Neural Network Based EEG Signal Processing

Project Report 1996-97

Submitted in partial fulfilment of the requirements
for the award of the Degree of
BACHELOR OF ENGINEERING
in Electronics and Communication Engineering
of the Bharathiar University

Submitted by

K. Suresh　　A. Anand
V. Rajesh Kumar　　J. Sri Ganesh

Guided by

Mrs. K. Chitra, M.E.,

Department of Electronics and Communication Engineering
Kumaraguru College of Technology
Coimbatore - 641 006

Department of Electronics and Communication Engineering

Kumaraguru College of Technology

Coimbatore - 641 006

Certificate

This is to certify that the Report entitled

Neural Network Based EEG Signal Processing

has been submitted by

Mr. A.ANAND ; M.SURESH ; V.RAJESH KUMAR ; [illegible]

In partial fulfilment for the award of Bachelor of Engineering in Electronics and Communication Engineering Branch of Bharathiar University, Coimbatore - 641 046 during the academic year 1996 - '97

Guide

Head of the Department

ate : 9.4.97

ertified that the candidate was examined by us in the project work iva-Voce Examination held on ____________ and the University egister Number was ____________

Internal Examiner

External Examiner

ACKNOWLEDGMENT

We thank the LORD Almighty for His blessings and the strength He bestowed on us to do this project work successfully.

We express our heartfelt gratitude to our principal Dr.S.SUBRAMANIAN, M.Sc.,(Engg.), Ph.D., M.I.S.T.E., for the encouragement and interest he had evinced in our project.

We express our deep indebtedness and gratitude to our beloved Prof. MUTHURAMAN RAMASAMY, M.E., M.I.S.T.E., M.I.E.E.E.(U.S.A.), M.I.E.,C(ENGG)., Professor and Head of the department of Electronics and Communication Engineering for being the source of inspiration and for his valuable ideas.

Our revered thanks to our guide Mrs.K.CHITRA, M.E., for her inspiring guidance, constructive support and timely advice in the successful completion of this project.

We thank Mr.M.Arul, Scientist, ANURAG, Hyderabad for his valuable suggestions which has helped us a lot to improvise on the project at every stage.

We also express our sincere thanks to all the staff members, non-teaching staff members of the ELECTRONICS AND COMMUNICATION ENGINEERING department and all our friends for their timely help in the prompt and successful completion of our project.

Synopsis

Presently, electroencephalography(EEG) is totally a hardware based technique. So, when a machine with better accuracy and sophistication arrives in the market, it is unaffordable for the rural hospitals. **This work aims at converting the EEG technique into a totally software based one. Neural networks** are a valuable tool in the software analysis of EEG wave patterns. Once this is achieved, up-to-date technology can be transferred from research institutes to even the remotest hospitals. It is just a matter of software version update.

Neural style processing represents a radical departure from traditional based handling of digital information and provides acceptable solutions to processing time. Identification of K-complex waveform from EEG is one such example. **Neural network is used as a pattern matcher** to compare the observed value with ideal values and detect the waveforms. This requires a definition of a set of features that adequately describe the waveform .**The coefficients of a 7^{th} order linear prediction filter are used as the feature set.** The Artificial Neural Network (ANN) provides solution to problems that are not amenable, to analytical methods or requiring huge amounts of processing time. Tested simulation results show that the artificial neural network was able to successfully recognize the K-complex pattern.

The charm of the neural network lies in its relative success over many real world problems which were unapproachable all these years by conventional techniques. The study of human brain is an ideal example. The beauty is that **this project work uses the computational technique inspired from the brain itself** to analyze the same magic stuff again !

In the urban areas, as the pace of industrialization and congestion increases it is becoming increasingly difficult to prepare a site without electromagnetic disturbances to install EEG machine. By designing a software based EEG machine, wide variety of **software filters can be designed to tackle this EM interference**.

CONTENTS

CHAPTER I

INTRODUCTION

CHAPTER II

ELECTROENCEPHALOGRAM

CHAPTER III

STUDY OF K-COMPLEXES

CHAPTER IV

EEG SIGNAL PROCESSING

CHAPTER V

ARTIFICIAL NEURAL NETWORKS

CHAPTER VI

SOFTWARE IMPLEMENTATION

CHAPTER VII

SIMULATION RESULTS

1.1 ELECTROENCEPHALOGRAM

Electroencephalogram (EEG) represents the pattern of minute changes in electrical potential of the scalp of a human. It reflects the general functional state of brain, such as different states of wakefulness and sleep of metabolic disturbances. Only in very few cases it is possible to establish a diagnosis from EEG alone and without having to use additional information on neurological symptoms. About 15% of the population show EEG abnormalities but do not suffer from any neurological disease. It is a noninvasive diagnostic tool in a wealth of neurological disorders, e.g. , epilepsy, early diagnosis and localization of brain tumors, coma assessment in intensive care, and in the definition and assessment of sleep stages.

