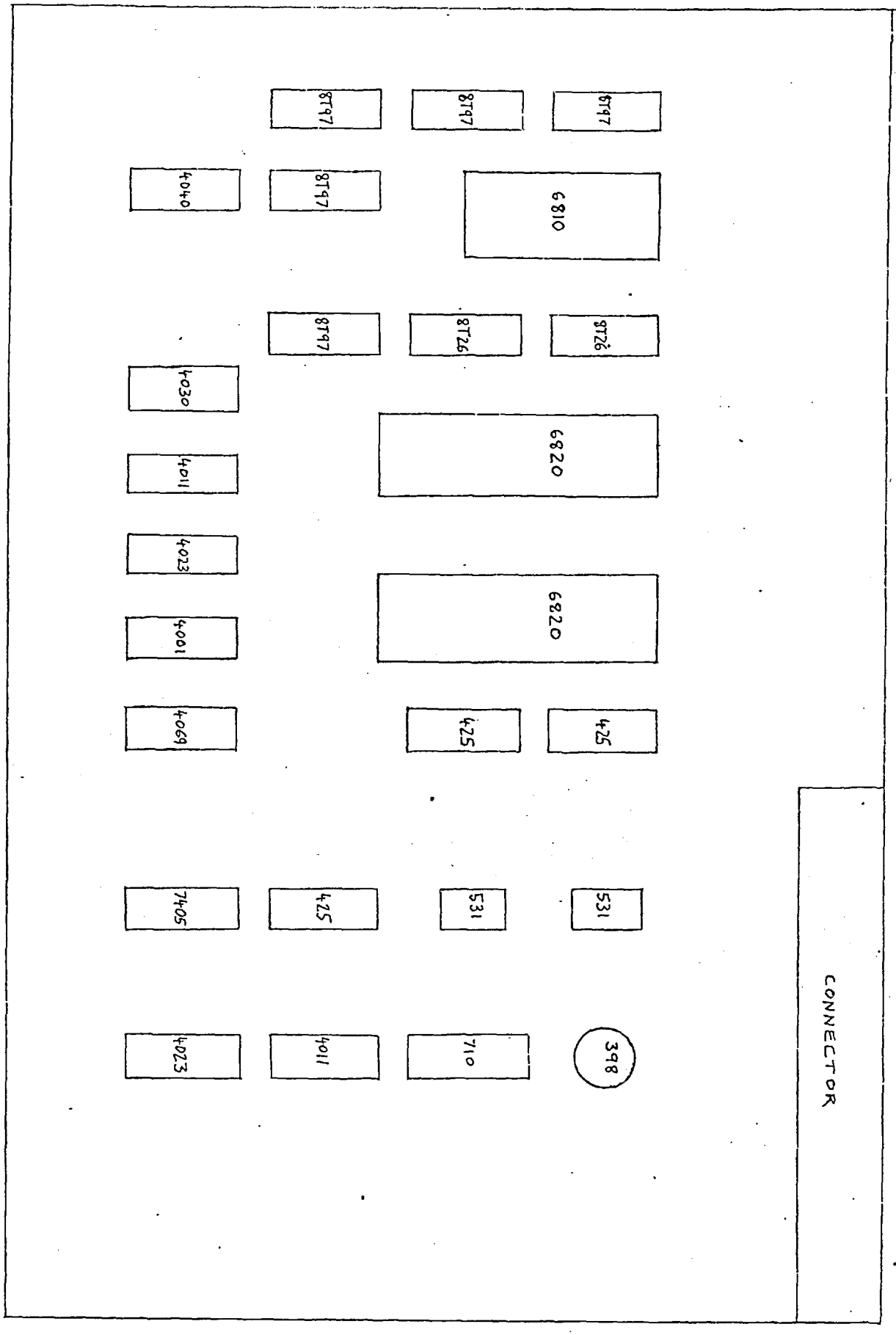


Figure A.6 - Data acqusition and display board: component layout.

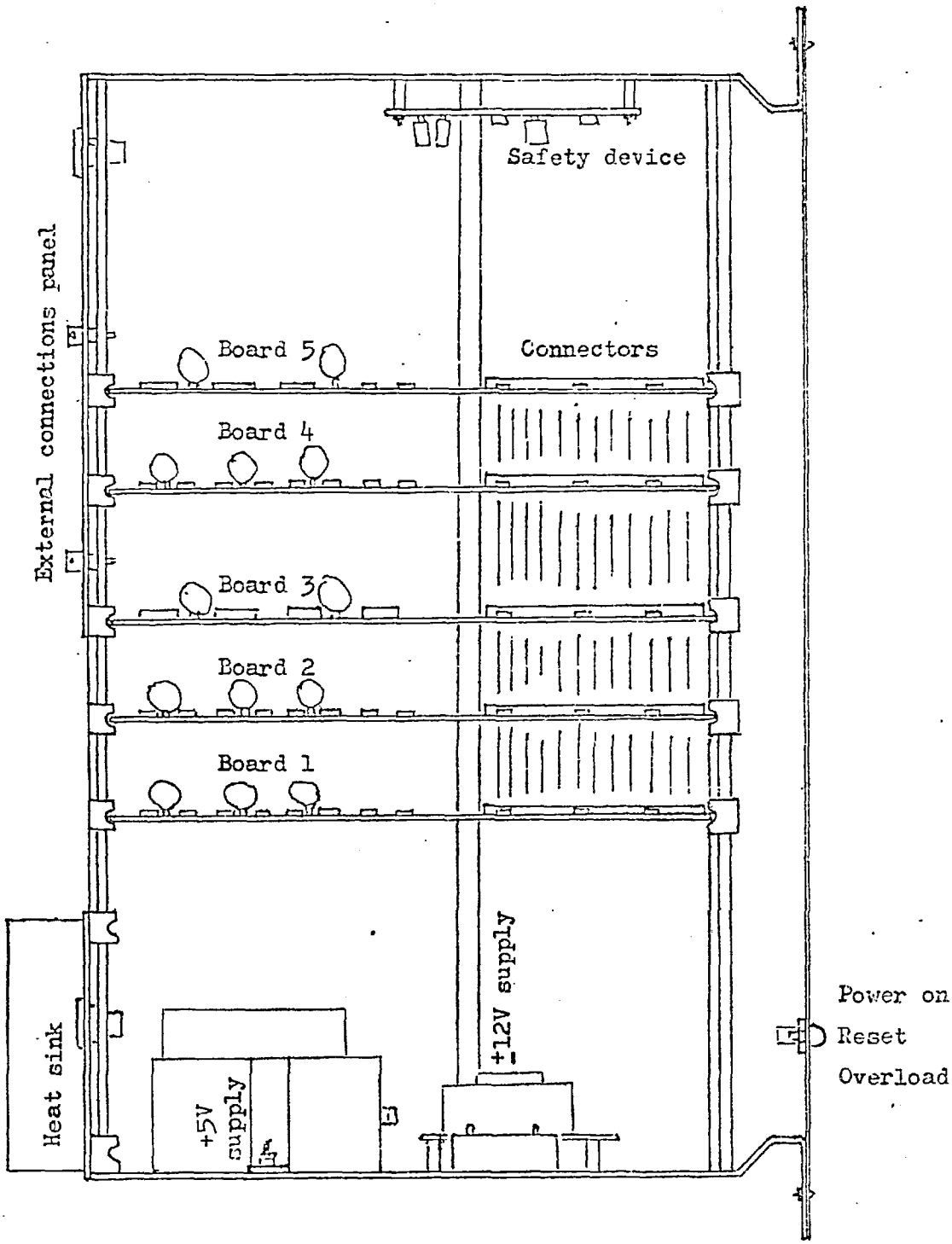
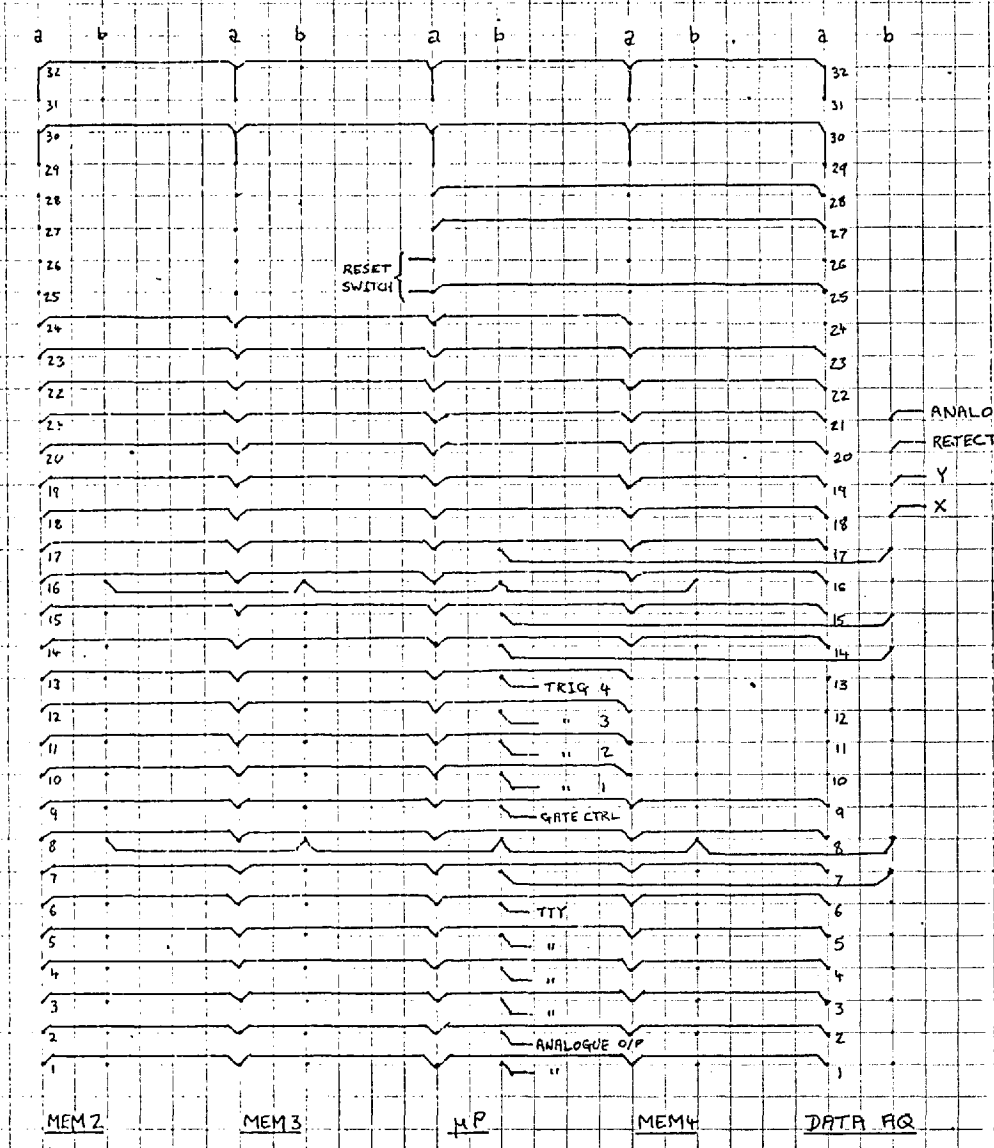


Figure A.7 Plan view of complete unit.

Board 1 : Memory 2000 - 2FFF Board 2 : Memory 3000 - 3FFF

Board 3 : Microprocessor Board 4 : Memory 4000 - 4FFF

Board 5 : Data acquisition and display



POWER SUPPLY THIS END

Figure A.8 - Board interconnections.

Pin	Function	Pin	Function
a1	Addr A0	b1	Analogue O/P
a2	A1	b2	Analogue OV
a3	A2	b3	TTY OV
a4	A3	b4	TTY Data In
a5	A4	b5	TTY Rdr Ctrl
a6	A5	b6	TTY Data Out
a7	A6	b7	$\overline{\text{IRQ}}$
a8	A7	b8	Data bus ctrl
a9	A8	b9	Gate Ctrl
a10	A9	b10	Trigger 1
a11	A10	b11	Trigger 2
a12	$\overline{\text{A11}}$	b12	Trigger 3
a13	$\overline{\text{A12}}$	b13	Trigger 4
a14	Data D0	b14	600 Hz
a15	D1	b15	76.8 kHz
a16	D2	b16	$\overline{4/5}$
a17	D3	b17	$\overline{\text{PIA}}$
a18	D4	b18	X
a19	D5	b19	Y
a20	D6	b20	Reject
a21	D7	b21	Analogue Input
a22	R/W		
a23	DBE		
a24	$\overline{2/3}$		
a25	Reset ON		
a26	Reset OFF		
a27	-12V		
a28	+12V		
a29	+5V		
a30	+5V		
a31	OV		
a32	OV		

Table A.1 - Function of board connector pins.

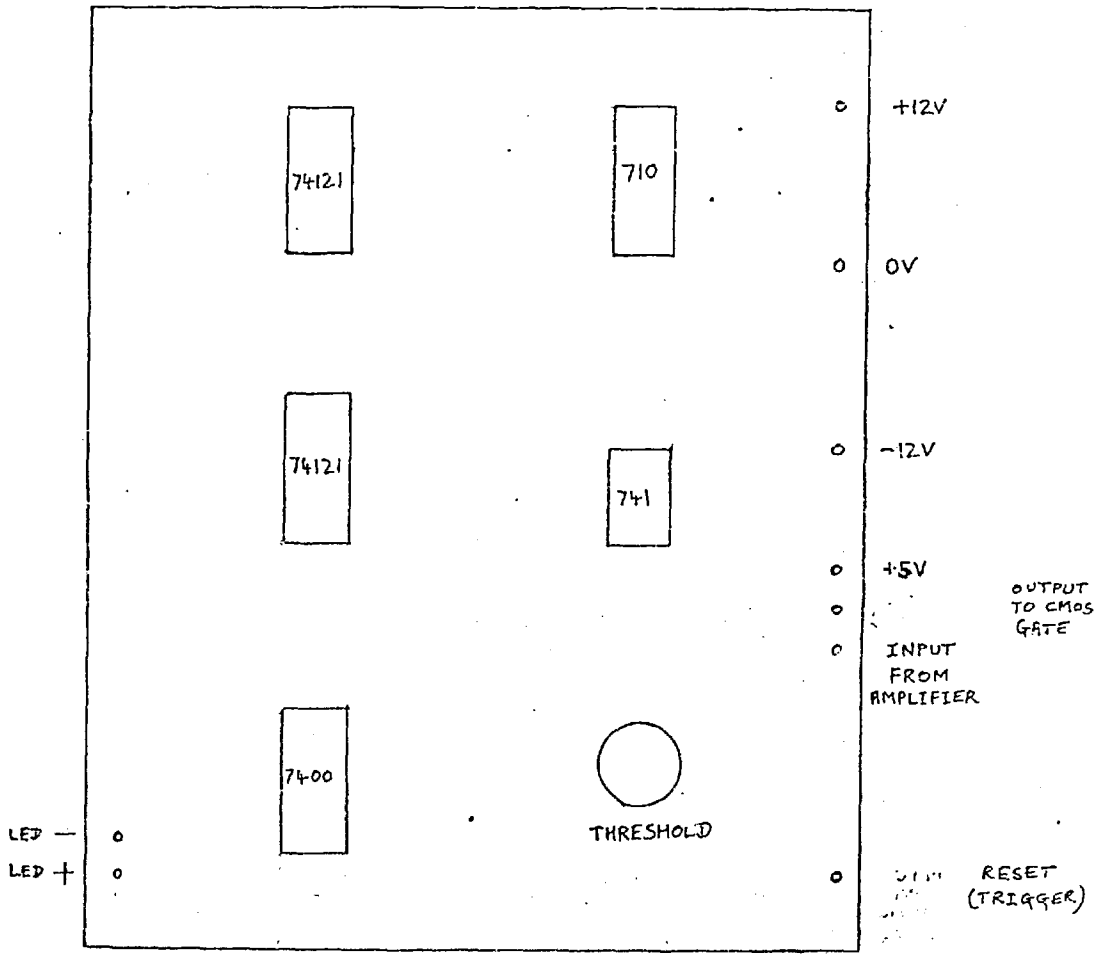


Figure A.9

Safety device- Component layout.

APPENDIX B

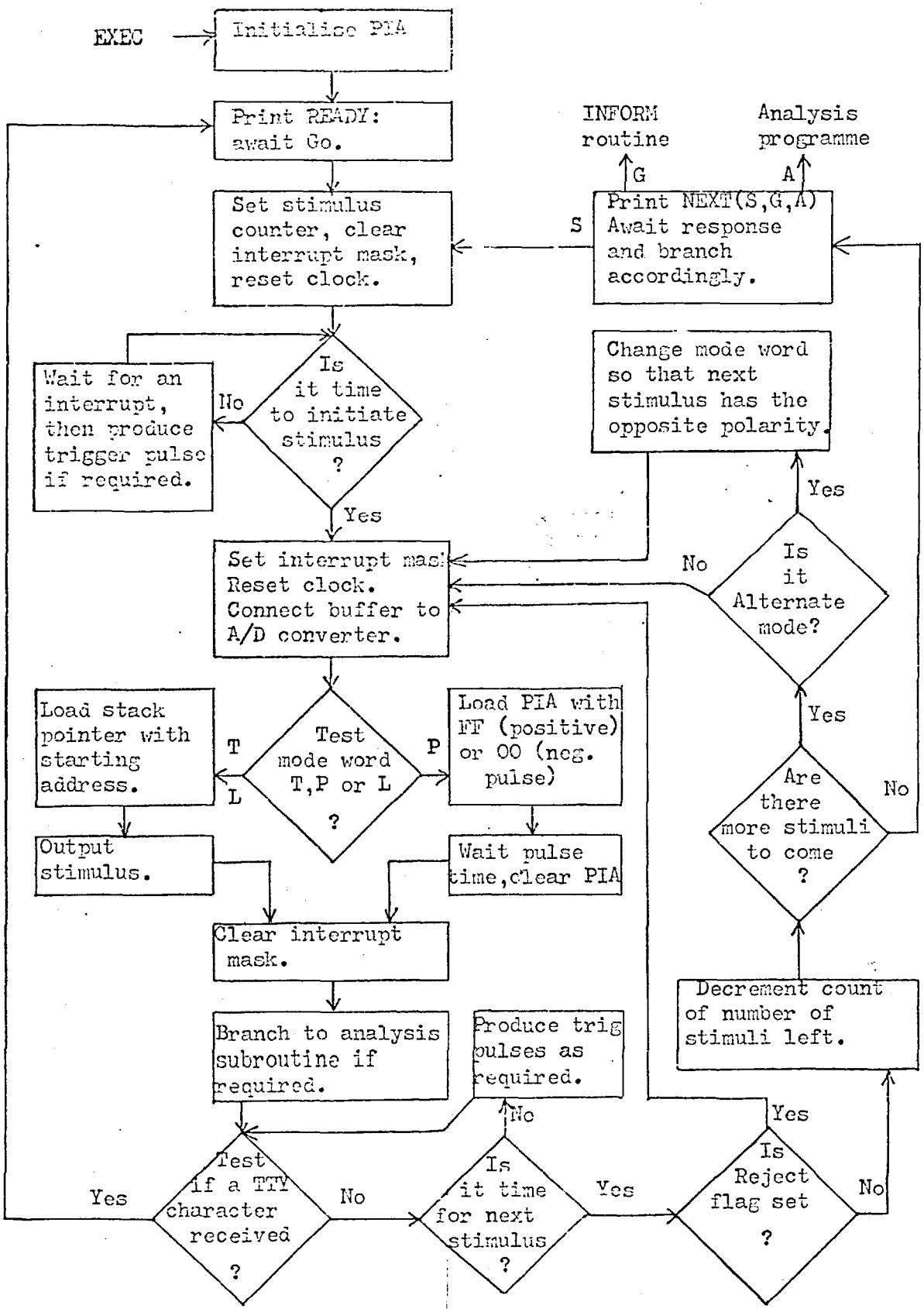


Figure B.1 Flow chart for EXEC routine.

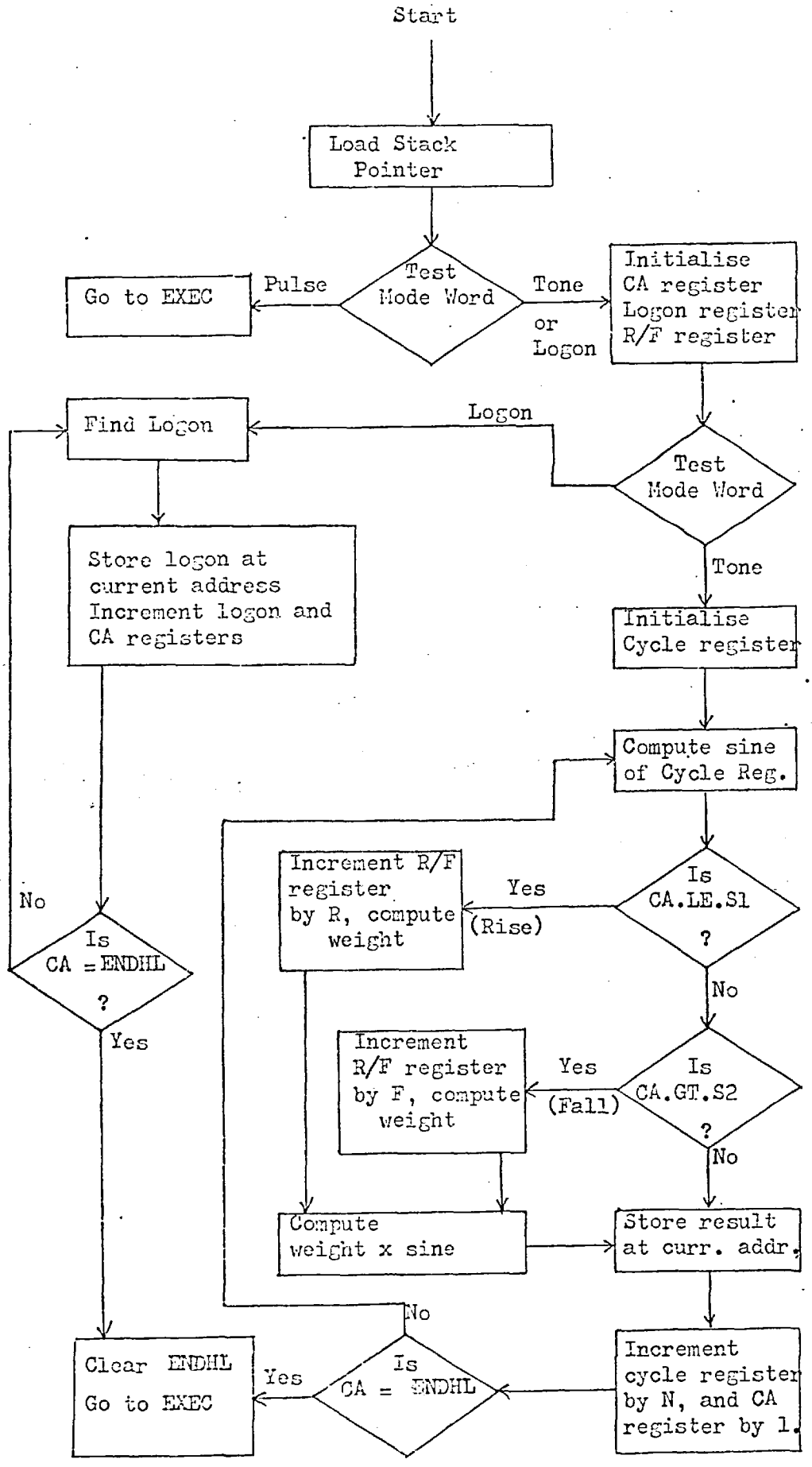


Figure B.2 Flow diagram for COMPIL routine.

Addr. in STIMB (Hex)	Mode		Address in STIMC
	Tone Mode	Logon Mode	
2000 2017	Data stored in INFORM programme		SCR SCR+23
2018 2019	CA Current address		SCR+24 SCR+25
201A 201B 201C	Rise/Fall register 3 bytes	201A not used Logon Register 2 bytes	 SCR+27 SCR+28
201D 201E 201F	Cycle Register 3 bytes		SCR+29 SCR+30 SCR+31
2020	Sine		SCR+32
2021	Weight		SCR+33
2022 2027	Scratch Area		SCR+34 SCR+39

Table B.1

Special registers used in COMPIL programme

(both STIMB and STIMC versions).

Address	Tone Mode	Pulse Mode	Logon Mode
SCR	Mode Word		
SCR+2 SCR+3	N Increment of cycle register		L Increment of logon register
SCR+4 SCR+5	S0 Starting addresss		S0 Starting address
SCR+6 SCR+7	S1 Address of end of rise section		
SCR+8 SCR+9	S2 Address of start of fall section		
SCR+10 SCR+11	R Increment of rise register	PU Pulse width	
SCR+12 SCR+13	F Increment of fall register		
SCR+15	P Period of repetition of stimuli		
SCR+16 SCR+17 SCR+18 SCR+19	TR1 Trigger times TR2 TR3 TR4		
SCR+20 SCR+21	NS Number of stimuli		
SCR+22 SCR+39	Scratch area 18 bytes		

Table B.2 Special registers used in INFORM routine (STIMC)

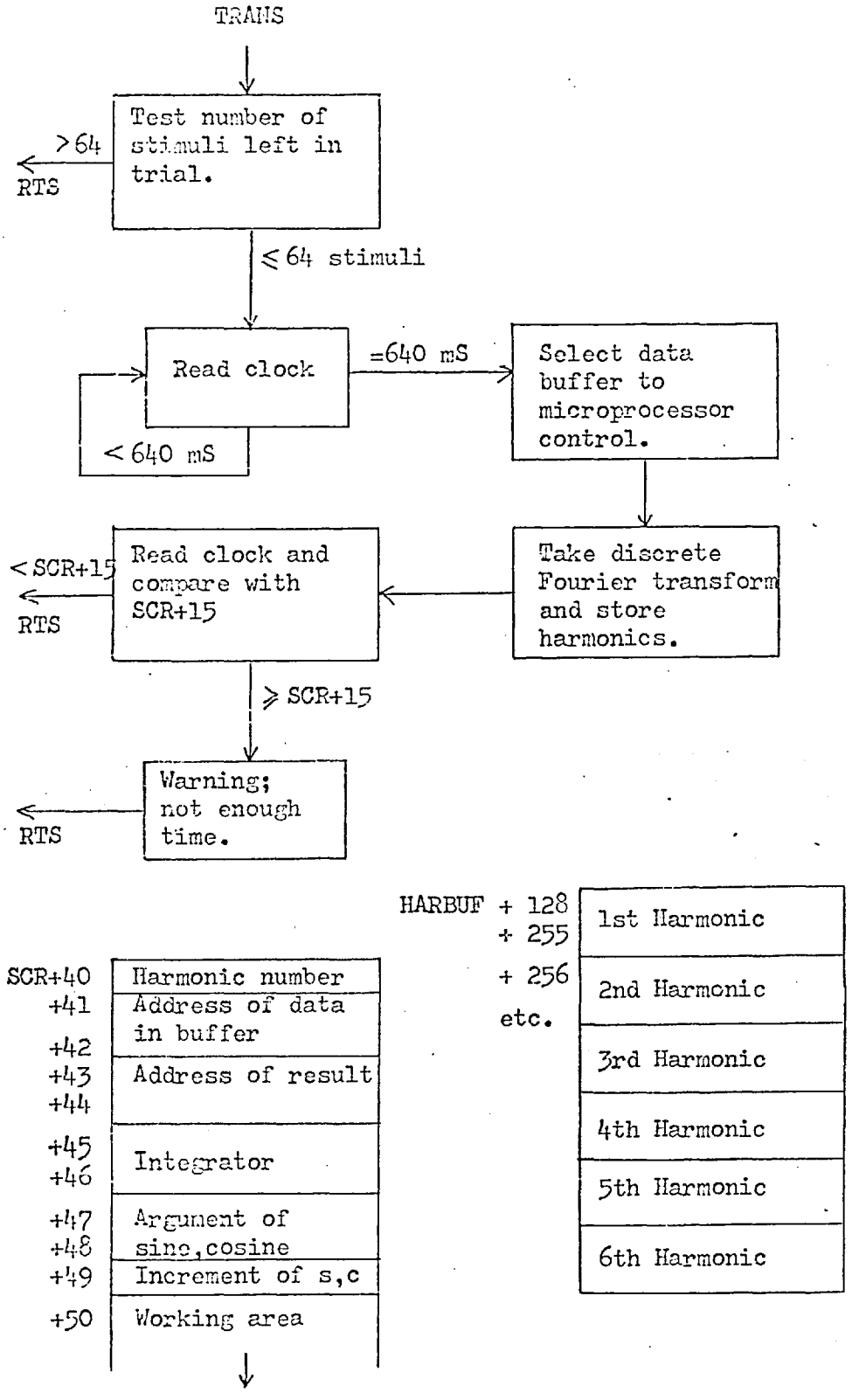
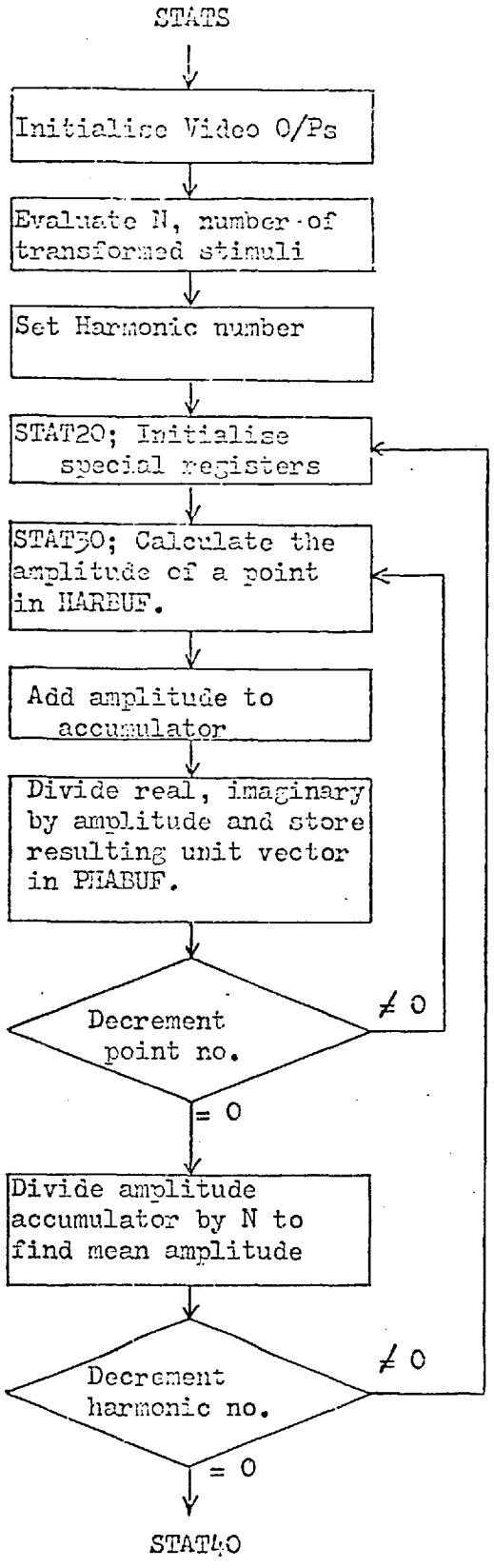


Figure B.3 Flow chart and special registers for TRANS subroutine.

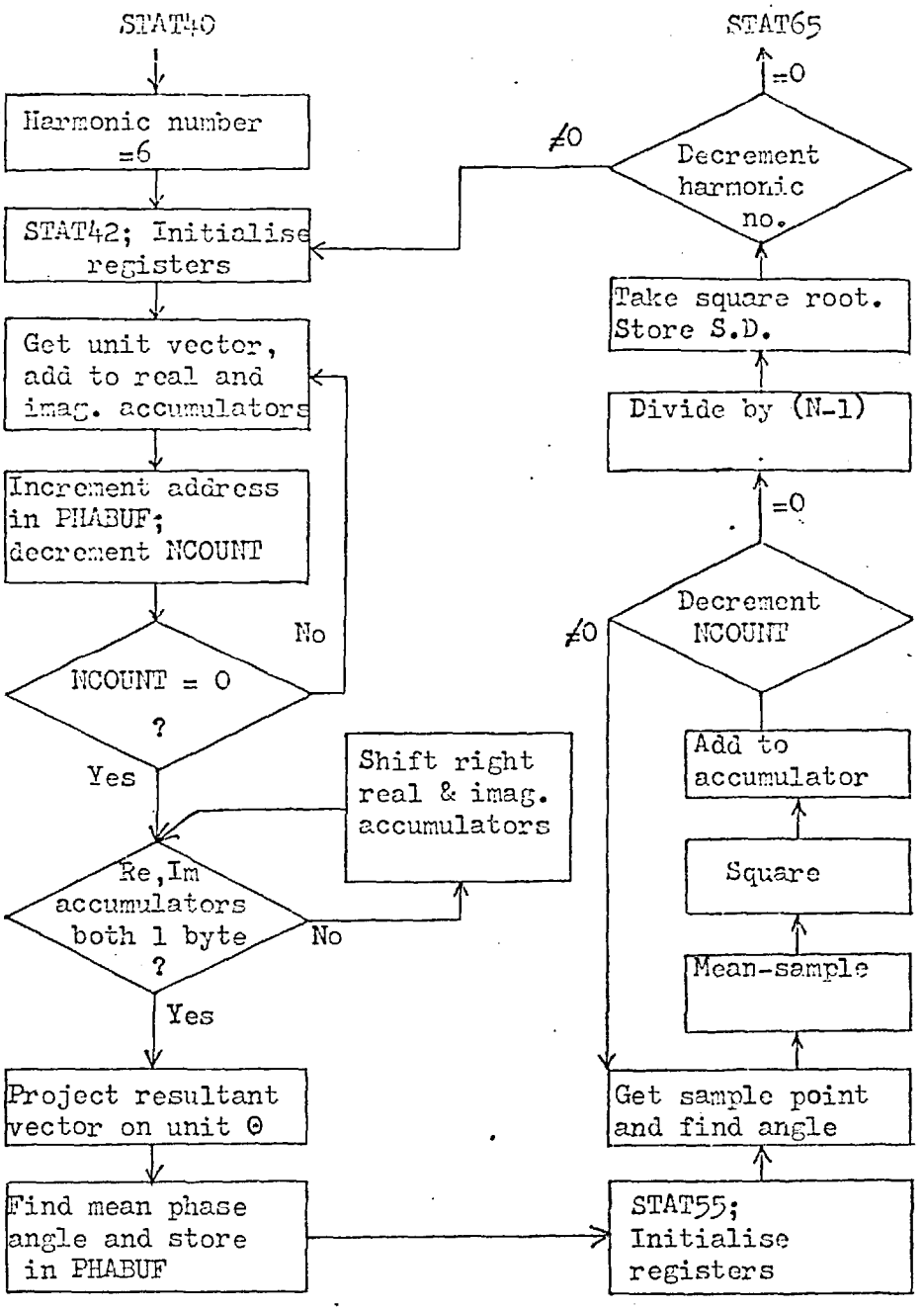


SCR +40	Harmonic Number
+41	N
+42 +43	Amplitude Accumulator
+44 +45	Address in HARBUF
+46 +47	Address in PHABUF
+48	N Count
+49	Amplitude
+50	Working Area

PHABUF +1	Harmonic 1 Mean Amplitude
+2	Harmonic 2 "
+3	Harmonic 3 "
+4	Harmonic 4 "
+5	Harmonic 5 "
+6	Harmonic 6 "

PHABUF+128	Harmonic 1 points projected onto unit circle
+255	
+256	Harmonic 2 "
+383	
+384	Harmonic 3 "
+511	
+512	4
etc.	
	5
	6

Figure B.4 Flow chart and special registers used in STAT20, STAT30



PHABUF +9	Harmonic 1 Mean Phase	
+10	H2	"
+11	H3	"
+12	H4	"
+13	H5	"
+14	H6	"

PHABUF +17	Harmonic 1 S.D.of phase	
+18	H2	"
+19	H3	"
+20	H4	"
+21	H5	"
+22	H6	"

Figure B.5 Flow chart and special registers for STAT40, STAT50.

PHABUF+24	X,Y coordinates of markers for mean, S.D.
PHABUF+127	

SCR+36	Working area
SCR+39	
SCR+40	Harmonic number
+41	No. of stimuli N
+42	Mean phase angle
+43	S.D. of phase ∠
+44	Address in MESBUF
+45	
+46	Address in PHABUF or HARBUF
+47	
+48	Addr of mean,S.D. and markers.
+49	
+50	Real mean or S.D.
+51	Imag mean or S.D.
+52	Amplitude

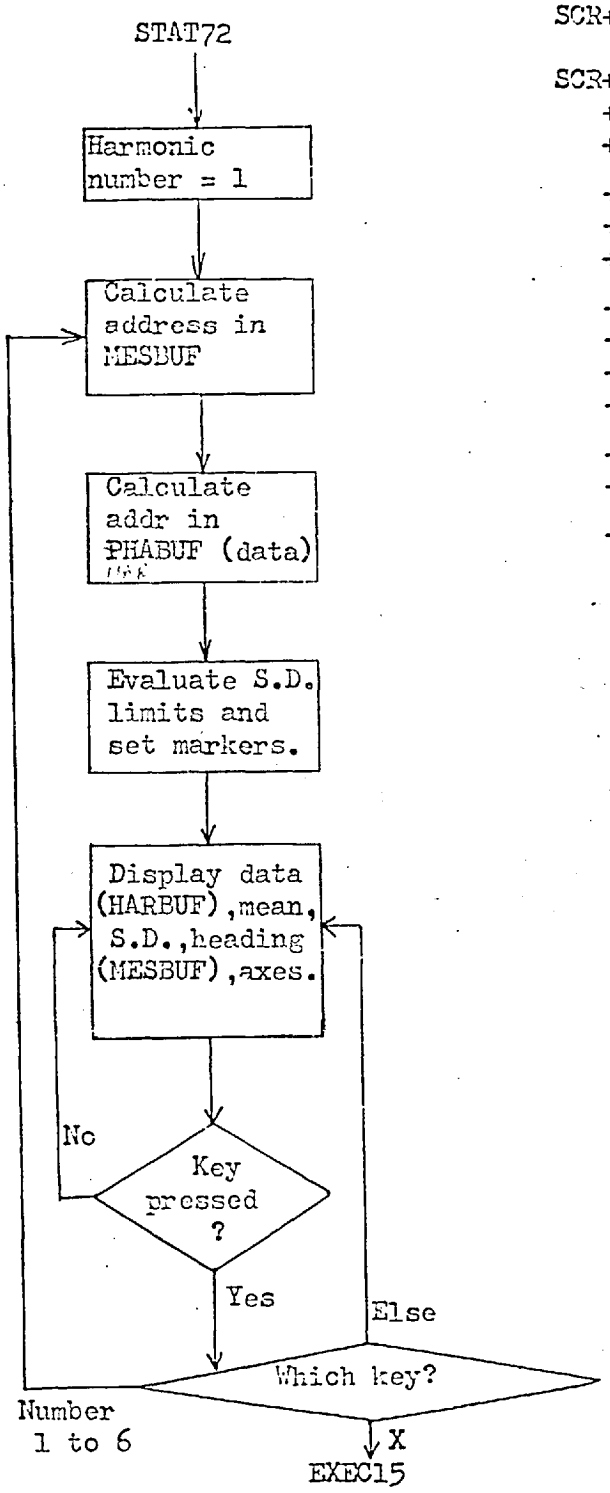


Figure B.6 Flow chart and special registers for STAT72 display routine.