1.2 ANALYSIS

1.2.1 MANUAL ANALYSIS

A normal EEG recording session typically yields a paper write-out of 18-36 meters of length of data. The analysis and interpretation of such a large volume of data is not only very time consuming but also mentally very taxing. However, the skilled neurophysician does not seem to take much time for this job and does it with relative ease. The reason for this becomes apparent when one considers the fact that invariably the EEG record will exhibit a certain stationarity known as **"background activity"**. From time to time the stationary activity is interrupted by the occurrence of different but special waveforms called **"paroxysms", if abnormal, "spindles"** or if they last longer than a couple of seconds "runs", which in themselves again have a stationary appearance.

Quite different kinds of non-stationarities that occur are the transient phenomena-simple conspicuous waves called **"spikes"** indicative of **epileptic disorders**. The neurophysician thus will spend as much time with the usually rare stretches of abnormal activity as with the background activity, which although predominant, carries little information. The diagnostic information in reality is contained in the above mentioned specific waveforms of the EEG.

1.2.2 AUTOMATED ANALYSIS

Recognition of these waveforms has been the subject of much research. A **12th order** low pass **chebyshev filter** has been designed for EEG frequency bands separation. Its implementation using the national semiconductor MF10 has been reported. Other techniques used, range from statistical methods to syntactic and knowledge based approaches. All these methods require the definition of the set of features that adequately describe the waveform to be detected and a pattern matcher to compare the observed values with the ideal ones. The general scheme of pattern recognition has applied to EEG is as shown below:

EEG → Features → Classification

Note now the problem of the detection of specific waveform in the EEG is reduced to that of a pattern recognition problem.

1.3 ROLE OF ANN IN AUTOMATED ANALYSIS

Recent developments in the field of neural networks have raised the possibility of using them for classification of patterns. A number of artificial neural network (ANN) algorithms and models have been published in the literature, both for continuous and binary data. ANNs for K-complex (A clinically important wave pattern in epileptic diagnostics) detection in EEG signal have been reported in using bandpass filtered EEG data. However, this study did not seem to be adequate for the detection of K-complexes. One of the reasons adduced is that the band pass filter did not perform location invariant detection. Also that the classification was attempted on a single channel basis when, in fact, the human detection is largely based on contextual information i.e. inter and intra channel comparisons .

In this work an ANN that is based on the principle which extracts features from the EEG by adaptive segmentation is constructed. The entire length of EEG data is segmented adaptively using the technique of Linear Prediction. A segment that corresponds to stationary activity is specified by its linear prediction coefficients and the non-stationary activity of typically 100 msec or less is specified by the graph-elements.

1.3.1 NEURAL NETWORK ALGORITHMS

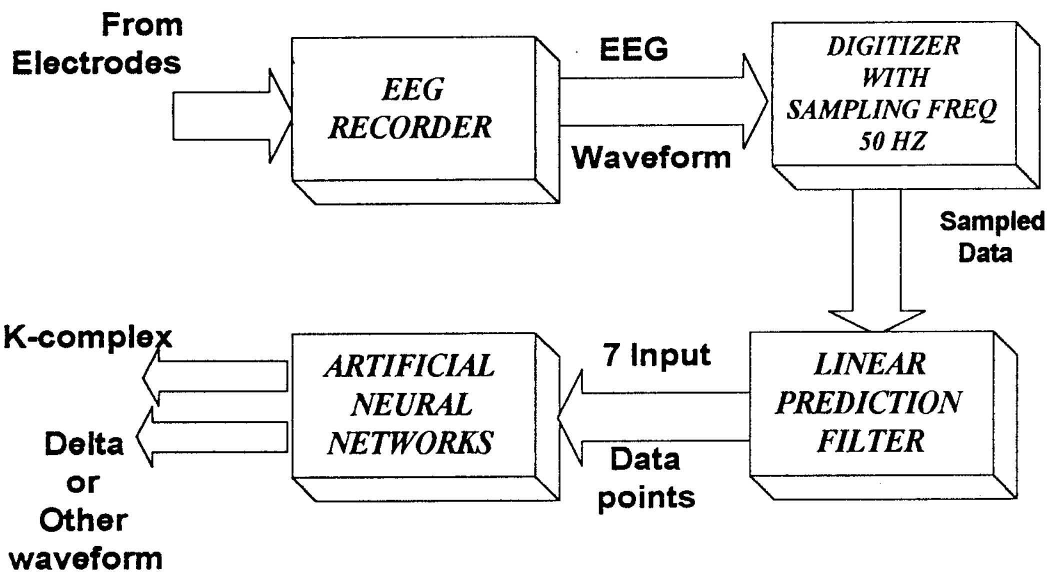
BACKPROPAGATION

For many years there was no theoretically sound algorithm for training multilayer artificial neural networks.

The invention of the backpropagation algorithm has played a large part in the resurgence of interest in artificial neural networks. **Backpropagation is a systematic method for training multilayer artificial neural networks**. It has a mathematical foundation that is strong if not highly practical. Despite its limitations, backpropagation has dramatically expanded the range of problems to which artificial neural network has applied ,and it has generated many successful demonstrations of its power.