APPENDIX C

Table C.1 - Stimulus Generator Programme

```
          M68SAM IS THE PROPERTY OF MOTOROLA SPD, INC.
             COPYRIGHT 1974 TO 1975 BY MOTOROLA INC

          MOTOROLA M6800 CROSS ASSEMBLER, RELEASE 1.2

00001                          NAM     STIMC
00002                     *STIMULUS GENERATOR PROGRAMME - PROM VERSION*
00003 0080                     ORG     $0080
00004 0080 0001           PIAA RMB     $01       AUDIO OUT
00005 0081 0001           PIACRA RMB   $01
00006 0082 0001           PIAB RMB     $01
00007 0083 0001           PIACRB RMB   $01
00008 0000                     ORG     $0000
00009 0000 0001           PIAC RMB     $01       TIME
00010 0001 0001           PIACRC RMB   $01
00011 0002 0001           PIAD RMB     $01
00012 0003 0001           PIACRD RMB   $01
00013 3A40                     ORG     $3A40
00014 3A40 0028           SCR  RMB     40        SCRATCH AREA
00015 FE00                     ORG     $FE00
00016 FE00 0001           INCH RMB     $01       IN MINIBUG
00017 FEAE                     ORG     $FEAE
00018 FEAE 0001           OUTCH RMB    $01
00019      0039           ENDHI EQU    $39
00020      00FF           ENDLO EQU    $FF
00021      39FF           ENDHL EQU    $39FF
00022      FF7F           STACK EQU    $FF7F
00023      0042           LOOKUP EQU   $42
00024                     *SINE/COSINE LOOKUP TABLE*
00025 4200                     ORG     $4200
00026 4200 8082                FDB     $8082,$8385,$8688,$898B
      4202 8385
      4204 8688
      4206 898B
00027 4208 8C8E                FDB     $8C8E,$9091,$9394,$9697
      420A 9091
      420C 9394
      420E 9697
00028 4210 999A                FDB     $999A,$9C9D,$9FA0,$A2A3
      4212 9C9D
      4214 9FA0
      4216 A2A3
00029 4218 A5A6                FDB     $A5A6,$A8A9,$ABAC,$AEAF
      421A A8A9
      421C ABAC
      421E AEAF
00030 4220 B1B2                FDB     $B1B2,$B3B5,$B6B8,$B9BA
      4222 B3B5
      4224 B6B8
      4226 B9BA
00031 4228 BCBD                FDB     $BCBD,$BFC0,$C1C3,$C4C5
      422A BFC0
```

```
                4220 C1C3
                422E C4C5
00032           4230 C7C8           FDB     $C7C8,$C9CA,$CCCD,$CECF
                4232 C9CA
                4234 CCCD
                4236 CECF
00033           4238 D1D2           FDB     $D1D2,$D3D4,$D5D6,$D8D9
                423A D3D4
                423C D5D6
                423E D8D9
00034           4240 DADB           FDB     $DADB,$DCDD,$DEDF,$E0E1
                4242 DCDD
                4244 DEDF
                4246 E0E1
00035           4248 E2E3           FDB     $E2E3,$E4E5,$E6E7,$E8E9
                424A E4E5
                424C E6E7
                424E E8E9
00036           4250 EAEA           FDB     $EAEA,$EBEC,$EDEE,$EFEF
                4252 EBEC
                4254 EDEE
                4256 EFEF
00037           4258 F0F1           FDB     $F0F1,$F1F2,$F3F3,$F4F5
                425A F1F2
                425C F3F3
                425E F4F5
00038           4260 F5F6           FDB     $F5F6,$F6F7,$F8F8,$F9F9
                4262 F6F7
                4264 F8F8
                4266 F9F9
00039           4268 FAFA           FDB     $FAFA,$FAFB,$FBFC,$FCFC
                426A FAFB
                426C FBFC
                426E FCFC
00040           4270 FDFD           FDB     $FDFD,$FDFD,$FEFE,$FEFE
                4272 FDFD
                4274 FEFE
                4276 FEFE
00041           4278 FEFF           FDB     $FEFF,$FFFF,$FFFF,$FFFF
                427A FFFF
                427C FFFF
                427E FFFF
00042                       *LOGON LOOKUP TABLE*
00043           4280 8080           FDB     $8080,$8080,$8080,$7F7F
                4282 8080
                4284 8080
                4286 7F7F
00044           4288 7F7E           FDB     $7F7E,$7E7D,$7D7C,$7B7A
                428A 7E7D
                428C 7D7C
                428E 7B7A
00045           4290 7978           FDB     $7978,$7775,$7472,$716F
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                42B2 7775
                42B4 7472
                42B6 716F
00046           42B8 6D65           FDB     $6D6B,$6A68,$6765,$6463
                42BA 6A69
                42BC 6765
                42BE 6463
00047           42C0 6363           FDB     $6363,$6364,$6567,$6A6D
                42C2 6364
                42C4 6567
                42C6 6A6D
00048           42C8 7175           FDB     $7175,$7A80,$868D,$959C
                42CA 7A80
                42CC 868D
                42CE 959C
00049           42D0 A5AD           FDB     $A59D,$B6BE,$C7CF,$D7DF
                42D2 B6BE
                42D4 C7CF
                42D6 D7DF
00050           42D8 E6EC           FDB     $E6EC,$F2F6,$FAFD,$FEFF,$FFFF
                42DA F2F6
                42DC FAFD
                42DE FEFF
                42E0 FFFF
00051                       *MESSAGE BUFFER*
00052           42E2 54     MSG1    FCC     17,TONE,PULSE,LOGON:
                42E3 4F
                42E4 4E
                42E5 45
                42E6 2C
                42E7 50
                42E8 55
                42E9 4C
                42EA 53
                42EB 45
                42EC 2C
                42ED 4C
                42EE 4F
                42EF 47
                42F0 4F
                42F1 4E
                42F2 3A
00053           42F3 45     MSG2    FCC     6,ERROR:
                42F4 52
                42F5 52
                42F6 4F
                42F7 52
                42F8 3A
00054           42F9 52     MSG3    FCC     13,REPT RATE HZ:
                42FA 45
                42FB 50
                42FC 54
```

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                42DD 20
                42DE 52
                42DF 41
                42E0 54
                42E1 45
                42E2 20
                42E3 48
                42E4 58
                42E5 3F
00055           42E6 52         MSG4    FCC     15,REPT PERIOD MS:
                42E7 45
                42E8 50
                42E9 54
                42EA 20
                42EB 50
                42EC 45
                42ED 52
                42EE 49
                42EF 4F
                42F0 44
                42F1 20
                42F2 4D
                42F3 53
                42F4 3A
00056           42F5 50         MSG5    FCC     15,PULSE WIDTH US:
                42F6 55
                42F7 4C
                42F8 53
                42F9 45
                42FA 20
                42FB 57
                42FC 49
                42FD 44
                42FE 54
                42FF 48
                4300 20
                4301 55
                4302 53
                4303 3A
00057           4304 50         MSG6    FCC     9,POLARITY:
                4305 4F
                4306 4C
                4307 41
                4308 52
                4309 49
                430A 54
                430B 59
                430C 3A
00058           430D 4C         MSG7    FCC     12,LOGON TO US:
                430E 4F
                430F 47
                4310 4F
```

```
                4311 4E
                4312 20
                4313 54
                4314 43
                4315 20
                4316 55
                4317 53
                4318 3A
00059' 4319 54          MSG8    FCC     13,TONE FREQ HZ:
                431A 4F
                431B 4E
                431C 45
                431D 20
                431E 46
                431F 52
                4320 45
                4321 51
                4322 20
                4323 48
                4324 5A
                4325 3A
00060  4326 54          MSG9    FCC     15,TONE PERIOD US:
                4327 4F
                4328 4E
                4329 45
                432A 20
                432B 50
                432C 45
                432D 52
                432E 49
                432F 4F
                4330 44
                4331 20
                4332 55
                4333 53
                4334 3A
00061  4335 42          MSG10   FCC     15,BURST WIDTH MS:
                4336 55
                4337 52
                4338 53
                4339 54
                433A 20
                433B 57
                433C 49
                433D 44
                433E 54
                433F 48
                4340 20
                4341 4D
                4342 53
                4343 3A
00062  4344 4E          MSG11   FCC     14:NO.OF STIMULI:
```

```
                4345 4F
                4346 2E
                4347 4F
                4348 46
                4349 20
                434A 53
                434B 54
                434C 49
                434D 4D
                434E 55
                434F 4C
                4350 49
                4351 3A
00063           4352 4E         MSG12   FCC     13,NO.OF CYCLES:
                4353 4F
                4354 2E
                4355 4F
                4356 46
                4357 20
                4358 43
                4359 59
                435A 43
                435B 4C
                435C 45
                435D 53
                435E 3A
00064           435F 52         MSG13   FCC     13,RISE TIME MS:
                4360 49
                4361 53
                4362 45
                4363 20
                4364 54
                4365 49
                4366 4D
                4367 45
                4368 20
                4369 4D
                436A 53
                436B 3A
00065           436C 46         MSG14   FCC     13,FALL TIME MS:
                436D 41
                436E 4C
                436F 4C
                4370 20
                4371 54
                4372 49
                4373 4D
                4374 45
                4375 20
                4376 4D
                4377 53
                4378 3A
```

```
00066 4379 20      MSG15  FCC    14, TRIG TIME MS:
      437A 54
      437B 52
      437C 49
      437D 47
      437E 20
      437F 54
      4380 49
      4381 4D
      4382 45
      4383 20
      4384 4D
      4385 53
      4386 3A
00067 4387 52      MSG17  FCC    6,READY:
      4388 45
      4389 41
      438A 44
      438B 59
      438C 3A
00068 438D 4E      MSG18  FCC    12,NEXT(S,G,A):
      438E 45
      438F 58
      4390 54
      4391 28
      4392 53
      4393 2C
      4394 47
      4395 2C
      4396 41
      4397 29
      4398 3A
00069                 *PROGRAMME FOR ENTERING
00070                 *INFORMATION ABOUT REQUIRED STIMULUS
00071 4399 0F      INFORM SEI
00072 439A 8E FF7F        LDS    ?STACK
00073 439D CE 4344        LDX    ?MSG11
00074 43A0 8D 36          BSR    OUTS
00075 43A2 CE 3A58        LDX    ?SCR+24
00076 43A5 BD 4642        JSR    INDEC      GET NO. OF STIMULI
00077 43A8 2A 03          BPL    INFOR1
00078 43AA 7E 446C        JMP    MODE5      BRANCH ON 'X'
00079 43AD 22 09   INFOR1 BHI    RATE       BRANCH ON '='
00080 43AF FE 3A58        LDX    SCR+24
00081 43B2 FF 3A54        STX    SCR+20     TEST FOR SINGLE
00082 43B5 09             DEX               STIMULUS
00083 43B6 27 74          BEQ    MODE
00084 43B8 CE 4209 RATE   LDX    ?MSG3
00085 43BB 8D 1B          BSR    OUTS       REPT RATE HZ
00086 43BD CE 3A5A        LDX    ?SCR+26
00087 43C0 BD 4642        JSR    INDEC
00088 43C3 2B 16          BMI    RATE2
```

```
00089 43C5 22 65          BHI    MODE
00090 43C7 09       RATE1 DEX
00091 43C8 09             DEX              X=SCR+24
00092 43C9 6F 00          CLR    0,X
00093 43CB 6F 05          CLR    5,X
00094 43CD 86 64          LDA A  #$64
00095 43CF A7 01          STA A  1,X
00096 43D1 BD 46B4        JSR    INP       CALCULATE REPT PERIOD
00097 43D4 25 E2          BCS    RATE      IN UNITS OF 10 MS
00098 43D6 20 17          BRA    RAT54
00099 43D8 7E 4632 OUTS   JMP    OUTSTR
00100 43DB CE 42E6 RATE2  LDX    #MSG4     HERE IF INPUTTING
00101 43DE BD 4636        JSR    OUTST1    REPT PERIOD IN MS
00102 43E1 CE 3A58        LDX    #SCR+24
00103 43E4 8D 7A          BSR    IND
00104 43E6 2B D0          BMI    RATE
00105 43E8 22 42          BHI    MODE
00106 43EA BD 4498        JSR    DPD10
00107 43ED 25 EC          BCS    RATE2
00108 43EF A6 05    RATE4 LDA A  5,X       STORE REPT PERIOD P
00109 43F1 B7 3A4F        STA A  SCR+15     IN SCR+15
00110 43F4 CE 3A50 TRIG   LDX    #SCR+16
00111 43F7 FF 3A60        STX    SCR+32
00112 43FA 86 31          LDA A  #$31       ASCII '1'
00113 43FC B7 3A5F TRIG1  STA A  SCR+31
00114 43FF 36             PSH A
00115 4400 BD 467C        JSR    OUTLFC
00116 4403 32             PUL A
00117 4404 BD FEAE        JSR    OUTCH
00118 4407 CE 4379        LDX    #MSG15
00119 440A BD 4638        JSR    OUTST2
00120 440D CE 3A58        LDX    #SCR+24
00121 4410 8D 4F          BSR    IND
00122 4412 22 0D          BHI    TRIG2
00123 4414 BD 4498        JSR    DPD10
00124 4417 B6 3A4F        LDA A  SCR+15
00125 441A A0 05          SUB A  5,X
00126 441C FE 3A60        LDX    SCR+32
00127 441F A7 00          STA A  0,X
00128 4421 7C 3A61 TRIG2  INC    SCR+33
00129 4424 B6 3A5F        LDA A  SCR+31
00130 4427 4C             INC A
00131 4428 81 35          CMP A  #$35
00132 442A 26 D0          BNE    TRIG1
00133 442C CE 42C2 MODE   LDX    #MSG1
00134 442F 8D A7          BSR    OUTS      TONE,PULSE,LOGON
00135 4431 BD 4688        JSR    INCHA
00136 4434 86 01          LDA A  #$01
00137 4436 C1 50          CMP B  #$50       PULSE
00138 4438 27 0C          BEQ    MODE2
00139 443A C1 4C          CMP B  #$4C       LOGON
00140 443C 27 06          BEQ    MODE1
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00141 443E C1 54          CMP B  #$54      TONE
00142 4440 26 EA          BNE    MODE
00143 4442 48             ASL A
00144 4443 48             ASL A
00145 4444 48       MODE1 ASL A
00146 4445 48             ASL A
00147 4446 B7 3A40 MODE2  STA A  SCR       STORE MODE WORD
00148 4449 CE 4304 MODE3  LDX    #MSG6    POLARITY
00149 444C BD 4636        JSR    OUTSTI
00150 444F BD 4688        JSR    INCHA
00151 4452 C1 50          CMP B  #$50      POSITIVE
00152 4454 27 16          BEQ    MODE5
00153 4456 B6 3A40        LDA A  SCR
00154 4459 C1 4E          CMP B  #$4E      NEGATIVE
00155 445B 26 06          BNE    MODE4
00156 445D 48             ASL A
00157 445E 20 09          BRA    MODE6
00158 4460 7E 4642 IND    JMP    INDEC
00159 4463 C1 41    MODE4 CMP B  #$41      ALTERNATE
00160 4465 26 E2          BNE    MODE3
00161 4467 8B 80          ADD A  #$80
00162 4469 B7 3A40 MODE6  STA A  SCR
00163 446C B6 3A40 MODE5  LDA A  SCR       TEST MODE WORD
00164 446F 85 03          BIT A  #$03
00165 4471 26 22          BNE    PUL
00166 4473 85 0C          BIT A  #$0C
00167 4475 26 1B          BNE    LOG
00168                     *HERE IF TONE BURST SELECTED*
00169 4477 CE 4319 TONE   LDX    #MSG8
00170 447A BD 4632        JSR    OUTSTR    TONE FREQ HZ
00171 447D CE 3A58        LDX    #SCR+24
00172 4480 8D DE          BSR    IND
00173 4482 2B 1F          BMI    TONE2
00174 4484 22 44          BHI    TWIDTH
00175 4486 86 01    TONE1 LDA A  #$01
00176 4488 A7 02          STA A  2,X       X1024/257
00177 448A A7 03          STA A  3,X
00178 448C 86 0A          LDA A  #$0A
00179 448E A7 06          STA A  6,X
00180 4490 20 2E          BRA    TONE4
00181 4492 7E 45E3 LOG    JMP    LOGON
00182 4495 7E 45BF PUL    JMP    PULSE
00183 4498 6F 02    DPD10 CLR    2,X       DIVIDE BY 10
00184 449A 6F 06          CLR    6,X
00185 449C 86 0A          LDA A  #$0A
00186 449E A7 03          STA A  3,X
00187 44A0 7E 4654 DPD1   JMP    DPD
00188 44A3 CE 4325 TONE2  LDX    #MSG5     TONE PERIOD US
00189 44A6 BD 4636        JSR    OUTSTI
00190 44A9 CE 3A5A        LDX    #SCR+26
00191 44AC 8D B2          BSR    IND
00192 44AE 2B C7          BMI    TONE
```

```
00193 44B0 22 18          BHI    TWIDTH
00194 44B2 09       TONE3 DEX
00195 44B3 09             DEX
00196 44B4 86 F3          LDA A  ?$F3
00197 44B6 A7 00          STA A  0,X
00198 44B8 86 30          LDA A  ?$30       DIVIDEND IS
00199 44BA A7 01          STA A  1,X        62256 X 64
00200 44BC 86 06          LDA A  ?$06
00201 44BE A7 06          STA A  6,X
00202 44C0 8D DE    TONE4 BSR    DPD1
00203 44C2 25 E3          BCS    TONE
00204 44C4 FE 3A5C        LDX    SCR+28
00205 44C7 FF 3A42        STX    SCR+2
00206                     *INPUT WIDTH OF TONE BURST*
00207 44C9 CE 4335 TWIDTH LDX    ?MSG10    BURST WIDTH MS
00208 44CD BD 4560        JSR    PF
00209 44D0 25 F8          BCS    TWIDTH
00210 44D2 29 32          BVS    RISE
00211 44D4 86 19    TWID6 LDA A  ?$19
00212 44D6 A1 04          CMP A  4,X        CHECK NO. OF
00213 44D8 24 07          BCC    TWID7      SAMPLES<$1A00
00214 44DA CE 42D3 TWID2  LDX    ?MSG2      ERROR
00215 44DD 8D 4C          BSR    OUTS1
00216 44DF 20 E9          BRA    TWIDTH
00217 44E1 CE 3A40 TWID7  LDX    ?SCR
00218 44E4 86 39          LDA A  ?ENDHI     LAST POINT
00219 44E6 C6 FF          LDA B  ?ENDLO
00220 44E8 E0 1D          SUB B  29,X
00221 44EA A2 1C          SBC A  28,X
00222 44EC A7 04          STA A  4,X
00223 44EE E7 05          STA B  5,X        CALCULATE START
00224 44F0 CE 3A5C        LDX    ?SCR+28     ADDRESS SO
00225 44F3 86 02          LDA A  ?$02
00226 44F5 A7 02          STA A  2,X
00227 44F7 86 92          LDA A  ?$92
00228 44F9 A7 03          STA A  3,X
00229 44FB 6F 06          CLR    6,X        CONVERT TO
00230 44FD 8D A1          BSR    DPD1       10 MS UNITS
00231 44FF B6 3A4F        LDA A  SCR+15
00232 4502 A1 05          CMP A  5,X        CHECK TONE WIDTH
00233 4504 25 D4          BCS    TWID2      <=REPT PERIOD
00234                     *INPUT RISE TIME*
00235 4506 CE 435F RISE   LDX    ?MSG13     RISE TIME MS
00236 4509 8D 62          BSR    PF
00237 450B 25 F9          BCS    RISE
00238 450D 29 2B          BVS    FALL
00239 450F CE 3A40 PISE1  LDX    ?SCR
00240 4512 A6 1C          LDA A  28,X       SR IN SCR+28,29
00241 4514 E6 1D          LDA B  29,X
00242 4516 EB 05          ADD B  5,X        ADD SR+S0
00243 4518 A9 04          ADC A  4,X
00244 451A 81 39          CMP A  ?ENDHI     CHECK RISE TIME
```