1.4 EEG SIGNAL PROCESSING

The EEG patterns are highly chaotic. The analysis of such complex data by conventional tools requires adequate description of the features of the waveforms. Thus EEG signal processing constitutes important part of the present work. The data processing involved the study of various methods including Spectrum Analysis and other conventional methods. Methods of feature extraction were studied and finally it was decided to use the coefficients of a 7^{th} order "LP" filter.



BLOCK DIAGRAM

NEURAL NETWORK BASED EEG SIGNAL PROCESSING

1.4.1 FUNCTIONAL ANALYSIS

The electrodes are placed in the standard electrode positions on the human head with the help of sophisticated EEG recorder and brain waves are recorded. These recorded EEG waveforms are sampled at a frequency of 50 Hz with the help of commercial scanner. These sampled data points are then fed to a Linear Prediction Filter. The 7 "LP" coefficients reduces the complexity of the neural network. The 7 data points are then fed as input to the ANN in which the backpropagation algorithm is implemented. This networks detects whether the input is K-complex ,delta or other waveform.

1.5 SCOPE OF PRESENT WORK

Keeping in view that the human detection of K-complex is largely based on contextual information, it is proposed to use multichannel data of EEG for a better and more robust detection of K-complexes. The detection algorithm is the Backpropagation algorithm.

1.6 STRATEGY OF PRESENT WORK

The work is carried out in three phases. Phase-I is devoted to carry out in-depth study of K-complexes. Phase-II is concerned with development of suitable data pre-processing strategy. Phase-III involves designing a suitable ANN for single channel EEG detection of the complexes and assessing the performance of the network.

OVERVIEW

The successive chapters will deal with the following topics. The second chapter deals with the EEG signals and the clinical importance of EEG waves. The third chapter gives an in-depth study of K-complex and associated wave forms. The fourth chapter deals with the data pre- processing strategies including Data collection and the feature extraction by LPC.

ANN is introduced in the fifth chapter. Principles of operations and designing principles are discussed. Sixth chapter deals with backpropagation algorithm and the implementation of Neural Net Simulator software. The Seventh chapter discusses the results, conclusion and future developments are also considered.

2.1 INTRODUCTION

It may have been more good fortune than prophetic insight which led Hughlings Jackson in 1873 to define **epileptic seizures as occasional sudden, excessive, rapid and local discharges of grey matter**, for half a century was to elapse before it became possible to record such discharges by means of the electroencephalogram, or EEG.

The fact that the brain exhibits spontaneous activity was reported by Caton (1875,1887), who used Thomson's reflecting galvanometer connected to the electrodes applied to a variety of different animals. It was about a half-century later when the electrical activity of the human brain was recorded by Berger(1929), who employed a string galvanometer connected to scalp electrodes. Bergers first and succeeding papers were largely unnoticed until Adrian and Mathewss (1934) in Great Britain and Jasper and Carmichael (1935) in the United States reviewed them and confirmed Berger's findings, thereby introducing electroencephalography to the English-speaking world.

2.2 EEG RECORDING

The electrical activity of the brain is recorded with three types of electrodes - scalp, cortical, and depth.

2.2.1 SCALP RECORDING

With scalp electrodes the recording is called an electroencephalogram(EEG). When electrodes are placed on the **exposed** surface (cortex) of the brain, the recording is called an electrocarticogram(ECOG). Electrodes also may be **advanced into the brain** , in which case the term **"depth recording"** designates the technique. It is interesting to note that there is surprisingly little damage to the brain with depth recording. Whether obtained from the scalp, cortex, or depths of brain. The potentials recorded represent the activity of numerous neurons in which fluctuating membrane and action potentials are occurring. These three different techniques are therefore examples of extracellular recording.

2.2.2 CORTICAL & DEPTH RECORDING

Intracranial electrodes provide a clearer picture of the electrophysiological events during a seizure than does the scalp EEG. In humans, the occasions to insert intracranial electrodes arises only where there is thought to be a possibility of neurosurgical treatment. An electrode at the site where the seizure commences will typically show at the onset of the attack a high frequency discharge, perhaps of 60/s or faster, reflecting a highly synchronized activity within a very restricted volume of surrounding brain. Sometimes seizure onset is characterized by alternating spiky waveforms and slower components (spike &wave), more commonly such activity appears only in a later phase of the seizure .

2.3 EFFECTS OF SLEEP

During sleep the EEG changes dramatically, showing first the loss of alpha rhythm , and then with increasing depth of sleep, progressively greater amounts of slow activity. Sleep depth is conventionally classified into four levels according to criteria proposed by Dement & Klietmann in 1957. There is further stage of sleep characterized by **Rapid Eye Movements** (REM) and associated with dreaming. Interictal epliptiform discharges are often very sensitive to changes in the state of awareness. With the onset of drowsiness and stage-1 sleep, generalized spike wave activity may either disappear or increase, but focal discharges will generally become more frequent or may appear if absent in the alert state. In light(stageII) sleep the focal epileptiform activity is generally most prominent, whereas generalized discharges may attain a maximum in stage III. REM sleep is usually associated with a reduction abolition of both generalized (Gastaut et al 1965, Ross et al 1966, Billiard 1982) and focal discharges (Batini et al 1963).