```
00245 451C 25 10          BCS    RISE5    LESS THAN TOTAL TIME
00246 451E 26 04          BNE    RISE4
00247 4520 C1 FF          CMP B  ?ENDLO
00248 4522 25 0A          BCS    RISE5
00249 4524 CE 42D3 RISE4  LDX    ?MSG2
00250 4527 8D 02          BSR    OUTS1    ERROR
00251 4529 20 DB          BRA    RISE
00252 452B 7E 4632 OUTS1  JMP    OUTSTR
00253 452E A7 06    RISE5 STA A  6,X       S1,START ADDRESS
00254 4530 E7 07          STA B  7,X       OF PLATEAU
00255 4532 8D 76    RISE6 BSR    RFINC
00256 4534 FE 3A5E        LDX    SCR+30    CALCULATE R
00257 4537 FF 3A4A        STX    SCR+10    INCREMENT OF RISE
00258                     *INPUT FALL TIME*
00259 453A CE 436C FALL   LDX    ?MSG14    FALL TIME MS
00260 453D 8D 2E          BSR    PF
00261 453F 25 F9          BCS    FALL
00262 4541 29 28          BVS    FALL7
00263 4543 C5 3A40 FALL1  LDX    ?SCP      SF IN SCR+28,29
00264 4546 86 39          LDA A  ?ENDHI
00265 4548 C6 FF          LDA B  ?ENDLO
00266 454A E0 1D          SUB B  29,X
00267 454C A2 1C          SBC A  28,X       COMPUTE S2
00268 454E A1 06          CMP A  6,X        START ADDRESS OF
00269 4550 25 06          BCS    FALL5      FALL SECTION
00270 4552 26 0B          BNE    FALL6
00271 4554 E1 07          CMP B  7,X        CHECK S2>=S1
00272 4556 24 07          BCC    FALL6
00273 4558 CE 42D3 FALL5  LDX    ?MSG2     ERROR
00274 455B 8D CE          BSR    OUTS1
00275 455D 20 DB          BRA    FALL
00276 455F A7 08    FALL6 STA A  8,X
00277 4561 E7 09          STA B  9,X
00278 4563 8D 45          BSR    RFINC     CALCULATE F
00279 4565 FE 3A5E        LDX    SCR+30    INCREMENT OF FALL
00280 4568 FF 3A4C        STX    SCR+12
00281 456B 20 74    FALL7 BRA    PULSE1
00282                     *RF SUBROUTINE FOR INPUT OF BURST WIDTH, *
00283                     *RISE AND FALL TIMES*
00284                     *ON EXIT: IF CARRY SET, RETURN TO*
00285                     *BEGINNING: CARRY NOT SET,OV SET--*
00286                     *JUMP TO NEXT SECTION,OTHERWISE CONTINUE*
00287 456D 8D BC    RF    BSR    OUTS1
00288 456F CE 3A58        LDX    ?SCR+24
00289 4572 FD 4642        JSR    INDFC
00290 4575 2B 12          BMI    RF2
00291 4577 22 2D          BHI    RF4
00292 4579 6D 00    RF1   TST    0,X        TEST < 256
00293 457B 26 2B          BNE    RF5
00294 457D 86 42          LDA A  ?$42
00295 457F F6 01          LDA B  1,X
00296 4581 BD 46F3        JSR    MULT
```

```
00297 45B4 A7 04          STA A  4,X       CONVERT FROM MS
00298 45B6 E7 05          STA B  5,X       TO SAMPLE PERIODS
00299 45B8 39             RTS
00300 45B9 CE 43D2 RF2    LDX    ?MSG12    NO. OF CYCLES
00301 45BC BD 4636        JSR    OUTST1
00302 45BF CE 3A58        LDX    ?SCR+24
00303 45C2 BD 4642        JSR    INDEC
00304 45C5 26 11          BNE    RF5
00305 45C7 86 12          LDA A  ?$12
00306 45C9 A7 06          STA A  6,X
00307 45CB FE 3A42        LDX    SCR+2
00308 45CE FF 3A5A        STX    SCR+26
00309 45D1 CE 3A58        LDX    ?SCR+24
00310 45D4 20 16    RF6   BRA    DPD2
00311 45D6 08       RF4   SEV
00312 45D7 39             RTS
00313 45D8 0D       RF5   SEC
00314 45D9 39       RF7   RTS
00315                     *RFINC SUBROUTINE CALCULATES*
00316                     *R OR F, INCREMENT OF RISE,FALL*
00317                     *REGISTER*
00318 45DA FE 3A5C RFINC  LDX    SCR+28
00319 45DD 27 FA          BEQ    RF7
00320 45DF CE 3A5A        LDX    ?SCR+26
00321 45E2 86 80          LDA A  ?$80
00322 45E4 A7 00          STA A  0,X
00323 45E6 6F 01          CLR    1,X
00324 45E8 86 02          LDA A  ?$02
00325 45EA A7 06          STA A  6,X
00326 45EC 7E 46D4 DPD2   JMP    DPD
00327                     *HERE IF PULSE MODE SELECTED*
00328 45EF CE 42F5 PULSE  LDX    ?MSG5     PULSE WIDTH US
00329 45C2 8D 6E          BSR    OUTSTR
00330 45C4 CE 3A58        LDX    ?SCR+24
00331 45C7 8D 79          BSR    INDEC
00332 45C9 2B F4          BMI    PULSE
00333 45CB 22 62          BHI    LOGON1
00334 45CD 86 3C          LDA A  ?$3C
00335 45CF A7 02          STA A  2,X
00336 45D1 86 C4          LDA A  ?$C4
00337 45D3 A7 03          STA A  3,X
00338 45D5 86 0A          LDA A  ?$0A
00339 45D7 A7 06          STA A  6,X
00340 45D9 8D E1          BSR    DPD2      COMPUTE PU
00341 45DB FE 3A5C        LDX    SCR+28    PULSE WIDTH IN
00342 45DF FF 3A4A        STX    SCR+10    SAMPLE PERIODS
00343 45E1 20 4C    PULSE1 BRA    LOGON1
00344                     *HERE IF LOGON MODE SELECTED*
00345 45E3 CE 43AD LOGON  LDX    ?MSG7     LOGON TO US
00346 45E6 8D 4A          BSR    OUTSTR
00347 45E8 CE 3A5A        LDX    ?SCR+26
00348 45EB 8D 55          BSR    INDEC
```

```
00349 45ED 2B F4          BMI     LOGDN.
00350 45EF 22 3E          BHI     LOGDN1
00351 45F1 09             DEX
00352 45F2 09             DEX
00353 45F3 86 97          LDA A   ?$97      DIVIDEND
00354 45F5 A7 00          STA A   0,X       IS 0x$97FF
00355 45F7 86 FF          LDA A   ?$FF
00356 45F9 A7 01          STA A   1,X
00357 45FB 86 03          LDA A   ?$03
00358 45FD A7 06          STA A   6,X
00359 45FF 8D BB          BSR     DPD2      COMPUTE L
00360 4601 25 E0          BCS     LOGON     INCREMENT OF
00361 4603 FE 3A5C        LDX     SCR+28    LOGON REGISTER
00362 4606 FF 3A42        STX     SCR+2     STORE IN SCR+2,3
00363 4609 FF 3A5A        STX     SCR+26
00364 460C CE 8000        LDX     ?$8000
00365 460F FF 3A58        STX     SCR+24
00366 4612 CE 3A58        LDX     ?SCR+24
00367 4615 86 01          LDA A   ?$01
00368 4617 A7 06          STA A   6,X
00369 4619 8D A1          BSR     DPD2      COMPUTE TOTAL NO.
00370 461B 86 19          LDA A   ?$19      OF SAMPLES,
00371 461D A1 04          CMP A   4,X       CHECK < $1A00.
00372 461F 25 C2          BCS     LOGON
00373 4621 86 39          LDA A   ?ENDHI
00374 4623 C6 FF          LDA B   ?ENDLO
00375 4625 E0 05          SUB B   5,X
00376 4627 A2 04          SBC A   4,X
00377 4629 B7 3A44        STA A   SCR+4     STARTING ADDRESS
00378 462C F7 3A45        STA B   SCR+5     IN SCR+4,5
00379 462F 7E 4731 LOGDN1 JMP     COMPIL
00380                     *SUBROUTINE TO OUTPUT STRING*
00381                     *STARTING AT X AND ENDING WITH A LF*
00382 4632 8D 48    OUTSTR BSR    OUTLFC    NEW LINE
00383 4634 20 02           BRA    OUTST2
00384 4636 8D 3A    OUTST1 BSR    OUT6S     SAME LINE
00385 4638 A6 00    OUTST2 LDA A  0,X
00386 463A 08              INX
00387 463B 8D 50           BSR    OUTCHR
00388 463D 81 3A           CMP A  ?$3A
00389 463F 26 F7           BNE    OUTST2
00390 4641 39              RTS
00391                     *INPUT 0 TO 4 DECIMAL DIGITS*
00392                     *TO X,X+1*
00393 4642 6F 00    INDEC  CLR    0,X
00394 4644 6F 01           CLR    1,X
00395 4646 BD FE0A INDEC   JSR    INCH      GET CHAR
00396 4649 81 30           CMP A  ?$30
00397 464B 2B 15           BMI    INDEF     NOT DEC
00398 464D 81 39           CMP A  ?$39
00399 464F 2E 11           BGT    INDEF
00400 4651 84 0F           AND A  ?$0F
```

```
00401 4653 C6 04          LDA B  ?$04
00402 4655 68 01    INDEE RSL    1,X
00403 4657 69 00          ROL    0,X       JUSTIFY DIGITS
00404 4659 5A             DEC B
00405 465A 26 F9          BNE    INDEE
00406 465C AB 01          ADD A  1,X
00407 465E A7 01          STA A  1,X
00408 4660 20 E4          BRA    INDED
00409 4662 81 2E    INDEF CMP A  ?$2E
00410 4664 27 2A          BEQ    DHEX
00411 4666 81 3D          CMP A  ?$3D
00412 4668 26 02          BNE    INDEG
00413 466A 4D             TST A
00414 466B 39             RTS
00415 466C 81 58    INDEG CMP A  ?$58
00416 466E 26 D2          BNE    INDEC
00417 4670 43             COM A
00418 4671 39             RTS
00419 4672 86 20    OUT6S LDA A  ?$20      PRINT SIX SPACES
00420 4674 C6 06    OUT6S1 LDA B ?$06
00421 4676 8D 15    OUT6S2 BSR   OUTCHA
00422 4678 5A             DEC B
00423 4679 26 FB          BNE    OUT6S2
00424 467B 39             RTS
00425 467C 86 0A    OUTLFC LDA A ?$0A      OUTPUT LINE FEED
00426 467E 8D 0D          BSR    OUTCHA
00427 4680 86 0D          LDA A  ?$0D
00428 4682 8D 09          BSR    OUTCHA    CARRIAGE RETURN
00429 4684 86 7F          LDA A  ?$7F
00430 4686 20 EC          BRA    OUT6S1    AND SIX RUBOUTS
00431 4688 BD FE00 INCHA  JSR    INCH
00432 468B 16             TAB
00433 468C 39             RTS
00434 468D 7E FE8E OUTCHA JMP    OUTCH
00435                     *DEC TO HEX CONVERSION ROUTINE*
00436 4690 86 10    DHEX  LDA A  ?$10
00437 4692 A7 02          STA A  2,X
00438 4694 A6 00          LDA A  0,X       FOUR BCD DIGITS IN 0,X:1,X
00439 4696 E6 01          LDA B  1,X
00440 4698 44       DHEX1 LSR A
00441 4699 56             ROR B
00442 469A 66 00          ROR    0,X
00443 469C 66 01          ROR    1,X
00444 469E 85 08          BIT A  ?$08
00445 46A0 27 02          BEQ    DHEX2
00446 46A2 80 03          SUB A  ?$03
00447 46A4 5D       DHEX2 TST B
00448 46A5 2A 02          BPL    DHEX3
00449 46A7 C0 30          SUB B  ?$30
00450 46A9 C5 08    DHEX3 BIT B  ?$08
00451 46AB 27 02          BEQ    DHEX4
00452 46AD C0 03          SUB B  ?$03
```

```
00453 46A5 6A 02    DMSX4   DEC     2,X
00454 46A7 26 E5            BNE     DMSX1
00455 46A9 39               RTS                 HEX IN 0,X:1,X
00456                   *DOUBLE PRECISION DIVIDE ROUTINE*
00457 46AA 6F 04    DPD     CLR     4,X
00458 46AC 6F 05            CLR     5,X
00459 46AE 6D 02            TST     2,X
00460 46B0 2B 0A            BMI     DPDB
00461 46B2 6C 06    DPDA    INC     6,X
00462 46B4 2D 2D            BMI     ERROR       DIVISION BY
00463 46B6 68 03            ASL     3,X         ZERO
00464 46B8 69 02            ROL     2,X         LEFT-JUSTIFY
00465 46BA 2A F6            BPL     DPDA        DIVISOR
00466 46BC 64 02    DPDB    LSR     2,X
00467 46BE 66 03            ROR     3,X
00468 46C0 A6 00    DPDC    LDA A   0,X
00469 46C2 E6 01            LDA B   1,X
00470 46C4 E0 03            SUB B   3,X
00471 46C6 A2 02            SBC A   2,X
00472 46C8 25 09            BCS     DPDD
00473 46CA A7 00            STA A   0,X         HERE IF DD>=DS
00474 46CC E7 01            STA B   1,X         DD BECOMES DD-DS
00475 46CE 0D               SEC
00476 46CF 69 05            ROL     5,X
00477 46D1 20 02            BRA     DPDE
00478 46D3 68 05    DPDD    ASL     5,X         HERE IF DD<DS
00479 46D5 69 04    DPDE    ROL     4,X
00480 46D7 68 01            ASL     1,X
00481 46D9 69 00            ROL     0,X
00482 46DB 6A 06            DEC     6,X
00483 46DD 26 E1            BNE     DPDC
00484 46DF 0C               CLC
00485 46E0 39               RTS
00486 46E1 CE 42D3  ERROR   LDX     ?MSG2
00487 46E4 BD 4632          JSR     OUTSTR
00488 46E7 0D               SEC
00489 46E8 39               RTS
00490                   *MULTIPLY ROUTINE ACCA X ACCB*
00491                   *TWO BYTE RESULT IN ACCA:ACCB*
00492 46E9 B7 FF00  MULT    STA A   $FF00
00493 46EC F7 FF01          STA B   $FF01
00494 46EF 86 08            LDA A   ?$08
00495 46F1 B7 FF02          STA A   $FF02       SET COUNT
00496 46F4 4F               CLR A
00497 46F5 5F               CLR B
00498 46F6 58       LP1     ASL B               DOUBLE PARTIAL
00499 46F7 49               ROL A               RESULT
00500 46F8 78 FF01          ASL     $FF01
00501 46FB 24 05            BCC     LP2
00502 46FD FB FF00          ADD B   $FF00       FORM PARTIAL
00503 4700 89 00            ADC A   ?$00        RESULT
00504 4702 7A FF02  LP2     DEC     $FF02
```

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00505 470F 26 EF          BNE    LP1
00506 4711 39             RTS
00507                     *FOUR QUADRANT SINE ROUTINE*
00508                     *START WITH OPERAND IN ACCB*ACCA*
00509 4712 C5 01    FOS   BIT B  ?$01
00510 4714 27 07          BEQ    FOSB
00511 4716 4D             TST A
00512 4717 26 03          BNE    FOSA
00513 4719 43             COM A                HERE IF 90 OR 270
00514 471A 20 0F          BRA    FOSC          ACCA = $FF
00515 471C 40       FOSA  NEG A
00516 471D 44       FOSB  LSR A
00517 471E B7 3A67        STA A  SCR+39        GET SINE OF
00518 4721 86 42          LDA A  ?LOOKUP        ANGLE BETWEEN
00519 4723 B7 3A66        STA A  SCR+38        0 AND 89 DEG
00520 4726 FE 3A66        LDX    SCR+38
00521 4729 A6 00          LDA A  0,X
00522 472B C5 02    FOSC  BIT B  ?$02
00523 472D 27 01          BEQ    FOSD
00524 472F 40             NEG A
00525 4730 39       FOSD  RTS                  RESULT IN ACCA
00526                     *COMPIL USES DATA COLLECTED IN INFORM*
00527                     *AND STORES REQUIRED TONE BURST OR LOGON*
00528                     *WAVEFORM*
00529 4731 8E FF7F COMPIL LDS    ?STACK
00530 4734 CE 3A40        LDX    ?SCR
00531 4737 E6 00          LDA B  0,X           MODE WORD
00532 4739 C5 03          BIT B  ?$03
00533 473B 26 5C          BNE    COMP3         GO TO EXEC IF PULSE
00534 473D 86 07          LDA A  ?$07
00535 473F A7 1A          STA A  26,X          INITIALISE RISE/FALL REGS
00536 4741 08       CLEAR INX                  CLEAR SPECIAL REGS
00537 4742 6F 1A          CLR    26,X
00538 4744 4A             DEC A
00539 4745 2A FA          BPL    CLEAR
00540 4747 FE 3A44        LDX    SCR+4         INITIALISE CURRENT
00541 474A FF 3A58        STX    SCR+24        ADDRESS REGISTER CA
00542 474D C5 0C          BIT B  ?$0C
00543 474F 26 73          BNE    LOGC          BRANCH IF LOGON
00544 4751 BC 3A46  TONC  CPX    SCR+6
00545 4754 27 04          BEQ    TONC10
00546 4756 8D 24          BSR    TONC2
00547 4758 20 F7          BRA    TONC
00548 475A 8D 10    TONC10 BSR   TONC7
00549 475C 8D 44          BSR    TONC6
00550 475E BC 3A48        CPX    SCR+8
00551 4761 26 F7          BNE    TONC10
00552 4763 8C 39FF  TONC11 CPX   ?ENDHL
00553 4766 27 31          BEQ    COMP3
00554 4768 8D 0A          BSR    TONC1
00555 476A 20 F7          BRA    TONC11
00556 476C F6 3A5D  TONC7  LDA B  SCR+29
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00557 476F B6 3A5E         LDA A  SCR+30
00558 4772 20 9E           BRA    FQS
00559 4774 B6 3A4C TONC1   LDA A  SCR+12    HERE ON FALL SECTION
00560 4777 F6 3A4D         LDA B  SCR+13
00561 477A 20 06           BRA    TONC3
00562 477C B6 3A4A TONC2   LDA A  SCR+10    HERE ON RISE SECTION
00563 477F F6 3A4B         LDA B  SCR+11
00564 4782 CE 3A5A TONC3   LDX    #SCR+26    INCREMENT R/F REGISTER
00565 4785 8D 2D           BSR    INCR
00566 4787 F6 3A5A         LDA B  SCR+26     (A,B)=R/F VALUE
00567 478A 8D 86           BSR    FQS        FIND WEIGHT
00568 478C 36              PSH A
00569 478D 8D DD           BSR    TON'C7     GET SIGNAL
00570 478F 33              PUL B
00571 4790 80 80           SUB A  #$80
00572 4792 2B 07           BMI    TONC4      BRANCH IF SIGNAL NEGATIVE
00573 4794 BD 46F3         JSR    MULT
00574 4797 20 07           BRA    TONC5      WEIGHT X SIGNAL
00575 4799 20 52   COMP3   BRA    LASTFT
00576 479B 40      TONC4   NEG A
00577 479C BD 46F3         JSR    MULT
00578 479F 40              NEG A
00579 47A0 8B 80   TONC5   ADD A  #$80
00580 47A2 FE 3A58 TONC6   LDX    SCR+24
00581 47A5 A7 00           STA A  0,X
00582 47A7 08              INX
00583 47A8 FF 3A58         STX    SCR+24     INCREMENT CA
00584 47AB CE 3A5D         LDX    #SCR+29
00585 47AE B6 3A42 INCR2   LDA A  SCR+2      INCREMENT CR
00586 47B1 F6 3A43         LDA B  SCR+3
00587                 *SUBROUTINE TO INCREASE (X,X+1,X+2) BY (A,B)*
00588 47B4 EB 02   INCR    ADD B  2,X
00589 47B6 A9 01           ADC A  1,X
00590 47B8 24 02           BCC    INCR1
00591 47BA 6C 00           INC    0,X
00592 47BC E7 02   INCR1   STA B  2,X
00593 47BE A7 01           STA A  1,X
00594 47C0 FE 3A58         LDX    SCR+24
00595 47C3 39              RTS
00596 47C4 86 42   LOGC    LDA A  #LOOKUP    HERE IF LOGON
00597 47C6 B7 3A5D         STA A  SCR+29
00598 47C9 B6 3A5B LOGC1   LDA A  SCR+27     LOAD ACCA FROM LOGON
00599 47CC 2A 01           BPL    LOGC2      REGISTER: NEGATE IF
00600 47CE 40              NEG A             FALLING EDGE
00601 47CF 44      LOGC2   LSR A             HALF A
00602 47D0 8E 80           ADD A  #$80
00603 47D2 B7 3A5E         STA A  SCR+30
00604 47D5 FE 3A5D         LDX    SCR+29     ADDRESS OF LOGON
00605 47D8 A6 00           LDA A  0,X
00606 47DA FE 3A58 LOGC3   LDX    SCR+24
00607 47DD A7 00           STA A  0,X
00608 47DF 08              INX
```

```
00609 47E0 FF 3A58          STX     SCR+24    INCREMENT CR
00610 47E3 CE 3A5F          LDX     #SCR+26    REGISTER
00611 47E6 8D C6            BSR     INCR2
00612 47E8 8C 39FF          CPX     #ENDHL
00613 47EB 26 DC            BNE     LOOC1
00614 47ED 7F 39FF LASTPT   CLR     ENDHL
00615                       *EXECUTE PROGRAMME*
00616 47F0 86 FF   EXEC     LDA A   #$FF
00617 47F2 97 00            STA A   PIAC
00618 47F4 97 80            STA A   PIAA      INITIALISE PIA
00619 47F6 97 82            STA A   PIAB
00620 47F8 C6 80            LDA B   #$80
00621 47FA D7 03            STA B   PIAD
00622 47FC 86 24            LDA A   #$24
00623 47FE 97 01            STA A   PIACRC
00624 4800 97 83            STA A   PIACRB
00625 4802 43               COM A
00626 4803 97 03            STA A   PIACRD
00627 4805 4A               DEC A
00628 4806 97 01            STA A   PIACRC
00629 4808 D7 80            STA B   PIAA
00630 480A 0F       EXEC00  SEI
00631 480B CE 4887          LDX     #MSG17    READY
00632 480E BD 4682          JSR     OUTSTR
00633 4811 BD 4689          JSR     INCHA
00634 4814 FE 3A64 EXEC0    LDX     SCR+20
00635 4817 FF 3A62          STX     SCR+34    NO. OF STIMULI
00636 481A 86 FD            LDA A   #$FD      RESET CLOCK
00637 481C 97 02            STA A   PIAD
00638 481E 4C               INC A
00639 481F 4C               INC A
00640 4820 97 02            STA A   PIAD
00641 4822 0E               CLI
00642 4823 3E       EXEC2   WAI
00643 4824 96 00            LDA A   PIAC
00644 4826 43               COM A
00645 4827 B1 3A4F          CMP A   SCR+15
00646 482A 26 F7            BNE     EXEC2
00647 482C 0F       EXEC5   SEI
00648 482D 7F FF03          CLR     $FF03     CLEAR REJECT FLAG
00649 4830 86 FD            LDA A   #$FD
00650 4832 97 02            STA A   PIAD      RESET CLOCK
00651 4834 7F 0082          CLR     PIAB
00652 4837 4C               INC A
00653 4838 97 02            STA A   PIAD
00654 483A F6 3A40          LDA B   SCR
00655 483D C5 01            BIT B   #$01
00656 483F 26 20            BNE     EXEC14    POS PULSE
00657 4841 C5 02            BIT B   #$02
00658 4843 26 20            BNE     EXEC15    NEG PULSE
00659 4845 86 80            LDA A   #$80
00660 4847 B6 3A44          LDS     SCR+4
```

```
00661 484A C5 20          BIT B  ?$20      NEG TONE OR LOGON
00662 484C 26 08          BNE    EXEC10
00663 484E 97 80   EXEC6  STA A  PIAA      HERE IF TONE OR LOGON
00664 4850 32             PUL A
00665 4851 4D             TST A
00666 4852 26 FA          BNE    EXEC6
00667 4854 20 06          BRA    EXEC11
00668 4856 97 80   EXEC10 STA A  PIAA
00669 4858 32             PUL A
00670 4859 40             NEG A
00671 485A 26 FA          BNE    EXEC10
00672 485C 8E FF7F EXEC11 LDS    ?STACK
00673 485F 20 11          BRA    EXEC17
00674 4861 86 FF   EXEC14 LDA A  ?$FF      HERE IF POSITIVE
00675 4863 20 02          BRA    EXEC16    PULSE
00676 4865 86 01   EXEC15 LDA A  ?$01      HERE IF NEGATIVE
00677 4867 C6 80   EXEC16 LDA B  ?$80      PULSE
00678 4869 FE 3A4A        LDX    SCR+10
00679 486C 97 80          STA A  PIAA
00680 486E 8D 42          BSR    DELAY     PULSE WIDTH
00681 4870 D7 80          STA B  PIAA
00682 4872 0E      EXEC17 CLI
00683 4873 01             NOP
00684 4874 BD FF07        JSR    EXEC30    JUMP TO ANALYSIS
00685 4877 B6 FCF4 EXEC18 LDA A  $FCF4     SUBROUTINE IF REQUIRED
00686 487A F6 FCF5        LDA B  $FCF5
00687 487D 47             ASR A             TEST WHETHER CHARACTER
00688 487E 25 8A          BCS    EXEC00     HAS BEEN RECEIVED
00689 4880 3E             WAI
00690 4881 96 00          LDA A  PIAC
00691 4883 43             COM A             TEST WHETHER TIME TO
00692 4884 B1 3A4F        CMP A  SCR+15     BEGIN NEXT STIMULUS
00693 4887 26 EE          BNE    EXEC18
00694 4889 7D FF03        TST    $FF03
00695 488C 26 9E          BNE    EXEC5
00696 488E FE 3A62        LDX    SCR+34
00697 4891 09             DEX
00698 4892 FF 3A62        STX    SCR+34
00699 4895 27 1E          BEQ    EXEC25
00700 4897 F6 3A40        LDA B  SCR
00701 489A 2A 90          BPL    EXEC5
00702 489C C5 15          BIT B  ?$15       HERE IF ALT MODE
00703 489E 27 05          BEQ    EXEC21
00704 48A0 58             ASL B
00705 48A1 CB 80          ADD B  ?$80       POS TO NEG CHANGE
00706 48A3 20 03          BRA    EXEC23
00707 48A5 54      EXEC21 LSR B             NEG TO POS CHANGE
00708 48A6 CB 40          ADD B  ?$40
00709 48A8 F7 3A40 EXEC23 STA B  SCR
00710 48AB 7E 4830        JMP    EXEC5
00711 48AE 01      DELAY1 NOP
00712 48AF 01             NOP
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00713 4FF0 01              NOP
00714 4FF1 09              DEX
00715 4FF2 26 FD    DELAY  BNE     DELAY1
00716 4FF4 39              RTS
00717 4FF5 0F       EXEC25 SEI
00718 4FF6 CE 4FF0         LDX     #MSG16    NEXT(S,S,A)
00719 4FF9 BD 4F6F         JSR     OUTSTR    STIMULATE, GO
00720 4FFC BD 4588         JSR     INCHAR    BACK TO INFORM
00721 4FFF C1 53           CMP B   #$53      OR GO TO ANALYSIS
00722 5001 26 03           BNE     EXEC32
00723 5003 7E 4814         JMP     EXEC0
00724 5006 C1 47    EXEC32 CMP B   #$47
00725 5008 26 03           BNE     EXEC34
00726 500A 7E 4399         JMP     INFORM
00727 500D C1 41    EXEC34 CMP B   #$41
00728 500F 26 F4           BNE     EXEC25
00729 5011 7E FF04         JMP     EXEC20
00730 FF04                 ORG     $FF04
00731 FF04 7E 4FF5 EXEC20  JMP     EXEC25
00732 FF07 39       EXEC30 RTS
00733 4FCE                 ORG     $4FCE
00734 4FCE 7D 0002 INTER7  TST     PIAD      SET REJECT FLAG IF
00735 4FD1 2B 03           BMI     INTER3    REJECT SIGNAL PRESENT
00736 4FD3 7C FF03         INC     $FF03     BEFORE MEDELEC TRIGGER
00737 4FD6 B1 3A52 INTER3  CMP A   SCR+18
00738 4FD9 26 02           BNE     INTER4
00739 4FDB CB 04           ADD B   #$04
00740 4FDD B1 3A53 INTER4  CMP A   SCR+19
00741 4FE0 26 02           BNE     INTER5
00742 4FE2 CB 08           ADD B   #$08
00743 4FE4 D7 82    INTER5 STA B   PIAB
00744 4FE6 3B              RTI
00745 4FE7                 ORG     $4FE7
00746 4FE7 5F       INTER1 CLR B               HERE ON INTERRUPT
00747 4FE8 D7 82           STA B   PIAB
00748 4FEA 96 00           LDA A   PIAC
00749 4FEC 43              COM A
00750 4FED B1 3A50         CMP A   SCR+16
00751 4FF0 26 01           BNE     INTER2
00752 4FF2 5C              INC B
00753 4FF3 B1 3A51 INTER2  CMP A   SCR+17
00754 4FF6 26 DE           BNE     INTER3
00755 4FF8 CB 02           ADD B   #$02
00756 4FFA 20 D2           BRA     INTER7
00757 FF2E                 ORG     $FF2E     START ADDRESS OF
00758 FF2E 43              FCB     $43       PROGRAMME
00759 FF2F 99              FCB     $99
00760                      END
```

SYMBOL TABLE

PIBA	0080	PIACRA	0081	PIAB	0082	PIACRB	0083	PIAC	0000
PIACRC	0001	PIFD	0002	PIACRD	0003	SCR	3F40	INCH	FE00
OUTCH	FE05	ENDHI	0039	ENDLO	00FF	ENDHL	39FF	STACK	FF7F
LOOKUP	0042	MSG1	42C2	MSG2	42D3	MSG3	42D9	MSG4	42E6
MSG5	42F5	MSG6	4304	MSG7	4300	MSG8	4319	MSG9	4326
MSG10	4335	MSG11	4344	MSG12	4352	MSG13	435F	MSG14	436C
MSG15	4379	MSG17	4387	MSG18	43FD	INFDPM	4399	INFDP1	43AD
RATE	43B2	RATE1	43C7	OUTS	43D6	RATE2	43DB	RATE4	43EF
TPIS	43F4	TPIG1	43FC	TPIG2	4401	MODE	4408	MODE1	4444
MODE2	4446	MODE3	4449	INT	4460	MODE4	4463	MODE6	4469
MODE5	446C	TONE	4477	TONE1	4486	LOG	4492	PUL	4495
DPD10	4498	DPD1	44A0	TONE2	44A3	TONE3	44B2	TONE4	44C0
TWIDTH	44CA	TWID6	44D4	TWID2	44DA	TWID7	44E1	RISE	4506
RISE1	450F	RISE4	4524	OUTS1	4528	RISE5	452E	RISE6	4532
FALL	453A	FALL1	4543	FALL5	4558	FALL6	455F	FALL7	456B
RF	456D	RF1	4579	RF2	4589	RF6	45A4	RF4	45B6
RF5	45B8	RF7	45B9	RFINC	45BA	DPD2	45DC	PULSE	45EF
PULSE1	45E1	LOGON	45E3	LOGON1	462F	OUTSTR	4632	OUTSY1	4636
OUTST2	4638	INDEC	4642	INDED	4646	INDEE	4655	INDEF	4662
INDEG	4660	OUT6S	4672	OUT6S1	4674	OUT6S2	4676	OUTLFC	467C
INCHA	4688	OUTCHA	468D	DHEX	4690	DHEX1	4698	DHEX2	46A4
DHEX3	46A9	DHEX4	46AF	DPD	46B4	DPDA	46BC	DPDB	46C6
DPDC	46CA	DPDD	46DD	DPDE	46DF	ERROR	46E8	MULT	46F3
LP1	4700	LP2	470C	FOS	4712	FOSA	471C	FOSB	471D
FOSC	472B	FOSD	4730	COMPIL	4731	CLEAR	4741	TONC	4751
TONC10	475A	TONC11	4763	TONC7	476C	TONC1	4774	TONC2	477C
TONC3	4782	COMP3	4799	TONC4	479B	TONC5	47A0	TONC6	47A2
INCR2	47AE	INCR	47B4	INCR1	47BC	LOGC	47C4	LOGC1	47C9
LOGC2	47CF	LOGC3	47DA	LASTPT	47ED	EXEC	47F0	EXEC00	480A
EXEC0	4814	EXEC2	4823	EXEC5	482C	EXEC6	484E	EXEC10	4856
EXEC11	485C	EXEC14	4861	EXEC15	4865	EXEC16	4867	EXEC17	4872
EXEC18	4877	EXEC21	48A5	EXEC23	48A8	DELAY1	48AE	DELAY	48B2
EXEC25	48B5	EXPC32	48C6	EXEC34	48CD	EXEC20	FF04	EXEC30	FF07
INTER7	4FCE	INTER3	4FD6	INTER4	4FDD	INTER5	4FE4	INTER1	4FE7
INTER2	4FF3								

Table C.2 - Analysis programme.

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MOTOROLA M6800 CROSS ASSEMBLER, RELEASE 1.2