2.4 CLINICAL VALUE OF THE EEG

The EEG has its greatest value as an aid in the diagnosis and differentiation of the many types of **epilepsy, a condition in which groups of neurons in the brain become hyperirritable and**

depending on their location, produce both sensory, motor and automatic manifestations. The epilepsies associated with cortical lesions are often detected by the scalp EEG. The EEG in epileptics is usually abnormal between the attacks. The EEG often provides information on the localization of the area (areas) of abnormal neuronal activity. In epilepsy in general, the characteristic finding is of spikes (i.e. ,short duration waves), alone or in association with other waves. For example, in petit-mal epilepsy, in which there is a transient alteration of consciousness (often not easily detected), the EEG shows a characteristic spike and wave activity.

3.1 STUDY OF K-COMPLEXES

K-complexes were first described by Loomis et al (1938); the reasons for calling them "complexes" remains obscure (there have been reports that naming was made at the spur of the moment without any significance to the letter K)

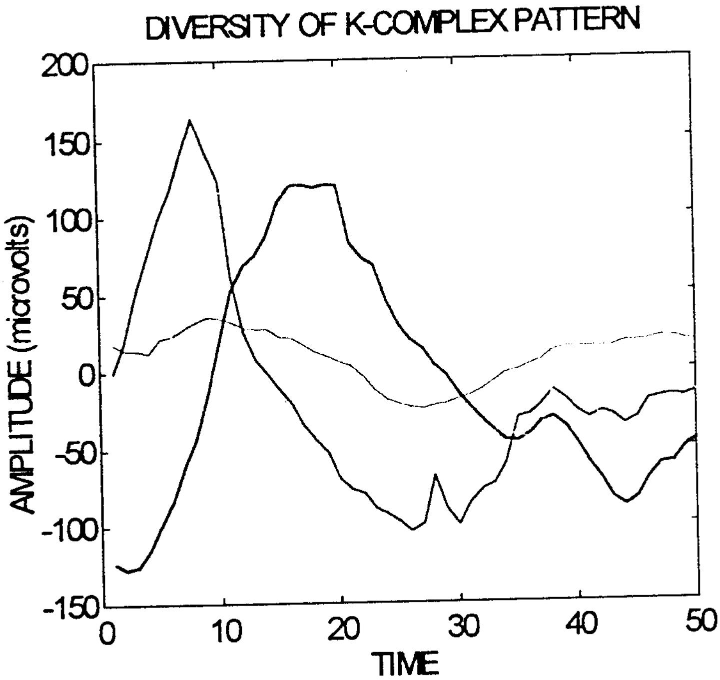
H. Davis et al (1939) gave an excellent description of the single component of the K-complex. As to the topographic distribution, the K-complex shows a maximum over the vertex, but there are also K-complexes with the indubitable maximum over the frontal midline (see fig 2.1).

Brazier (1949) presumed two distinct generators : these were area 6, corresponding to the vertex and area 9, corresponding to the frontal midline. The distinction of these two types has important epileptological implications. The sharp component was thoroughly investigated by Roth et al (1956).

Modern descriptions and EEG glossaries have blurred the dividing line between the K-complex originating from the vertex and the frontal midline. Dutertre (1977) stresses the vertex maximum only.

The ontogenitic evaluation of the K-complexes has certain epileptological implications. A distinction between spontaneous and click evoked K-complexes was made by Halasz et al (1982), who investigated the relation between these two.

3.2 K-COMPLEX WAVE MORPHOLOGY



An in-depth study of K-complex from medical literature revealed the following important features about K-complexes which have a direct bearing on the design of optimal neural net topology for their detection.

K-complexes make their appearance in stage II sleep and constitute an impressive response to arousing stimuli. An ideal K-complex consists of an initial sharp component followed by a slow component that fuses with a superimposed fast component (fig 2.1). The sharp component is biphasic and it shows greater complexity and greater variation from complex to complex. The sharp component was thoroughly investigated by Roth et al. who stated that the maximum amplitude of this is about 200 microvolts. The slow component is represented by a large slow wave that may exceed 1000 msec in duration. Superimposed on the slow component are 12-14 Hz sleep spindles that represent the fast component. Often, sleep spindles (delta activity) are also found in the neighborhood of K-complexes. Apart from the above description of the K-complex itself, the **occurrence of delta activity can also be used to detect it.**

The **age factor** has a **strong influence** on the wave morphology. The sharp component of the K-complex is particularly prominent after the age of 4 and starts declining during second decade. The K-complex is largest in older children and starts to decline in early adolescence. With **advancing age**, the K-complex shows a **decline of voltage** and often degenerates into an insignificant slow potential with tiny superimposed spindle like waves. Probably the brain needs retirement !

Depending on the site of origin in brain, the K-complexes are divided into 3 types, 1) frontal, 2)central and 3)vertex (fig-2.2). These areas in the scalp are indicated in fig-2.3 showing the standard EEG electrode positions approved by International Committee for EEG. An EEG QUICK REFERENCE CHART (APPENDIX-III) may be useful in understanding the terminology of the EEG technique.