00001                        NAM    ANALYS
00002                      *PERFORMS PHASE SPECTRAL ANALYSIS*
00003                      *USED WITH STIMULUS GENERATOR PROGRAMME STIMC*
00004                      *VERSION FOR PROM IMPLEMENTATION*
00005 0000                   ORG    $0000
00006 0000 0001    PIAC      RMB    $01       TIME
00007 0001 0001    PIACRC    RMB    $01
00008 0002 0001    PIAD      RMB    $01
00009 0003 0001    PIACRD    RMB    $01
00010 0040                   ORG    $0040
00011 0040 0001    PIAE      RMB    $01       VIDEO
00012 0041 0001    PIACRE    RMB    $01
00013 0042 0001    PIAF      RMB    $01
00014 0043 0001    PIACRF    RMB    $01
00015      003D    HARBUF    EQU    $3D
00016      003A    PHABUF    EQU    $3A
00017      3A40    SCR       EQU    $3A40     SCRATCH AREA
00018      FE00    INCH      EQU    $FE00
00019      FEBE    OUTCH     EQU    $FEBE     IN MINIBUG
00020      FEBB    OUT2H     EQU    $FEBB
00021      FF7F    STACK     EQU    $FF7F
00022                      *LINKAGE WITH STIMC*
00023                      *UPDATE THESE LOCATIONS IF NECESSARY*
00024                      *WHENEVER STIMC IS RE-ASSEMBLED*
00025 FF04                   ORG    $FF04
00026 FF04 7E 4A2E EXEC20    JMP    STATS     REPLACES EXEC20
00027 FF07 7E 48D4 EXEC30    JMP    TRANS     REPLACES EXEC30
00028      4399    INFORM    EQU    $4399
00029      48A5    EXEC25    EQU    $48A5
00030      46F3    MULT      EQU    $46F3
00031      46B4    DPD       EQU    $46B4
00032      4712    FOS       EQU    $4712
00033      467C    OUTLFC    EQU    $467C
00034      4672    OUT6S     EQU    $4672
00035      4632    OUTSTR    EQU    $4632
00036                      *MESSAGE BUFFER*
00037      004F    MESBUF    EQU    $4F
00038 4F00                   ORG    $4F00
00039                      *LETTER H IN X,Y, COORDINATES*
00040 4F00 807C    MSG20     FDB    $807C,$807A,$8078,$8076
      4F02 807A
      4F04 8078
      4F06 8076
00041 4F08 8074              FDB    $8074,$8278,$8478,$867C
      4F0A 8278
      4F0C 8478
      4F0E 867C
```

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00042 4F1A 8A7B            FDB   $8A7B,$8E78,$8E76,$8E74
      4F1C 8E78
      4F1E 8E76
      4F20 8E74
00043                      *FIGURE 1*
00044 4F22 8C7E            FDB   $8C7E,$8D7C,$8D7B,$8D7A
      4F24 8D7C
      4F26 8D7B
      4F28 8D7A
00045 4F2A 8D79            FDB   $8D79,$8D78,$8D77,$8D76
      4F2C 8D78
      4F2E 8D77
      4F30 8D76
00046 4F32 8D75            FDB   $8D75,$8D74,$8C74,$8E74
      4F34 8D74
      4F36 8C74
      4F38 8E74
00047                      *FIGURE 2*
00048 4F3A 8C7C            FDB   $8C7C,$8D7E,$8F7E,$917E
      4F3C 8D7E
      4F3E 8F7E
      4F40 917E
00049 4F42 927C            FDB   $927C,$907A,$9078,$8E76
      4F44 907A
      4F46 9078
      4F48 8E76
00050 4F4A 8C74            FDB   $8C74,$8E74,$9074,$9274
      4F4C 8E74
      4F4E 9074
      4F50 9274
00051                      *FIGURE 3*
00052 4F52 8C7C            FDB   $8C7C,$8D7E,$8F7E,$917E
      4F54 8D7E
      4F56 8F7E
      4F58 917E
00053 4F5A 927C            FDB   $927C,$907A,$9078,$9276
      4F5C 907A
      4F5E 9078
      4F60 9276
00054 4F62 9174            FDB   $9174,$8F74,$8D74,$8C76
      4F64 8F74
      4F66 8D74
      4F68 8C76
00055                      *FIGURE 4*
00056 4F6A 8F7E            FDB   $8F7E,$8E7C,$8D7A,$8C78
      4F6C 8F7C
      4F6E 8D7A
      4F70 8C78
00057 4F72 8D78            FDB   $8D78,$8E78,$8F78,$9078
      4F74 8E78
      4F76 8F78
      4F78 9078
```

```
00058 4F70 8F7C            FDB   $8F7C,$8F7A,$8F76,$8F74
      4F72 8F7A
      4F74 8F76
      4F76 8F74
00059                      *FIGURE 5*
00060 4F78 907E            FDB   $907E,$8E7E,$8C7E,$8C7C
      4F7A 8E7E
      4F7C 8C7E
      4F7E 8C7C
00061 4F80 8C7A            FDB   $8C7A,$8E7A,$907A,$9178
      4F82 8E7A
      4F84 907A
      4F86 9178
00062 4F88 9176            FDB   $9176,$9074,$8E74,$8C75
      4F8A 9074
      4F8C 8E74
      4F8E 8C75
00063                      *FIGURE 6*
00064 4F90 917E            FDB   $917E,$8F7E,$8D7D,$8C7B
      4F92 8F7E
      4F94 8D7D
      4F96 8C7B
00065 4F98 8C77            FDB   $8C77,$8C75,$8E74,$9074
      4F9A 8C75
      4F9C 8E74
      4F9E 9074
00066 4FA0 9176            FDB   $9176,$9178,$8F78,$8D78
      4FA2 9178
      4FA4 8F78
      4FA6 8D78
00067 4FA8 48      MSG30   FCC   31,HN  AMP MEAN  PHASE MEAN  S.D.:
      4FA9 4E
      4FAA 20
      4FAB 20
      4FAC 41
      4FAD 4D
      4FAE 50
      4FAF 20
      4FB0 4D
      4FB1 45
      4FB2 41
      4FB3 4E
      4FB4 20
      4FB5 20
      4FB6 50
      4FB7 48
      4FB8 41
      4FB9 53
      4FBA 45
      4FBB 20
      4FBC 4D
      4FBD 45
```

```
                4F1E 41
                4F1F 4E
                4F20 20
                4F21 20
                4F22 53
                4F23 2E
                4F24 44
                4F25 2E
                4F26 3A
00068 4EE8                      ORG     $4EE8
00069 4EE8 20           MSG31   FCC     22,     VOLTS/HZ  DEGREES:
                4EE9 20
                4EEA 20
                4EEB 20
                4EEC 56
                4EED 4F
                4EEE 4C
                4EEF 54
                4EF0 53
                4EF1 2F
                4EF2 48
                4EF3 5A
                4EF4 20
                4EF5 20
                4EF6 44
                4EF7 45
                4EF8 47
                4EF9 52
                4EFA 45
                4EFB 45
                4EFC 53
                4EFD 3A
00070                   *TRANS TAKES DISCRETE FOURIER TRANSFORM*
00071                   *OF SAMPLED DATA*
00072 48D4                      ORG     $48D4
00073 48D4 B6 3A62 TRANS  LDA A  SCR+34
00074 48D7 27 01          BEQ    TRAN1    RTS IF MORE THAN
00075 48D9 39             RTS             64 STIMULI LEFT
00076 48DA B6 3A63 TRAN1  LDA A  SCR+35   IN TRIAL
00077 48DD 81 41          CMP A  ?$41
00078 48DF 25 01          BCS    TRAN2
00079 48E1 39             RTS
00080 48E2 96 00    TRAN2 LDA A  PIAC     READ CLOCK, WAIT
00081 48E4 48             ASL A           IF LESS THAN 640MS
00082 48E5 25 FB          BMI    TRAN2
00083 48E7 86 FF          LDA A  ?$FF     DATA BUFFER UNDER
00084 48E9 97 02          STA A  PIAD     MICROPROCESSOR CONTROL
00085 48EB 86 06    TRAN3 LDA A  ?$06     SET HARMONIC NO.
00086 48ED B7 3A60        STA A  SCR+40
00087 48F0 CE 3A68 TRAN9  LDX    ?SCR+40   CLEAR SPECIAL REGS
00088 48F3 4F             CLR A
00089 48F4 A7 05          STA A  5,X
```

```
00090 48F6 A7 06          STA A  6,X
00091 48F8 4C             INC A
00092 48F9 A7 01          STA A  1,X
00093 48FB A7 07          STA A  7,X
00094 48FD 86 3F          LDA A  ?$3F
00095 48FF A7 02          STA A  2,X
00096 4901 A6 00          LDA A  0,X
00097 4903 16             TAB
00098 4904 58             ASL B             GET HARMONIC NO.
00099 4905 58             ASL B
00100 4906 58             ASL B
00101 4907 58             ASL B
00102 4908 01             NOP
00103 4909 E7 09          STA B  9,X        INCREMENT OF SINE,
00104 490B E7 08          STA B  8,X
00105 490D 5F             CLR B             COSINE REGISTER
00106 490E 44             LSR A
00107 490F 56             ROR B
00108 4910 8B 3D          ADD A  ?HARBUF
00109 4912 54             LSR B  .
00110 4913 FB 3A63        ADD B  SCR+35     ADD TO B
00111 4916 5A             DEC B             2 * (STIM. NO. - 1)
00112 4917 58             ASL B
00113 4918 A7 03          STA A  3,X        ADDRESS OF REAL PART
00114 491A E7 04          STA B  4,X        OF RESULT
00115 491C A6 08          LDA A  8,X
00116 491E 8D 2A          BSR    TRAN15
00117 4920 CE 3A68        LDX    ?SCR+40
00118 4923 6C 04          INC    4,X        ADDRESS OF IMAGINARY
00119 4925 6F 05          CLR    5,X
00120 4927 6F 06          CLR    6,X
00121 4929 86 3F          LDA A  ?$3F
00122 492B A7 02          STA A  2,X
00123 492D 86 02          LDA A  ?$02
00124 492F A7 07          STA A  7,X
00125 4931 A6 09          LDA A  9,X
00126 4933 A7 08          STA A  8,X
00127 4935 8D 13          BSR    TRAN15
00128 4937 7A 3A68 TRAN12 DEC    SCR+40     NEW HARMONIC NO.
00129 493A 26 B4          BNE    TRAN9
00130 493C 96 00          LDA A  PIAC       READ CLOCK
00131 493E 43             COM A
00132 493F B1 3P4F        CMP A  SCR+15
00133 4942 25 05          BCS    TRAN14
00134 4944 86 2A          LDA A  ?$2A       PRINT ASTERISK IF NOT
00135 4946 7E FERE        JMP    OUTCH      ENOUGH TIME FOR
00136 4949 39       TRAN14 RTS               TRANSFORM
00137 494A F6 3A6F TRAN15 LDA B  SCR+47
00138 494D BD 4712        JSR    FOS
00139 4950 CB 80          ADD A  ?$80
00140 4952 FE 3A69        LDX    SCR+41
00141 4955 E6 00          LDA B  0,X
```

```
00142 4957 C8 80          ADD B  #$80
00143 4959 8D 9A          BSR    TWOMPY
00144 495B 58             ASL B                TRUNCATE WITH ROUNDING
00145 495C 89 00          ADC A  #$00
00146 495E 2A 03          BPL    TRAN17        ADD PRODUCT TO INTEGRATOR
00147 4960 7A 3A5D        DEC    SCR+45
00148 4963 BB 3A6E TRAN17 ADD A  SCR+46
00149 4966 24 03          BCC    TRAN18
00150 4968 7C 3A6D        INC    SCR+45
00151 496B B7 3A6E TRAN18 STA A  SCR+46
00152 496E B6 3A70        LDA A  SCR+48
00153 4971 BB 3A71        ADD A  SCR+49
00154 4974 24 03          BCC    TRAN26        INCREMENT SINE/COS
00155 4976 7C 3A6F        INC    SCR+47        REGISTER
00156 4979 B7 3A70 TRAN26 STA A  SCR+48
00157 497C 7A 3A6A        DEC    SCR+42        DECREMENT ADDRESS
00158 497F 2A C9          BPL    TRAN15        OF DATA IN BUFFER
00159 4981 B6 3A6D TRAN35 LDA A  SCR+45
00160 4984 F6 3A6E        LDA B  SCR+46
00161 4987 47             ASR A                DIVIDE INTEGRATOR
00162 4988 56             ROR B                TO GIVE ONE BYTE
00163 4989 47             ASR A                RESULT
00164 498A 56             ROR B
00165 498B 47             ASR A
00166 498C 56             ROR B
00167 498D C9 00          ADC B  #$00          ROUNDING
00168 498F FE 3A6B        LDX    SCR+43
00169 4992 E7 00          STA B  0,X
00170 4994 39             RTS
00171                *TWOS COMPLEMENT MULTIPLY ROUTINE*
00172                *(ACCA)X(ACCB)=(ACCA,ACCB)*
00173                *USES MULT ROUTINE IN STIMC*
00174 4995 4D       TWOMPY TST A                ENTER HERE IF A,B ARE
00175 4996 2B 06           BMI    TWOMP2        BOTH TWOS COMPLEMENT
00176 4998 5D       TWOMP2 TST B                ENTER HERE IF A IS
00177 4999 2B 0B           BMI    TWOMP5        UNSIGNED BUT B IS
00178 499B 7E 46F3         JMP    MULT          TWOS COMPLEMENT
00179 499E 40       TWOMP2 NEG A
00180 499F 5D              TST B
00181 49A0 2A 05           BPL    TWOMP6
00182 49A2 50              NEG B
00183 49A3 7E 46F3         JMP    MULT
00184 49A6 50       TWOMP5 NEG B
00185 49A7 BD 46F3  TWOMP6 JSR    MULT
00186 49AA 43       NEGAB  COM A                NEGATES(A,B)
00187 49AB 53              COM B
00188 49AC CB 01           ADD B  #$01
00189 49AE 89 00           ADC A  #$00
00190 49B0 39              RTS
00191                *
00192                *STATISTICS PROGRAMME*
00193                *
```

```
00194                    *AMPLI COMPUTES AMPLITUDE OF A COMPLEX*
00195                    *NUMBER: REAL, IMAGINARY PARTS IN TWOS*
00196                    *COMPLEMENT IN ACCB AND ACCA*
00197                    *RESULT IN ACCB AS AN UNSIGNED INTEGER*
00198 49B1 E7 09    AMPLI  STA B  3,X
00199 49B3 16               TAB
00200 49B4 8D DF            BSR    TWOMPY   SQUARE IMAG
00201 49B6 A7 04            STA A  4,X
00202 49B8 E7 05            STA B  5,X
00203 49BA A6 03            LDA A  3,X
00204 49BC 16               TAB
00205 49BD 8D D6            BSR    TWOMPY   SQUARE REAL
00206 49BF EB 05            ADD B  5,X
00207 49C1 A9 04            ADC A  4,X
00208                    *SQRT COMPUTES SQUARE ROOT OF*
00209                    *(ACCA,ACCB) BY THE NEWTON-RAPHSON*
00210                    *METHOD. RESULT IN ACCB.*
00211 49C3 E7 08    SQRT   STA B  8,X
00212 49C5 A7 07            STA A  7,X
00213 49C7 26 07            BNE    SQRT2
00214 49C9 5D               TST B
00215 49CA 27 2D            BEQ    SQRT10   ZERO RESULT
00216 49CC C6 01            LDA B  #$01     *FIRST ESTIMATE
00217 49CE 20 02            BRA    SQRT3    IS 1 IF ACCA = 0
00218 49D0 C6 FF    SQRT2  LDA B  #$FF      OR $FF IF ACCA NOT 0
00219 49D2 E7 09    SQRT3  STA B  9,X
00220 49D4 A6 07            LDA A  7,X
00221 49D6 A7 00            STA A  0,X
00222 49D8 A6 08            LDA A  8,X
00223 49DA A7 01            STA A  1,X
00224 49DC E7 03            STA B  3,X
00225 49DE 6F 02            CLR    2,X
00226 49E0 6F 06            CLR    6,X
00227 49E2 BD 46B4          JSR    DPD
00228 49E5 E6 05            LDA B  5,X
00229 49E7 EB 09            ADD B  9,X
00230 49E9 56               ROR B
00231 49EA 26 01            BNE    SQRT9    AVOIDS DIVN BY ZERO
00232 49EC 5C               INC B           *ACCB IS HALF OF (LAST
00233 49ED A6 09    SQRT9  LDA A  9,X       EST+SQUARE/LAST EST)
00234 49EF 10               SBA
00235 49F0 27 07            BEQ    SQRT10   EXIT IF NEW ESTIMATE
00236 49F2 4A               DEC A           MINUS LAST ESTIMATE IS
00237 49F3 27 04            BEQ    SQRT10   WITHIN ONE BIT
00238 49F5 4C               INC A
00239 49F6 4C               INC A
00240 49F7 26 D9            BNE    SQRT3
00241 49F9 39       SQRT10 RTS
00242                    *ARC SUBROUTINE FINDS ANGLE WHOSE
00243                    *SINE IS IN ACCA, COSINE IN ACCB
00244                    *WHERE UNIT RADIUS IS 340 AND
00245                    *360 DEGREES IS EQUIVALENT TO $100
```

```
00246 49FA 36          ARC     PSH A
00247 49FB 37                  PSH B
00248 49FC 4D                  TST A                   TAKE ABSOLUTE
00249 49FD 2A 01               BPL     ARC01           VALUE OF SINE
00250 49FF 40                  NEG A                   AND COSINE
00251 4A00 5D          ARC01   TST B
00252 4A01 2A 01               BPL     ARC02
00253 4A03 50                  NEG B
00254 4A04 11          ARC02   CBA                     SELECT ANGLE LESS
00255 4A05 24 04               BCC     ARC04           OR EQUAL TO 45 DEG
00256 4A07 8D 15               BSR     ARC45           FIND ARCSIN
00257 4A09 20 06               BRA     ARC10
00258 4A0B 17          ARC04   TBA
00259 4A0C 8D 10               BSR     ARC45           FIND ARCCOS
00260 4A0E 50                  NEG B                   SUBTRACT FROM 90 DEG
00261 4A0F CB 40               ADD B   #$40
00262 4A11 32          ARC10   PUL A
00263 4A12 4D                  TST A
00264 4A13 2A 03               BPL     ARC12           SUBTRACT FROM 180 DEG
00265 4A15 50                  NEG B                   IF COSINE NEGATIVE
00266 4A16 CB 80               ADD B   #$80
00267 4A18 32          ARC12   PUL A
00268 4A19 4D                  TST A
00269 4A1A 2A 01               BPL     ARC14           NEGATE IF SINE NEG
00270 4A1C 50                  NEG B
00271 4A1D 39          ARC14   RTS                     RESULT IN ACCB
00272 4A1E 48          ARC45   ASL A
00273 4A1F 8B 80               ADD A   #$80            SCALE TO COMPARE WITH
00274 4A21 CE 4200             LDX     #$4200          LOOKUP TABLE
00275 4A24 5F                  CLR B
00276 4A25 A1 00       ARC50   CMP A   0,X             FIND ARCSIN
00277 4A27 23 F4               BLS     ARC14
00278 4A29 08                  INX
00279 4A2A 08                  INX
00280 4A2B 5C                  INC B
00281 4A2C 20 F7               BRA     ARC50
00282                  *INITIALISE VIDEO
00283 4A2E 0F          STATS   SEI
00284 4A2F 4F                  CLR A
00285 4A30 97 40               STA A   PIAF
00286 4A32 97 42               STA A   PIAF
00287 4A34 86 DB               LDA A   #$DB
00288 4A36 97 41               STA A   PIACRE
00289 4A38 97 43               STA A   PIACRF
00290                  *EVALUATE N NUMBER OF TRANSFORMED*
00291                  *STIMULI MAXIMUM N IS 64*
00292 4A3A 7D 3A5A             TST     SCP+20
00293 4A3D 26 07               BNE     STAT10
00294 4A3F B6 3A5B             LDA A   SCP+21
00295 4A42 81 40               CMP A   #$40
00296 4A44 25 02               BCS     STAT12
00297 4A46 86 40       STAT10  LDA A   #$40
```

```
00298 4A49 B7 3A69 STRT18 STA A  SCR+41
00299 4A4C C6 06          LDA B  #$06
00300 4A4E B7 3A68        STA A  SCR+40    HARMONIC NO.
00301                *FIND MEAN AMPLITUDE OF EPCH*
00302                *HARMONIC, PROJECT POINTS ONTO UNIT*
00303                *CIRCLE AND STORE IN PHABUF*
00304 4A50 CE 3A68 STRT20 LDX    #SCR+40
00305 4A53 5F             CLR B
00306 4A54 E7 02          STA B  2,X       INITIALISE
00307 4A56 E7 03          STA B  3,X       REGISTERS
00308 4A58 A6 00          LDA A  0,X
00309 4A5A 44             LSR A
00310 4A5B 56             ROR B
00311 4A5C 8B 3D          ADD A  #HARBUF
00312 4A5E A7 04          STA A  4,X
00313 4A60 E7 05          STA B  5,X
00314 4A62 80 3D          SUB A  #HARBUF
00315 4A64 8B 3A          ADD A  #PHABUF
00316 4A66 A7 06          STA A  6,X
00317 4A68 E7 07          STA B  7,X
00318 4A6A A6 01          LDA A  1,X
00319 4A6C A7 08          STA A  8,X
00320 4A6E FE 3A6C STAT30 LDX    SCR+44
00321 4A71 A6 00          LDA A  0,X
00322 4A73 E6 01          LDA B  1,X       GET AMPLITUDE
00323 4A75 CE 3A72        LDX    #SCR+50    OF POINT
00324 4A78 BD 49B1        JSR    AMPLI
00325 4A7B F7 3A71        STA B  SCR+49
00326 4A7E FB 3A6B        ADD B  SCR+43    ADD AMPLITUDE
00327 4A81 24 03          BCC    STAT32    TO ACCUMULATOR
00328 4A83 7C 3A6A        INC    SCR+42
00329 4A86 F7 3A6B STAT32 STA B  SCR+43
00330 4A89 FE 3A6C        LDX    SCR+44
00331 4A8C A6 00          LDA A  0,X
00332 4A8E F6 3A71        LDA B  SCR+49
00333 4A91 CE 3A72        LDX    #SCR+50
00334 4A94 8D 5E          BSR    DIV2C     REAL PART OF
00335 4A96 FE 3A6E        LDX    SCR+46    UNIT AMPLITUDE
00336 4A99 A7 00          STA A  0,X       VECTOR
00337 4A9B FE 3A6C        LDX    SCR+44
00338 4A9E A6 01          LDA A  1,X
00339 4AA0 F6 3A71        LDA B  SCR+49
00340 4AA3 CE 3A72        LDX    #SCR+50    IMAGINARY
00341 4AA6 8D 4C          BSR    DIV2C     PART
00342 4AA8 FE 3A6E        LDX    SCR+46
00343 4AAB A7 01          STA A  1,X
00344 4AAD CE 3A68        LDX    #SCR+40
00345 4AB0 6C 05          INC    5,X
00346 4AB2 6C 07          INC    7,X
00347 4AB4 6C 05          INC    5,X
00348 4AB6 6C 07          INC    7,X
00349 4AB8 6A 08          DEC    8,X
```

```
00350 4AA5 26 B2          BNE     STAT30    NEXT POINT
00351 4AA7 96 3A          LDA A   ?PARBUF
00352 4AA9 A7 06          STA A   6,X
00353 4AAB A6 00          LDA A   0,X       HARMONIC NO.
00354 4AAD A7 07          STA A   7,X
00355 4AAF A6 02          LDA A   2,X
00356 4AB1 A7 0A          STA A   10,X      AMPLITUDE
00357 4AB3 A6 03          LDA A   3,X       ACCUMULATOR
00358 4AB5 A7 0B          STA A   11,X
00359 4AB7 A6 01          LDA A   1,X
00360 4AB9 A7 0D          STA A   13,X
00361 4ABB CE 3A72        LDX     ?SCR+50
00362 4ABE 6F 02          CLR     2,X
00363 4AC0 6F 06          CLR     6,X
00364 4AC2 BD 46B4        JSR     DP1       DIVIDE BY NO.
00365 4AC5 A6 05          LDA A   5,X       OF POINTS
00366 4AC7 FE 3A6E        LDX     SCR+46
00367 4ACA A7 00          STA A   0,X       STORE MEAN AMPLITUDE
00368 4ACC 7A 3A68        DEC     SCR+40
00369 4ACF 27 03          BEQ     STAT40    NEW HARMONIC NO.
00370 4AD1 7E 4A50        JMP     STAT20
00371                   *ADD TOGETHER ALL REAL PARTS AND*
00372                   *ALL IMAGINARY PARTS OF UNIT VECTORS*
00373                   *PHASE ANGLE OF RESULTANT VECTOR*
00374                   *IS THE MEAN PHASE OF THE HARMONIC*
00375 4AD4 86 06    STAT40 LDA A   ?$06
00376 4AD6 CE 3A68  STAT41 LDX     ?SCR+40
00377 4AD9 A7 00           STA A   0,X
00378 4ADB 8D 1F           BSR     STAT42
00379 4ADD 20 35           BRA     STAT44
00380                   *DIV2C DIVIDES A 1 BYTE TWOS COMP*
00381                   *NUMBER IN ACCA BY A 1 BYTE UNSIGNED*
00382                   *INTEGER IN ACCB AND MULTIPLIES BY*
00383                   *$40. TWOS COMP RESULT IN ACCA*
00384 4ADF E7 03    DIV2C  STA B   3,X
00385 4AE1 26 01           BNE     DIV2C3    DO NOTHING IF
00386 4AE3 39              RTS               ZERO DIVISOR
00387 4AE4 6F 00    DIV2C3 CLR     0,X
00388 4AE6 6F 02           CLR     2,X
00389 4AE8 C6 06           LDA B   ?$06
00390 4AEA E7 06           STA B   6,X
00391 4AEC 4D              TST A
00392 4AED 2A 05           BPL     DIV2C1
00393 4AEF 40              NEG A
00394 4AF0 8D 02           BSR     DIV2C1
00395 4AF2 40              NEG A
00396 4AF3 39              RTS
00397 4AF4 A7 01    DIV2C1 STA A   1,X
00398 4AF6 BD 46B4         JSR     DP1
00399 4AF9 A6 05           LDA A   5,X
00400 4AFB 39              RTS
00401 4AFC A6 01    STAT42 LDA A   1,X
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00402 4B13 A7 08          STA A  8,X
00403 1315 5F             CLR B                SUBROUTINE TO
00404 4B16 E7 02          STA B  2,X           INITIALISE REGISTERS
00405 4B18 E7 03          STA B  3,X
00406 4B1A E7 04          STA B  4,X
00407 4B1C E7 05          STA B  5,X
00408 4B1E A6 00          LDA A  0,X
00409 4B20 44             LSR A
00410 4B21 56             ROR B
00411 4B22 8B 3A          ADD A  #PARBUF
00412 4B24 A7 06          STA A  6,X
00413 4B26 E7 07          STA B  7,X
00414 4B28 39             RTS
00415 4B29 FE 3F6E STAT44 LDX    SCP+46
00416 4B2C A6 00          LDA A  0,X
00417 4B2E CE 3F65        LDX    #SCP+37     ADD TO REAL
00418 4B31 8D FC          BSR    TCINT       ACCUMULATOR
00419 4B33 FE 3F6E        LDX    SCP+46
00420 4B36 A6 01          LDA A  1,X
00421 4B38 CE 3A67        LDX    #SCP+39
00422 4B3B 8D 22          BSR    TCINT       ADD TO IMAGINARY
00423 4B3D 6C 08          INC    8,X
00424 4B3F 6C 08          INC    8,X
00425 4B41 6A 09          DEC    9,X
00426 4B43 26 E4          BNE    STAT44
00427 4B45 A6 03   STAT46 LDA A  3,X
00428 4B47 E6 04          LDA B  4,X
00429 4B49 8D 22          BSR    TSTTC
00430 4B4B 25 08          BCS    STAT48
00431 4B4D A6 05          LDA A  5,X
00432 4B4F E6 06          LDA B  6,X
00433 4B51 8D 1A          BSR    TSTTC
00434 4B53 24 25          BCC    STAT50
00435 4B55 67 03   STAT48 ASR    3,X          DIVIDE ACCUMULATORS
00436 4B57 66 04          ROR    4,X          BY TWO UNTIL REAL,
00437 4B59 67 05          ASR    5,X          IMAGINARY  ARE BOTH
00438 4B5B 66 06          ROR    6,X          ONE BYTE TWOS COMP
00439 4B5D 20 E6          BRA    STAT46       NUMBERS
00440 4B5F 4D        TCINT TST A
00441 4B60 2A 02          BPL    TCINT1       TWOS COMP INTEGRATE
00442 4B62 6A 05          DEC    5,X
00443 4B64 AB 06   TCINT1 ADD A  6,X
00444 4B66 24 02          BCC    TCINT2
00445 4B68 6C 05          INC    5,X
00446 4B6A A7 06   TCINT2 STA A  6,X
00447 4B6C 39             RTS
00448 4B6D 4D        TSTTC TST A                TSTTC TESTS THE
00449 4B6E 27 04          BEQ    TSTTC1       TWO BYTE NUMBER (ACCA,ACCB)
00450 4B70 43             COM A                IF ACCB IS A VALID
00451 4B71 26 05          BNE    TSTTC2       TWOS COMP NUMBER THEN
00452 4B73 53             COM B                CARRY IS CLEARED;
00453 4B74 5D        TSTTC1 TST B                OTHERWISE SET.
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00454 4B75 2B 01          BMI    TSTTC2
00455 4B77 39             RTS
00456 4B78 0D       TSTTC2 SEC
00457 4B79 39             RTS
00458 4B7A A6 04    STAT50 LDA A  4,X       DIVIDE RESULTANT
00459 4B7C E6 06          LDA B  6,X       VECTOR BY ITS
00460 4B7E CE 3A72        LDX    ?SCR+50    AMPLITUDE
00461 4B81 BD 49D1        JSR    AMPLI
00462 4B84 F7 3A71        STA B  SCR+49
00463 4B87 A6 3A6B        LDA A  SCR+43
00464 4B8A BD 4AF4        JSR    DIV2C
00465 4B8D B7 3A6B        STA A  SCR+43
00466 4B90 F6 3A71        LDA B  SCR+49
00467 4B93 B6 3A6D        LDA A  SCR+45
00468 4B96 BD 4AF4        JSR    DIV2C
00469 4B99 B7 3A6D        STA A  SCR+45
00470 4B9C F6 3A6B        LDA B  SCR+43
00471 4B9F BD 49FA        JSR    ARC
00472 4BA2 86 3A          LDA A  ?PHABUF
00473 4BA4 B7 3A6E        STA A  SCR+46
00474 4BA7 B6 3A68        LDA A  SCR+40
00475 4BAA B7 3A6F        STA A  SCR+47
00476 4BAD FE 3A6E        LDX    SCR+46     STORE MEAN
00477 4BB0 E7 08          STA B  8,X        PHASE ANGLE
00478 4BB2 CE 3A68        LDX    ?SCR+40
00479 4BB5 E7 09          STA B  9,X
00480 4BB7 BD 4B11        JSR    STAT42     INITIALISE REGS
00481 4BBA FE 3A6E  STAT55 LDX   SCR+46
00482 4BBD E6 00          LDA B  0,X
00483 4BBF A6 01          LDA A  1,X
00484 4BC1 BD 49FA        JSR    ARC
00485 4BC4 B6 3A71        LDA A  SCR+49
00486 4BC7 10             SBA               MEAN-SAMPLE
00487 4BC8 16             TAB
00488 4BC9 BD 4995        JSR    TWOMPY     SQUARE
00489 4BCC CE 3A6B        LDX    ?SCR+43
00490 4BCF EB 02          ADD B  2,X
00491 4BD1 A9 01          ADC A  1,X
00492 4BD3 24 02          BCC    STAT57
00493 4BD5 6C 00          INC    0,X
00494 4BD7 E7 02    STAT57 STA B  2,X
00495 4BD9 A7 01          STA A  1,X        ADD SQUARE TO ACCUMULATOR
00496 4BDB 6C 04          INC    4,X        (SCR+43,44,45)
00497 4BDD 6C 04          INC    4,X
00498 4BDF 6A 05          DEC    5,X        NEXT POINT
00499 4BE1 26 D7          BNE    STAT55
00500 4BE3 86 04          LDA A  ?S04
00501 4BE5 64 00    STAT59 LSR    0,X        DIVIDE ACCUMULATOR
00502 4BE7 66 01          ROR    1,X        BY 16 TO FORM TWO
00503 4BE9 66 02          ROR    2,X        BYTE UNSIGNED INTEGER
00504 4BEB 4A             DEC A
00505 4BEC 26 F7          BNE    STAT59
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00506 4FFE A6 01          LDA A  1,X
00507 4100 A7 07          STA A  7,X
00508 4102 A6 02          LDA A  2,X
00509 4104 A7 08          STA A  8,X
00510 4106 6F 09          CLR    9,X
00511 4108 B6 3F69        LDA A  SCR+41
00512 410B 4A             DEC A
00513 410C A7 0A          STA A  10,X       DIVIDE BY N-1
00514 410E 86 04          LDA A  #$04
00515 4110 A7 0D          STA A  13,X       MULTIPLY BY 16
00516 4112 CE 3A72        LDX    #SCR+50
00517 4115 BD 4634        JSR    APD
00518 4118 A6 04          LDA A  4,X
00519 411A E6 05          LDA B  5,X        TAKE SQUARE ROOT TO
00520 411C BD 49C3        JSR    SQRT       GET STANDARD DEVIATION
00521 411F 86 3A          LDA A  #PNABUF
00522 4121 B7 3A6E        STA A  SCR+46
00523 4124 B6 3F68        LDA A  SCR+40
00524 4127 B7 3A6F        STA A  SCR+47
00525 412A FE 3A6E        LDX    SCR+46
00526 412D E7 10          STA B  16,X       STORE S.D.
00527 412F 4A             DEC A             NEXT HARMONIC NO.
00528 4130 27 03          BEQ    STAT65
00529 4132 7E 4AEB        JMP    STAT41
00530 4135 BD 467C STAT65 JSR    OUTLFC
00531 4138 CE 4FA8        LDX    #MSG30
00532 413B BD 4632        JSR    OUTSTR     PRINT HEADINGS
00533 413E CE 4EE8        LDX    #MSG31
00534 4141 BD 4632        JSR    OUTSTR
00535 4144 BD 467C        JSR    OUTLFC
00536 4147 86 01          LDA A  #$01
00537 4149 B7 3A68 STAT67 STA A  SCR+40
00538 414C B7 3A6F        STA A  SCR+47
00539 414F 8D 3E          BSR    OUT$4      PRINT HARMONIC NUMBER
00540 4151 BD 4672        JSR    OUT6S      LEAVE SIX SPACES
00541 4154 FE 3A6E        LDX    SCR+46
00542 4157 A6 00          LDA A  0,X        GET MEAN AMPLITUDE
00543 4159 C6 CB          LDA B  #$CB
00544 415B CE 3A72        LDX    #SCR+50
00545 415E BD 46F3        JSR    MULT       MULTIPLY BY SCALING
00546 4161 58             ASL B             FACTOR
00547 4162 49             ROL A
00548 4163 59             ROL B
00549 4164 97 53          BSR    HDEC       HEX-TO-DECIMAL CONVERSION
00550 4166 86 2E          LDA A  #$2E
00551 4168 8D 27          BSR    OUTS5      PRINT DECIMAL POINT
00552 416A A6 01          LDA A  1,X
00553 416C AB 01          ADD A  1,X
00554 416E 19             DAA               MULTIPLY BY TWO (BCD CODE)
00555 416F 69 02          ROL    2,X
00556 4171 A7 01          STA A  1,X
00557 4173 A6 02          LDA A  2,X
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00558 4C65 8D 18          BSR    OUTS4    PRINT MOST SIGNIFICANT DIGIT
00559 4C67 08             INX
00560 4C68 BD FEBB        JSR    OUT2H    PRINT OTHER TWO DIGITS
00561 4C6B 8D 17          BSR    STRT70   PRINT PHASE MEAN
00562 4C6D 8D 15          BSR    STRT70   PRINT PHASE S.D.
00563 4C6F BD 4A7C        JSR    OUTLFC
00564 4C72 96 3A+8        LDA A  SCR+40
00565 4C75 4C             INC A
00566 4C76 81 07          CMP A  #$07
00567 4C78 26 BF          BNE    STRT67   NEXT HARMONIC NUMBER
00568 4C7A BD 4A7C        JSR    OUTLFC
00569 4C7D 20 42          BRA    STRT72
00570 4C7F 8B 30   OUTS4  ADD A  #$30     *OUTPUT DECIMAL DIGIT
00571 4C81 7E FEBF OUTS5  JMP    OUTCH
00572 4C84 BD 4A72 STRT70 JSR    OUTS3    OUTPUT SIX SPACES
00573 4C87 96 3A6F        LDA A  SCR+47
00574 4C8A 8B 08          ADD A  #$08
00575 4C8C B7 3A6F        STA A  SCR+47
00576 4C8F FE 3A6E        LDX    SCR+46   GET ADDRESS OF DATA
00577 4C92 A6 00          LDA A  0,X      TO BE PRINTED
00578 4C94 CE 3A72        LDX    #SCR+50
00579 4C97 C6 B4          LDA B  #$B4
00580 4C99 BD 46F3        JSR    MULT     *180
00581 4C9C 58             ASL B
00582 4C9D 49             ROL A           *2
00583 4C9E 59             ROL B
00584 4C9F 8D 08          BSR    HDEC
00585 4CA1 A6 02          LDA A  2,X
00586 4CA3 8D DA          BSR    OUTS4    PRINT 3 DIGIT INTEGER
00587 4CA5 08             INX
00588 4CA6 7E FEBB        JMP    OUT2H
00589                *HEXADECIMAL TO DECIMAL CONVERSION*
00590                * 9 BIT BINARY TO 3 DIGIT DECIMAL *
00591                *HEX IN (ACCB(LSB):ACCA) ; DEC RESULT IN (2,X:1,X) *
00592 4CA9 A7 00   HDEC   STA A  0,X
00593 4CAB C4 01          AND B  #$01
00594 4CAD E7 01          STA B  1,X
00595 4CAF 17             TBA
00596 4CB0 C6 08          LDA B  #$08
00597 4CB2 6F 02          CLR    2,X
00598 4CB4 68 00   HDEC1  ASL    0,X
00599 4CB6 A9 01          ADC A  1,X
00600 4CB8 19             DAA
00601 4CB9 69 02          ROL    2,X
00602 4CBB A7 01          STA A  1,X
00603 4CBD 5A             DEC B
00604 4CBE 26 F4          BNE    HDEC1
00605 4CC0 39             RTS
00606                *ROUTINE TO CONTROL DISPLAY ON OSCILLOSCOPE*
00607 4CC1 C6 01   STRT72 LDA B  #$01
00608 4CC3 CE 3A68 STRT74 LDX    #SCR+40
00609 4CC6 E7 00          STA B  0,X
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00610 4CC8 B6 <4F          LDA A  ?MESBUF
00611 4CCB A7 04           STA A  4,X
00612 4CCC 58              ASL B
00613 4CCD 58              ASL B
00614 4CCE 58              ASL B
00615 4CCF 17              TBA
00616 4CD0 58              ASL B                ACCB*24
00617 4CD1 1B              ABA
00618 4CD2 A7 05           STA A  5,X
00619 4CD4 F6 00           LDA A  0,X
00620 4CD6 5F              CLR B
00621 4CD7 44              LSR A
00622 4CD8 56              ROR B
00623 4CD9 E7 07           STA B  7,X
00624 4CDB BB 3D           ADD A  ?HARBUF
00625 4CDD C6 3A           LDA B  ?PHABUF
00626 4CDF A7 06           STA A  6,X
00627 4CE1 E7 08           STA B  8,X
00628 4CE3 A6 00           LDA A  0,X
00629 4CE5 A7 09           STA A  9,X
00630 4CE7 FE 3A70         LDX    SCR+48
00631 4CEA A6 08           LDA A  8,X          MEAN OF PHASE
00632 4CEC E6 10           LDA B  16,X         S.D. OF PHASE
00633 4CEE CE 3A64         LDX    ?SCR+36
00634 4CF1 A7 06           STA A  6,X
00635 4CF3 E7 07           STA B  7,X
00636 4CF5 C6 18           LDA B  ?$18
00637 4CF7 E7 0D           STA B  13,X
00638 4CF9 C6 68           LDA B  ?$68
00639 4CFB 8D 16           BSR    STAT78       MEAN MARKER
00640 4CFD A6 06           LDA A  6,X
00641 4CFF AB 07           ADD A  7,X
00642 4D01 C6 78           LDA B  ?$78
00643 4D03 8D 0E           BSR    STAT78       MEAN+SD MARKER
00644 4D05 A6 06           LDA A  6,X
00645 4D07 A0 07           SUB A  7,X
00646 4D09 C6 78           LDA B  ?$78
00647 4D0B 8D 06           BSR    STAT78       MEAN-SD MARKER
00648 4D0D 86 18           LDA A  ?$18
00649 4D0F A7 0D           STA A  13,X
00650 4D11 20 53           BRA    DISP20
00651                   *COMPUTE COORDS OF RADIAL MARKERS*
00652                   *X=?SCR+36, ANGLE OF MARKER IN ACCA, $100=360 DEG*
00653                   *ACCB CONTROLS LENGTH OF MARKER AND NO. OF POINTS*
00654                   *ACCB=0 FOR MAX LENGTH,7E FOR ZERO LENGTH*
00655                   *ADDR OF REAL PART OF FIRST POINT IS IN SCR+48*
00656 4D13 E7 10    STAT78 STA B  16,X
00657 4D15 5F              CLR B
00658 4D16 48              ASL A
00659 4D17 59              ROL B
00660 4D18 48              ASL A
00661 4D19 59              ROL B
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00666 4D1A 36              PSH A
00667 4D1B 37              PSH B
00668 4D1C BD 4712         JSR    FOS       GET SINE
00669 4D1F 8B 80           ADD A  ?$80
00670 4D21 B7 3A72         STA A  SCR+50
00671 4D24 33              PUL B
00672 4D25 5C              INC B
00673 4D26 32              PUL A
00674 4D27 BD 4712         JSR    FOS       GET COSINE
00675 4D2A CE 3A64         LDX    ?SCR+36
00676 4D2D 8B 80           ADD A  ?$80
00677 4D2F A7 0F           STA A  15,X
00678 4D31 E6 0F    STAT80 LDA B  15,X
00679 4D33 8D 05           BSR    STAT82    REAL
00680 4D35 E6 0E           LDA B  14,X
00681 4D37 8D 07           BSR    STAT82    IMAG
00682 4D39 6C 10           INC    16,X
00683 4D3B 6C 10           INC    16,X      INCREMENT AMPLITUDE
00684 4D3D 2A F2           BPL    STAT80    MULTIPLIER
00685 4D3F 39              RTS
00686 4D40 A6 10    STAT82 LDA A  16,X
00687 4D42 BD 4998         JSR    TWOMPZ
00688 4D45 FE 3A70         LDX    SCR+48
00689 4D48 A7 00           STA A  0,X
00690 4D4A CE 3A64         LDX    ?SCR+36    INCREMENT ADDRESS
00691 4D4D 6C 0D           INC    13,X       OF RESULT
00692 4D4F 39              RTS
00693 4D50 C4 7F    STAT86 AND B  ?$7F
00694 4D52 C1 31           CMP B  ?$31       KEY TEST
00695 4D54 2B 10           BMI    DISP20
00696 4D56 C1 36           CMP B  ?$36       NUMBER 1 TO 6
00697 4D58 2F 07           BLE    STAT88
00698 4D5A C1 58           CMP B  ?$58       ASCII X
00699 4D5C 26 08           BNE    DISP20
00700 4D5F 7E 48B5         JMP    EXEC25
00701 4D61 C0 30    STAT88 SUB B  ?$30
00702 4D63 7E 4CC3         JMP    STAT74
00703                *DISPLAY ROUTINES*
00704 4D66 FE 3A70 DISP20 LDX    SCR+48    DRAW MARKERS
00705 4D69 86 14           LDA A  ?$14
00706 4D6B 8D 27           BSR    DISP32
00707 4D6D CE 4F00 DISP25 LDX    ?MS620
00708 4D70 8D 20           BSR    DISP30    DRAW LETTER H
00709 4D72 FE 3A6C         LDX    SCR+44
00710 4D75 8D 13           BSR    DISP30    DRAW HARMONIC NO.
00711 4D77 8D 33           BSR    DISP10    DRAW AXES
00712 4D79 FE 3A6E         LDX    SCR+46
00713 4D7C B6 3A69         LDA A  SCR+41
00714 4D7F 8D 13           BSR    DISP32    DISPLAY POINTS
00715 4D81 B6 FCF4         LDA A  $FCF4
00716 4D84 F6 FCF5         LDA B  $FCF5
00717 4D87 47              ASR A             CARRY SET IF CHARACTER
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00714 4D68 B5 C8          BCS     STAT86    RECEIVER
00715 4D6A 94 00          LDA A   PIAC
00716 4D6C 85 20          BIT A   ?$20      READ CLOCK
00717 4D6E 27 08          BEQ     DISP25
00718 4D70 20 04          BRA     DISP20
00719                *DISPLAY N COMPLEX POINTS*
00720                *INDEX REG CONTAINS ADDRESS OF REAL*
00721                *PART OF FIRST POINT*
00722 4D72 86 0C    DISP30 LDA A   ?$0C
00723 4D74 B7 3F54  DISP22 STA A   SCR+36
00724 4D77 A6 00    DISP34 LDA A   0,X
00725 4D79 E6 01           LDA B   1,X
00726 4D7B 8B 80           ADD A   ?$80      SCALE FOR
00727 4D7D CB 80           ADD B   ?$80      VIDEO OUTPUTS
00728 4D7F 53              COM B
00729 4D80 97 40           STA A   PIAE
00730 4D82 D7 42           STA B   PIAF
00731 4D84 08              INX
00732 4D85 08              INX
00733 4D86 7A 3F54         DEC     SCR+36
00734 4D89 26 EC           BNE     DISP34
00735 4D8B 39              RTS
00736                *RULE X AND Y AXES*
00737 4D8C 86 80    DISP10 LDA A   ?$80
00738 4D8E 97 42           STA A   PIAF
00739 4D90 5F              CLR B
00740 4D91 D7 40    DISP11 STA B   PIAE
00741 4D93 CB 04           ADD B   ?$04
00742 4D95 26 FA           BNE     DISP11
00743 4D97 97 40           STA A   PIAE
00744 4D99 D7 42    DISP12 STA B   PIAF
00745 4D9B CB 04           ADD B   ?$04
00746 4D9D 26 FA           BNE     DISP12
00747 4D9F C6 40    DISP14 LDA B   ?$40      DRAW MARKS ON AXES
00748 4DC1 8D 01           BSR     DISP15
00749 4DC3 50              NEG B             AT +$40 AND -$40
00750 4DC4 86 83    DISP15 LDA A   ?$83
00751 4DC6 97 40           STA A   PIAE
00752 4DC8 D7 42           STA B   PIAF
00753 4DCA 40              NEG A
00754 4DCB 97 40           STA A   PIAE
00755 4DCD 97 42           STA A   PIAF
00756 4DCF D7 40           STA B   PIAE
00757 4DD1 40              NEG A
00758 4DD2 97 42           STA A   PIAF
00759 4DD4 86 80           LDA A   ?$80
00760 4DD6 39              RTS
00761 4E00                 ORG     $4E00
00762 4E00 2A       MSG35  FCC     23,*MICROPROCESSOR SYSTEM*
      4E01 4D
      4E02 49
      4E03 43
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                4E04 52
                4E05 4F
                4E06 50
                4E07 52
                4E08 4F
                4E09 43
                4E0A 45
                4E0B 53
                4E0C 53
                4E0D 4F
                4E0E 52
                4E0F 20
                4E10 53
                4E11 59
                4E12 53
                4E13 54
                4E14 45
                4E15 4D
                4E16 2A
00763           4E17 0D0A           FDB    $0D0A,$0A7F,$7F7F
                4E19 0A7F
                4E1B 7F7F
00764           4E1D 53             FCC    26,STIMULUS GENERATOR + PHASE
                4E1E 54
                4E1F 49
                4E20 4D
                4E21 55
                4E22 4C
                4E23 55
                4E24 53
                4E25 20
                4E26 47
                4E27 45
                4E28 4E
                4E29 45
                4E2A 52
                4E2B 41
                4E2C 54
                4E2D 4F
                4E2E 52
                4E2F 20
                4E30 2B
                4E31 20
                4E32 50
                4E33 48
                4E34 41
                4E35 53
                4E36 45
00765           4E37 20             FCC    25, ANALYSIS (A) OR STIMULUS
                4E38 41
                4E39 4E
                4E3A 41
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       4E3B 4C
       4E3C 59
       4E3D 53
       4E3E 49
       4E3F 53
       4E40 20
       4E41 38
       4E42 41
       4E43 29
       4E44 20
       4E45 4F
       4E46 52
       4E47 20
       4E48 53
       4E49 54
       4E4A 49
       4E4B 4D
       4E4C 55
       4E4D 4C
       4E4E 55
       4E4F 53
00766  4E50 20              FCC    21, GENERATOR ONLY (G)?:
       4E51 47
       4E52 45
       4F53 4E
       4E54 45
       4E55 52
       4E56 41
       4E57 54
       4E58 4F
       4E59 52
       4E5A 20
       4E5B 4F
       4E5C 4E
       4E5D 4C
       4E5E 59
       4E5F 20
       4E60 28
       4E61 47
       4E62 29
       4E63 23
       4E64 3A
00767                  *START UP ROUTINE*
00768  4E66                    ORG    $4F66
00769  4E66 0F                 SEI
00770  4E67 86 F1              LDA A  ?$F1
00771  4E69 B7 FCF4            STA A  $FCF4
00772  4E6C 8E FF7F            LDS    ?STACK
00773  4E6F CE 4500            LDX    ?M3685
00774  4E72 BD 4035            JSR    OUTSTR
00775  4F75 C6 7E              LDA B  ?$7E      JMP INSTR
00776  4E77 F7 FF04            STA B  $FF04     EXEC20
```

```
00777 4E7A FD FE00          JSR     INCH
00778 4E7D 81 47            CMP A   ?$47
00779 4E7F 27 07            BEQ     START2
00780 4E81 81 41            CMP A   ?$41
00781 4E83 27 11            BEQ     START4
00782 4E85 7E FED6          JMP     $FED6       GO TO MINIBUG CONTROL
00783 4E88 CE 4E8E START2   LDX     ?FXEC25
00784 4E8B FF FF05          STX     $FF05       STIM GEN ONLY
00785 4E8E C6 39            LDA B   ?$39        RTS INSTR
00786 4E90 F7 FF07 START3   STA B   $FE07       EXEC30
00787 4E93 7E 4399          JMP     INFOPM
00788 4E96 CE 4A6F START4   LDX     ?STATS      STIM GEN + ANALYSIS
00789 4E99 FF FF05          STX     $FF05
00790 4E9C CE 48D4          LDX     ?TRANS
00791 4E9F FF FF06          STX     $FF06
00792 4EA2 20 EC            BRA     START3
00793 FF57                  ORG     $FF57       INTERRUPT
00794 FF57 7E 4FE7          JMP     $4FE7
00795 FF2E                  ORG     $FF2F
00796 FF2E 4E66             FDB     $4E66       START FROM MINIBUG
00797                       END
```

SYMBOL TABLE

```
PIAC   0000  PIACRC 0001  PIAD   0002  PIACRD 0003  PIAE   0040
PIACRE 0041  PIAF   0042  PIACRF 0043  HARBUF 003D  PHABUF 003A
SCR    3A40  INCH   FE00  OUTCH  FEBE  OUT2H  FEBB  STACK  FF7F
EXEC20 FF04  EXEC30 FF07  INFOPM 4399  EXEC25 48B5  MULT   46F3
DPD    46B4  FOS    4712  OUTLFC 467C  OUT6S  46B2  OUTSTR 4632
MESBUF 004F  MS620  4F00  MS630  4FA8  MS631  4EE8  TRANS  48D4
TRAN1  48DA  TRAN2  48E2  TRAN8  48EB  TRAN9  48F0  TRAN12 4937
TRAN14 4949  TRAN15 494A  TRAN17 4963  TRAN18 496B  TRAN26 4979
TRAN35 4981  TWOMPY 4995  TWOMP2 4998  TWOMP2 499E  TWOMP5 49A6
TWOMP6 49A7  NEGAB  49AA  AMPLI  49B1  SQRT   49C3  SQRT2  49D0
SQRT3  49D2  SQRT9  49ED  SQRT10 49F9  ARC    49FA  ARC01  4A00
ARC02  4A04  ARC04  4A0B  ARC10  4A11  ARC12  4A18  ARC14  4A1D
ARC45  4A1E  ARC50  4A25  STATS  4A2E  STAT10 4A46  STAT12 4A48
STAT20 4A50  STAT30 4A6E  STAT32 4A86  STAT40 4AE9  STAT41 4AEB
DIV2C  4AF4  DIV2C8 4AF9  DIV2C1 4B09  STAT42 4B11  STAT44 4B29
STAT46 4B45  STAT48 4B55  TCINT  4B5F  TCINT1 4B64  TCINT2 4B6A
TSTTC  4B6D  TSTTC1 4B74  TSTTC2 4B78  STAT50 4B7A  STAT55 4BBA
STAT57 4BD7  STAT59 4BE5  STAT65 4C25  STAT67 4C39  OUTS4  4C7F
OUTS5  4C81  STAT70 4C94  HDEC   4CA9  HDEC1  4CB4  STAT72 4CC1
STAT74 4CC3  STAT78 4D13  STAT80 4D31  STAT82 4D40  STAT86 4D50
STAT88 4D61  DISP20 4D66  DISP25 4D6D  DISP30 4D92  DISP32 4D94
DISP34 4D97  DISP10 4DAC  DISP11 4DB1  DISP12 4DB9  DISP14 4DBF
DISP15 4DC4  MS635  4E00  START2 4E88  START3 4E90  START4 4E96
```