4.1 DATA COLLECTION

To account for the above mentioned variations of K-complex depending on the age, the patients were **selected from all age groups in the years viz. 1, 5, 8, 10, 17 , 38 and 47.** Apart from these, two patients were included without age information. From their EEG, thirty three K-complexes, thirty three non K-complexes and 16 delta waveforms were taken for the experiment. The data was divided into two sets of which one is training data and the other is testing data.

All the **EEG data** used in this experiment were obtained from the **frontal channels**.

4.1.1 DATA REPRESENTATION

<u>A brief background</u>

Basically, neural networks need vectors of numbers as inputs. So, our first task is to represent the K-complex as a vector of numerical values. After this digitization process, an investigation is needed to determine the way of representing this vector in an optimal way because neural networks learn faster with lesser inputs.

Earlier works

The main problem encountered in previous attempts was that the weights never converged even after long training sessions. This is due to the large number of neurons required in the net which became essential because of the large number of input points (500).This high number of inputs was the result of taking 10 sec input data. The 10 sec input data invariably contains a sleep spindle before K-complex which was used as a confirmatory factor.

The first exercise was to cut down the number of input points to design a neural net of moderate number of neurons. It was observed that in all the data collected, all the **three component of the K-complex were pronounced in 1sec interval**. That 1 sec interval was chosen in which the K-complex occurs and it was digitized at 50 Hz using a laser scanner.

These scanners will convert the **EEG waveform** sheet into an **image**. The format of the image can be PCX or BMP or any popular image format. This image is displayed by the **"Paint Brush"** utility in windows. Then in the 'view' menu option, 'cursor position' option is selected. In the top right corner of the screen X,Y co-ordinates will be displayed. By dividing the 1 second interval into 50 points on X axis, corresponding Y values can be noted by moving the cursor (co-ordinates will be upside down .Appropriate scaling is needed).The digitizing frequency of 50 Hz was chosen because the diagnostically relevant **spectral content of the EEG lies within the range of 1 to 25 Hz** and this criterion satisfies the Nyquist sampling theorem also (Minimum sampling frequency is twice the maximum signal frequency).

Now the number of inputs is reduced from 500 to 50. Even then, a large number of neurons is required. To solve this problem, it was decided to use a 7^{th} order linear prediction filter for 50 consecutive data points and these **7 LP coefficients will form the feature set** of that particular 50 data points.

4.2 Feature Extraction Using Linear Prediction

Prediction constitutes a special form of estimation. Specifically, the requirement is to use a finite set of present and past samples of a stationary process to predict a sample of the process in the future. The difference between the actual sample of the process at the future time of interest and the predictor output is called predictor error. According to Wiener filter theory, a predictor is designed to minimize mean-square value of the predictor error.

We shall assume that the signal is sampled at discrete times, that is, we consider the time series,

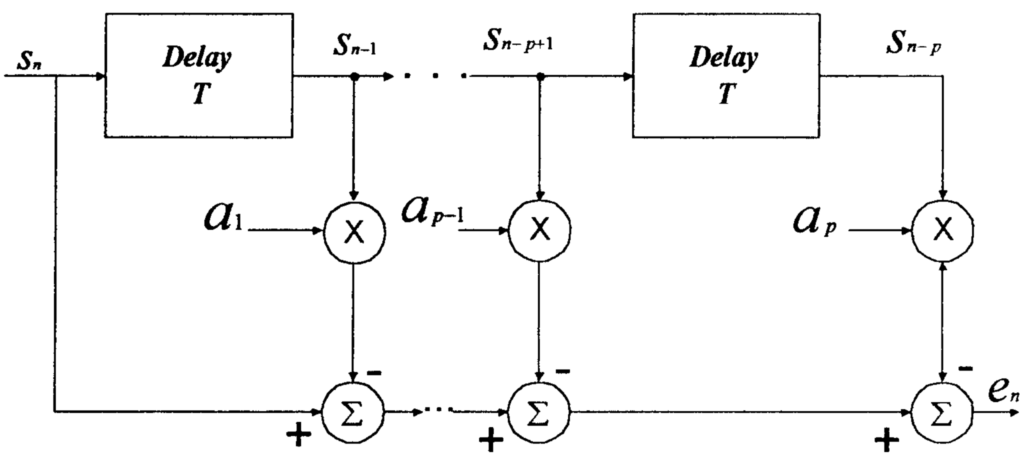
$$\{\ s_n\} = \{\ .\ .\ .\ ,\ ,\ s_{-1}, s_0, s_1,\ .\ .\ .\} \qquad ......(2.1)$$

Suppose the requirement is to make a prediction of the sample s_n. Let s_n denote the random value resulting from this prediction. We thus write ,

$$s_n' = -\sum_{k=1}^{p} a_k \cdot s_{n-k} \qquad .....(2.2)$$

The coefficients 'a_k' are called the "predictor coefficients ", and 'p' is the filter length. The error made in this estimation, the 'prediction error' (PE), is given by the equation

$$e_n = s_n - s_n' = \sum_{k=0}^{p} a_k \cdot s_{n-k} \quad \text{Where } a_0 = 1 \qquad .....(2.3)$$



Using the "autocorrelation method ", minimization of the rms prediction error over a finite interval of length N leads to the normal equations for the predictor coefficients thus :

$$\sum_{k=1}^{p} a_k \cdot R(i-k) = -R(i), \quad i = 1 \ldots p \qquad \ldots.(2.4)$$

Where the autocovariance matrix R is defined by the equation

$$R(i) = \frac{1}{N} \cdot \sum_{n=1}^{N-|i|} s_n \cdot s_{n+|i|} \qquad \ldots..(2.5)$$

We will denote the set of coefficients $\{1, a_1, \ldots, a_p\}$ by the "LP" filter.

4.3 FILTER IMPLEMENTATION

The fifty data points obtained by digitizing each of the one second EEG data are converted to the corresponding 7 LP filter coefficients as follows :

Step- I: Determine the autocovariance matrix R(i):

$$R(i) = \frac{1}{N} \cdot \sum_{n=1}^{N-|i|} s_n \cdot s_{n+|i|} \qquad i = 0, \ldots, 7 \qquad \ldots\ldots(2.6)$$

where N= no. of samples (50)

s_n = EEG data points

and

Step II: Solve the autocorrelation normal equation :

$$\begin{pmatrix} R_0 & R_1 & \cdots & R_6 \\ R_1 & R_2 & \cdots & R_5 \\ \vdots & \vdots & & \vdots \\ R_6 & R_5 & \cdots & R_0 \end{pmatrix} * \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_7 \end{pmatrix} = \begin{pmatrix} R_1 \\ R_2 \\ \vdots \\ R_7 \end{pmatrix} \qquad \ldots\ldots(2.7)$$

$a_1 \cdots a_7$ are the desired LP coefficients. The program for the determination of LP coefficients was implemented in MATLAB.

4.4 DATA STRUCTURE

The filter order should ensure that the predictor will yield a sufficient feature set. A rule of thumb is that the **predictor order should be atleast twice the number of expected resonances in the spectrum**. Experience shows that rarely more than two resonances are present in the EEG simultaneously. So an optimum number of 7 was chosen as the filter order. We have arrived the following data structure.

No. of inputs	- 7 [LP coefficients]
No. of outputs	- 1 [whether a k-complex or delta activity or other random activity]

5.1 INTRODUCTION

Artificial neural net models or simply "neural nets" go by many names such as connectionist models, parallel distributed processing models, and neuromorphic systems. Whatever the names, all these models attempt to achieve good performance via **dense interconnection of simple computational elements.** In these respect, artificial neural network structure is based on our present understanding of biological nervous system.

Neural network models have the greatest potential in areas such as speech and image recognition where many hypotheses are pursued in parallel and computation rates are required. It may be noted that the current best systems are far from equaling from human performance. Instead of performing a program of instructions sequentially as in a Von Neumann computer, neural net models explore many competing hypotheses simultaneously using **massively parallel** nets composed of many computational elements connected by links with variable weights.

Computational elements or nodes used in neural net models are nonlinear, are typically analog, and may be slow compared to modern digital circuitry. Fig.3 shows two common types of nonlinearities; threshold logic elements and sigmoidal nonlinearity. More complex nodes may include temporal integration or other types of time dependencies and more complex mathematical operations than summation.

Neural net models are specified by the **net topology, node characteristics, and training or learning rules.** These rules specify an initial set of weights and indicate how weights should be adapted during use to improve performance. Both design procedures and training rules are topic of much current research.

The potential benefits of neural nets extend beyond the high computational rates provided by massive parallelism. Neural nets typically provide a greater degree of robustness or fault tolerance than Von Neuman sequential computers because there are many more processing nodes , each with primarily local connections. **Damage to a few nodes or links thus need not impair overall performance significantly.**

Most neural network algorithms also adapt connection weights in time to improve performance based on current results. Adaptation or learning is a major focus of neural net research. The ability to adapt and continue learning is essential in areas such as speech recognition where training data is limited and new words, new words, new dialects, new phrases and new environments are continuously encountered. Adaptation also provides a degree of robustness by compensating for minor variability's in characteristics of processing elements.

Traditional statistical techniques are not adaptive, but typically process all training datas simultaneously before being used with new data. Neural net classifiers are also non-parametric and make weaker assumptions concerning the shapes of underlying distributions than traditional statistical classifiers. They may thus prove to be more robust when distributions are strongly non-gaussian. Designing artificial neural nets to solve problems and lead to new insights and algorithmic improvements.