Table C.3 EPROM number 1 located at 4200 to 43FF

(The EPROM contents are printed here in the format of the MINIBUG loader. Each line begins with 'S1' , except the last line which begins with 'S9'. The next two characters specify the length of the line. Next there are four hexadecimal characters which identify the address of the first byte of the data which follows. The last byte of the line is not a data byte but a checksum, used for error detection in MINIBUG.)

```
S1134200808082836588888898B8C8E909193949697EF
S1134210999999C9D9FA0A2A3A5A6A8A9ABACAEAF5A
S1134220B1B2B3B5B6B8B9BABCBDBFC0C1C3C4C5D9
S1134230C7C8C9CACCCDCECFD1D2D3D4D5D6D8D97C
S1134240DADBDCDDDEDFE0E1E2E3E4E5E6E7E8E952
S1134250EAEAEBECEDEEEFEFF0F1F1F2F3F3F4F563
S1134260F5F6F6F7F8F8F9F9FAFAFAFBFBFCFCFC88
S1134270FDFDFDFDFEFEFEFEFEFFFFFFFFFFFFFF57
S1134280808080808080807F7F7F7E7E7D7D7C7B46
S1134290797877757472716F6D6B6A6867656463 3A
S11342A0636363646563676A6D71757A80868D959CB6
S11342B0A5ADB6BEC7CFD7DFE6ECF2F6FAFDFEFF3A
S11342C0FFFF544F4E452C50554C53452C4C4F47F3
S11342D04F4E3A4552524F523A524550542052415 1
S11342E054452048 5A3A52455054205045524 94F5B
S11342F044204D533A50554C53452057494454485 3
S1134300205553 3A504F4C4152495459 3A4C4F4717
S1134310 4F4E2054432055533A544F4E4520465255
S1134320455120485A3A544F4E4520504552494F22
S1134330442055533A42555253542057494454480 8
S1134340204D533A4E4F2E4F462053544 94D554C11
S1134350493A4E4F2E4F46204359434C45533A5207
S1134360495345205449 4D45204D533A46414C4C00
S1134370205449 4D45204D533A20545249 7205426
S1134380494D45204D533A5245414459 3A4E4558BA
S1134390542853 2C472C41293A0F8EFF7FCE434497
S11343A08D36CE3A58BD46422A037E446C2209FE1D
S11343B03A58FF3A54092774CE42D98D18CE3A5A43
S11343C0BD46422B1622650909 6F006F068664A755
S11343D001BD46B425E220177E4632CE42F6BD46F4
S11343E036CE3A588D7A2BD02242BD449825ECA67D
S11343F005B73A4FCE3A50FF3A608631B73A5F3646
S90000
```

Table C.4 EPROM number 2 located at 4400 to 47FF

```
S1134400BD467C32BDFE8ECE4379BD4638CE3A5869
S113441C8D4E2E20DFD4498B63A4FA005FE3A60A7D2
S1134438000703A61B63A5F40813526D0CE42C28DCB
S113445CA7ED488886C1C150270CC14C270AC1542C
S1134480B6EA484848487B3A40CE4304BD4635BDFC
S11344A5046880150271863A40C14E2B0648200960
S11344C07E4642C14126E28B80B73A40B63A408547
S11344E003F62B850C261BCE4319BD4632CE3A585C
S1134500BDE2B1F2E44860187027030860AA706F6
S1134520202E7E45E37E45BF6F026F06860AA70382
S113454A07E46B4CE432ABD4636CE3A5A8DB22BC78D
S113456B0218030986F3A700863047018604A706F5
S113458C08DBE25B3FE3A5CFF3A42CE4325BD456DF1
S11345AD025F82932861981042407CE42D38D4C8015
S11345CE0E9CE3F402863C6FFE01DA21CA704E705C1
S11345F0CE3A5C8602A7028692A7036F068DA1B608
S1134610A4FA10525D4CE435F8D6225F9298BCEE0
S1134630A40A61CE61DEB05A904A13925102604A2
S1134650C1FF250ACE42D38D0220DB7E4638A70688
S1134670E7078D76FE3A5EFF3A4ACE436C8D2E2510
S1134690F92928CE3A408639C6FFE01DA21CA106EF
S11346B50250626BFE1072407CE42D38DCE20DBA708
S11346D008E7098D45FE3A5EFF3A4C20748DBCCEB7
S11346F703A58BD46422B18222D6D00262B8642E668
S1134718001BD46F3A704E70539CE4352BD4636CEF6
S1134730A58BD4642261186128A706FE3A42FF3A11
S1134748A05ACE3A5820160B390D39FE3A5C27FACE0A
S1134760A5A8680A7006F018602A7067E46B4CECB
S1134778042F58D6ECE3A588D792BF42262863CA743
S1134790028C4A70386DA97068DE1FE3A5CFF3A69
S11347A804A204CCE430D8D4ACE3A5A8D552BF42297
S11347C03E09098697A70086FFA7018603A7068DB3
S11347E0BB25E0FF3A5CFF3A42FF3A5ACE8000FFF7
S1134800103A58CE3A528601A7068DA18619A10425D9
S1134820C28639C6FFE005A204B73A44F73A457E8C
S1134840473181D4820028D3AA600088D50813A26D4
S1134860F7396F006F01BDFE0081302B15A1392EC3
S1134880511840FC6046801690054A26F9AB01A70149
S11348A020E4812E272A813D26024D39815826D205
S11348C0433986200C6068D155A26FB3986DA8D0DC8
S11348E0860D8D09867F20ECBDFE0016397EFEAEB8
S1134900861DA702A600E601445666006601850856
S1134920270280035D2A02C030C50827020036ABBE
S1134940022BE5396F046F056D022B0A6C062B2B5D
S1134960680369022AF664026603A600E601E003B1
S1134980A202250DA700E7010D690520026805690B
S11349A0046801690064A626E10C39CE42D3BD464E
S11349C0320D39B7FF00F7FF0186087FFF034F5F9D
S11349E0059478FF012405FBFF0089007AFF02263F
S1134A10EF39C501870741286043200F4044B73A1C
S1134A20E78642B73A66FE3A66A6000C5022701408C
S1134A4030988FFF7FCE3A40E600C503265C8607A784
S1134A6401A026F1A4A2AFAFE3A44FF3A58C50C2648
S1134A8070BC3A4627048D2426F78D168D448C3A4F
S1134AA04826F78C39FF27318D0A20F7F63A5DB6D3
S1134AC03A5E209EBF3A4CFA3A4D2006B63A4AF6D0
S1134AE03A4BCE3A588D20F63A5A8D863680DB3314
S1134B0080802B07BD46F320072052408D46F340DE
S1134B208B80FE3A599700086FF3A58CE3A5DB63AD5
S1134B4048F63A43E602A9012402BC00E702A70186
S1134B60FE3A5839F642B73A5DBF3A5B2A014044DC
S1134B8088801B73A5EFE3A5DA600FE3A598A7000801
S1134BA0CF3A58CE3A5A9DC89C39FF2A6C7F38FF02
S1134BC086FF9700978079820680D702866249781B8
```

EPROM number 3 located at 4800 to 4BFF

```
S1134800F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134810F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134820F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134830F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134840F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134850F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134860F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134870F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134880F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134890F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11348A0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11348B0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11348C0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11348D0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11348E0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11348F0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134900F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134910F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134920F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134930F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134940F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134950F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134960F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134970F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134980F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134990F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11349A0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11349B0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11349C0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11349D0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11349E0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S11349F0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A00F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A10F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A20F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A30F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A40F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A50F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A60F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A70F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A80F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134A90F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134AA0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134AB0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134AC0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134AD0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134AE0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134AF0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B00F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B10F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B20F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B30F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B40F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B50F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B60F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B70F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B80F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134B90F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134BA0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134BB0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134BC0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134BD0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134BE0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
S1134BF0F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8F8
```

Table C.6 EPROM number 4 located at 4C00 to 4FFF

```
S1134C00870DCE3A72FD45B4A604E605BD49C386D7
S1134C103A873A6E3A68A6E73AAFFE3A6EE7104A58
S1134C203703704E4E8BD4A7CCE4EAFFD4633CE4F0E
S1134C30E0D04632FD467C8601573AA8573A6FA0D07
S1134C40E8D4A72FE3AEEAF00C6CBCE3A72FD4653
S1134C50F3584958980D5396E6D87A601AB011969A6
S1134C6002870186028D1809BFEBB8D178D15BDC8
S1134C704670F43A654C810766FFD4A7CD4088F1
S1134C80807FFEAEBD4672A63A6F8A08B73A6FFE01
S1134C903A6FA600CE3A72C6F45D46F3584958D851
S1134CA002A6038DDA087EFEBFA700C401E701173F
S1134CB0C6096F026800A9011969A2A7015A26F4FF
S1134CC029C601CE3A6857006E4FA7045858581 7EA
S1134CD0581FA705A6005F4456E7078B3C63AA7B5
S1134CE09AE708A60097 09FE3A70A608E610CE3A21
S1134CF064A706E707C618E70DC6688D16A606ABB7
S1134D0007C6788D0EA606A007C6788D0686 18A756
S1134D100D2058E7105F4858485936 37FD47128B69
S1134D2080D73A72335C32D4712CE3A64FB80A7A7
S1134D300FE60FE80FE6 0E6D076C106C102FF239FE
S1134D40A610BD4998FE3A70A700CE3A646C0D395E
S1134D50C47FC1312B10C1362F07C1582E087E48A5
S1134D60B5C0307E4CC3FE3A708614BD27CF4F09FA
S1134D708D20FE3A6C8D1B8D33FE3A6EB63A698DEA
S1134D8013E6FCF4F6FCF54725C69600853027DDFE
S1134D9020D4860CB73A64A600E6018B8CB8053FE
S1134DA0974 0D74208087A3A6426EC39868097 42BD
S1134DB05FD740CB0426FA9740D742CB0426FAC6E5
S1134DC0408D01508683974 0D74240974097 42D701
S10A4DD04040974286803940
S1134E002A4D4943524F5052 4F434553534F52201A
S1134E10535953544 54D2A0D0A0A7F7F7F535449F1
S1134E204D554C5553204745 4E45524154 4F522001
S1134E302B2050484153452041 4E414C595349532E
S1134E402028412920 4F522053544 94D554C555345
S1134E502047454E455241544F52204F4E4C592005
S1084E6028472923 3A54
S10D4E660F86B1B7FCF48EFF7FCE77
S1134E704E00BD4632C67EF7FF04BDFE008147 27C3
S1134E80078141271176FED6CE48B5FFFF05C639FE
S1134E90F7FF077E4399CE4A2EFFFF05CE48D4FF85
S1074EA0FF0820ECF7
S10B4EE8202020205 64F4C54F9
S1114EF0532F485A2020444547524545533A13
S1134F00807C807A807880768074827884786 67CCD
S1134F10867A867886786748C7B8D7C8D7B8D7A7A
S1134F208D798D788D778D768D758D748C748E7466
S1134F308C7C8D7E8F7E917E927C927A90788F7618
S1134F408C743E749074 9274 8C7C8D7E8F7E917E22
S1134F5092 7C927A9078927A9174 8F748D748C761A
S1134F608F758E7C8D7A8C798D788E788F78907801
S1134F708F7C8F7B8F768F74907E8E7E8C7E8C7CE5
S1134F808C7A9E7A907A9178917690748E748C75EE
S1134F90917E8F7E8D7D8C7B8C778C758E749074D6
S1134FA0917691788F768D78484E8020414D50200D
S1134FB04D45414E20205048415345204D45414EDA
S10A4FC0202059 2E443E3A79
S1134FCE7D00023B037FFF03B13A52260 2CB04B1BF
S10C4FD83A532602CF09D7923FAA
S10C4FE75FD7923A0043B13A50F1
S10F4FF026015CB13A5126DECB0220D22F
S90000
```

Table 3.7 Routines to print out the amplitude and phase of the first six harmonics of every response in a trial of up to 64 stimuli.

Locations in ANALYS to be changed are:

4A78	JSR AMPLI	becomes	JSR PRTAMP
4A79	49	"	20
4A7A	B1	"	00
4BC1	JSR ARC	"	JSR PRTPHA
4BC2	49	"	20
4BC3	FA	"	36

Also,

3A7E should be reset to 00

```
2000  BD 49 B1   PRTAMP  JSR  AMPLI     Here to print
                                        amplitudes
      37           PRTO   PSHB
2004  86 0F              LDAA ?0F
      B5 3A              BITA SCR+62
2008  7E 26 06           BNE  PRT1
      BD 46 7C           JSR  OUTLFC    New line, once
200C                                    every 16 points
      BD FE              JSR  OUTS
2010  C7 7C 3A 7E PRT1   INC  SCR+62
2014  32           PULA
      36           PSHA
      5F           CLRB
      BD 4C A9           JSR  HDEC      Convert to
2018                                    decimal form
      A6 02              LDAA 2,X
```

```
201C  8B          ADDA  ?30
      30
      BD          JSR   OUTCH'      Print
      FE                            MS digit
2020  AE
      08          INX
      BD          JSR   OUT2HS      Print two
      FE                            least
2024  C5                            significant
      09          DEX               digits
      09          DEX
      86          LDAA  ?01
2028  01
      B1          CMPA  SCR+48
      3A
      70
202C  26          BNE   PRT2
      06                            Leave one
      7F          CLR   SCR+62      blank line
      3A                            after last
2030  7E                            response
      BD          JSR   OUTLFC
      46
      7C
2034  33    PRT2  PULB
      39          RTS
      BD    PRTPHA JSR  ARC         Print
      49                            phases
2038  FA
      CE          LDX   ?SCR+50
      3A
      72
203C  20          BRA   PRTO
      C5
```

Table C.8 Programme to test the data acquisition board.

This programme may be used to test the calibration of the A/D converter and the general operation of the data acquisition board. Its effect is to print out the reading from the A/D converter about once every second.

```
        4000  0F    SEI                    Initialize PIA's
              86    LDAA    ?FF
              FF
              97    STAA     00
        4004  00
              86    LDAA    ?80
              80
              97    STAA     02
        4008  02
              86    LDAA    ?DB
              DB
              97    STAA     01
        400C  01
              97    STAA     03
              03
LP1           86    LDAA    ?FD            Reset clock
        4010  FD
              97    STAA     02
              02
              7C    INC      02            Data buffer to A/D
        4014  00
              02
LP2           08    INX                    Delay
              01    NOP
        4018  26    BNE      LP2
              FC
              86    LDAA    ?7F
              7F
        401C  97    STAA     02
              02
              CE    LDX     ?0101
              01
        4020  01
              BD    JSR     OUT2HS          (In MINIBUG)
              FE
              C5
        4024  20    BRA      LP1
              E9
```

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