5.2 PRINCIPLE OF OPERATION OF ANN

The central element in neural network analysis, or "neurocomputing" is the node which is analogous to a biologic neuron. A network node receives inputs from any number of nodes, sums them, and subjects this value to some function to produce an output that can then be propagated to subsequent nodes in the network (fig-3.2). The processing function can be as simple as all or none activation once the sum of input reaches a certain threshold. A more desirable function is a **sigmoidal relationship, which prevents small signals from being overwhelmed by larger ones.** Unless this property(sometimes referred to as a `squashing` function) is present, multilayer networks perform no better than a single layer network. Intermediate layers of nodes are often called as **hidden**

layers. A network takes any number of inputs(which can be presented as a vector)and processes these through the hidden layers to produce a final output(which can also be represented as a vector).

At each connection in the network, inputs are multiplied by a weighting factor before being summed. During training of a network, the weighting factors at each connection in the network are adjusted using well defined rules until the desired output is obtained. Learning algorithms are designed so that the weighting factors of the network changes slowly, but steadily, to a final set of values. This final set may not be the optimal solution but acceptable.

5.3 DESIGN AND IMPLEMENTATION OF ANN

The design of ANN involves the following factors;

a) Choosing a neural net training algorithm from a wide option available in the literature considering the nature of the problem at the hand.

b)Deciding the network topology i.e. the number of hidden layers.

c) Optimizing the number of nodes in the input layer and the hidden layers.

d) Optimizing the network parameters viz. 1)type of non linearity 2)gain term 3)momentum term and 4)tolerance term.

e) Optimizing the data representation strategy. In the specific context of EEG analysis, this involves the number of channels.

Backpropagation algorithm was chosen because it had been already applied to a number of pattern classifier problems successfully. A three layered network architecture (fig-3.3) was selected due to its ability to generate arbitrarily complex decision regions.

The backpropagation algorithm for training the neural net was implemented in Neural Net Simulator, a neural network simulation program developed in Turbo C ++. Neural net optimization was done as outlined in forthcoming chapters.

5.4 ANN IN EEG ANALYSIS

Using the simple concept of nodes, networks of various designs can be built to simulate a quite complex behavior, the most common and well described application is that of pattern recognition. Earlier we have seen that the problem of detection of specific waveforms in the EEG is nothing but a pattern recognition problem. The use of neural networks for pattern discrimination became possible with the description of the backpropagation training algorithm for multilayer networks.

This algorithm uses the error between the desired output and that which is produced by the network as the adjustment factor of the set of weights acting on the inputs into the last layer of nodes. This algorithm works backward through the network, adjusting the weighting factors at each connection; hence the term "backpropagation". There is a minimum of one hidden layer in this type of network. The number of nodes in this layer can be varied. Learning is completed when the difference between the network and actual output values is less than a selected value called the learning threshold. **A network is trained using a paired input/output data sets, and the process of training is termed "supervised learning".**

When training is done using supervised learning, it must be done on a known data set. To both train and test the network on the same data set, one needs to divide the data set into training and testing sets. The most common method is to use two thirds of the total data for training and to test the network success on the remaining one third.

6.1 INTRODUCTION

The feedforward backpropagation network is a very popular model in neural networks. It does not have feedback connections, but errors are backpropagated during training. Least mean squared error is used. Many applications can be formulated for using a feedforward backpropagation network, and the methodology has been a model for most multilayer neural networks. Errors in the output determine measures of hidden layer output errors, which are used as a basis adjustment of connection weights between the input and hidden layers. A momentum parameter can also be used in scaling the adjustments from a previous iteration and adding to the adjustments in the current iteration.

6.2 MAPPING

The feedforward backpropagation network maps the input vectors to output vectors. Pairs of input and output vectors are chosen to train the network first. Once training is completed, the weights are set and the network can be used to find outputs for new inputs. The dimension of the input vector determines the number of neurons in the input layer, and the number of neurons in the output layer is determined by the dimension of the outputs. Once trained, the network gives the image of a new input vector under mapping.

6.3 LAYOUT

The architecture of a feedforward backpropagation network is shown in figure. The number of neurons in the input layer and that in the output layer are determined by the dimensions of the input and the output patterns, respectively. It is not easy to determine how many neurons are needed for the hidden layer. The figure shows the layout with five input neurons, three input neurons in the hidden layer and four output neurons, with a few representative connections.

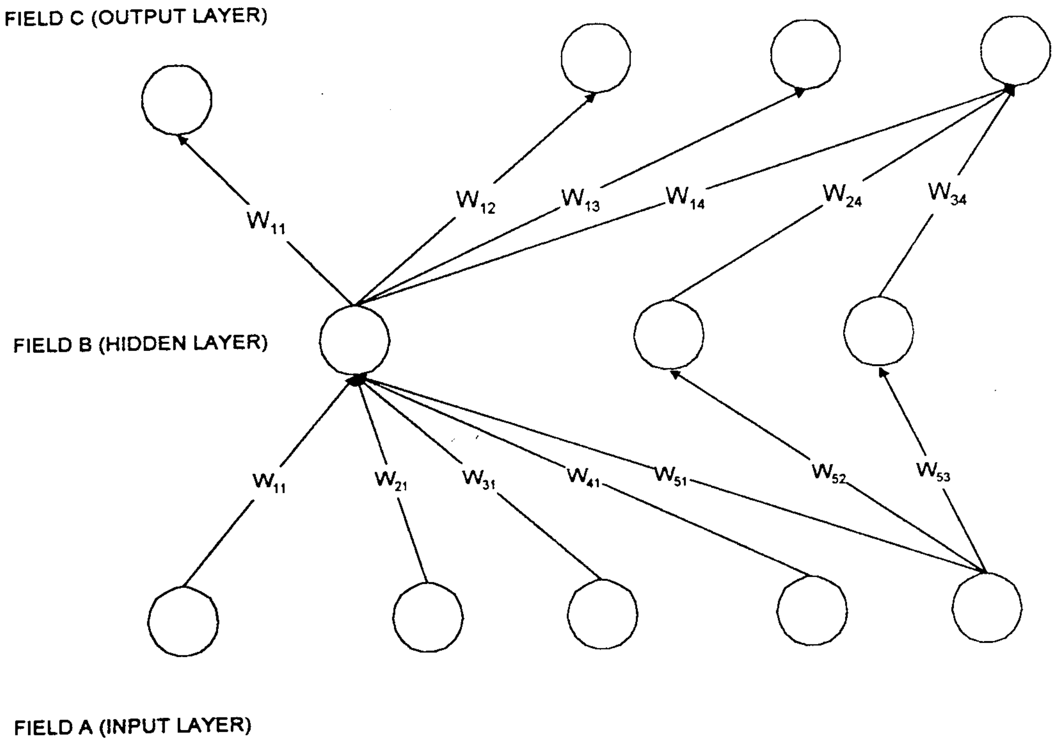


fig. LAYOUT OF A FEED FORWARD BACK PROPAGATION NETWORK

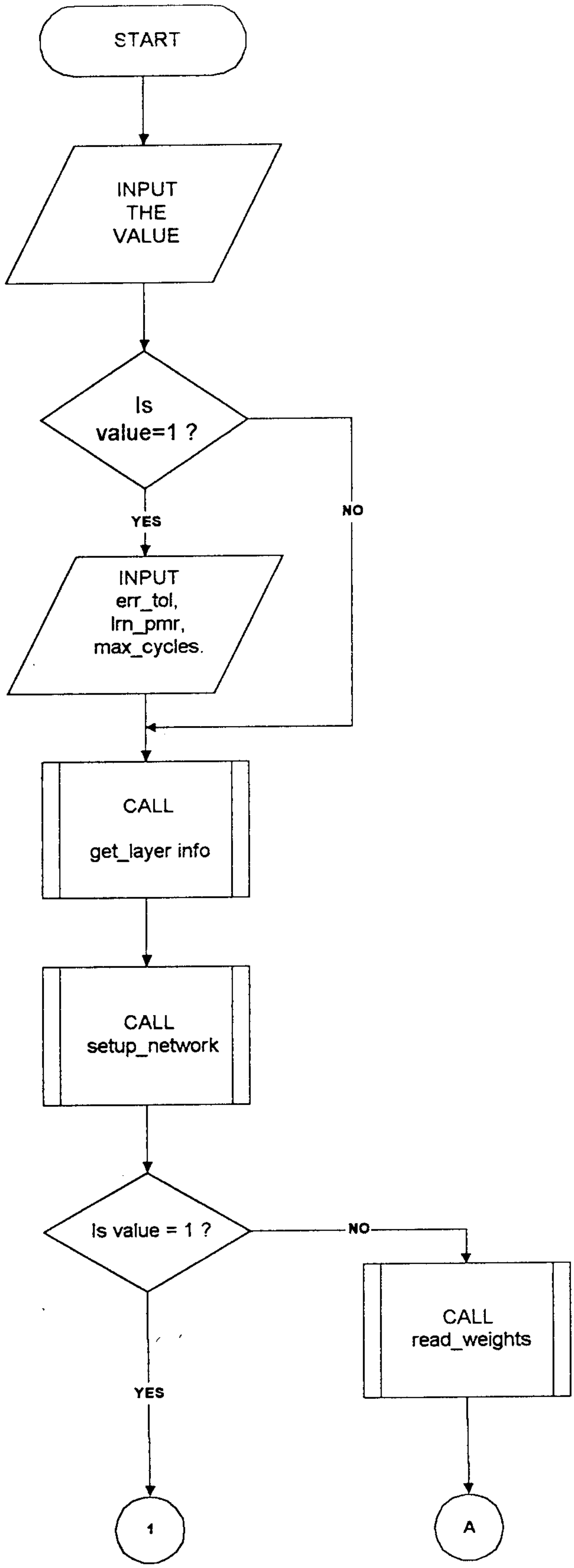
The network has three fields of neurons: one for input neurons, one for hidden processing elements, and one for the output neurons. As already stated, connections are for feed forward activity. There are connections from every neuron in field A to every one in field B, and, in turn, from every neuron in field B to every neuron in field C. Thus, there are two sets of weights, those figuring in the activations. In training, all of these weights are adjusted by considering what can be called a cost function in terms of the error in the computed output pattern and the desired output pattern.

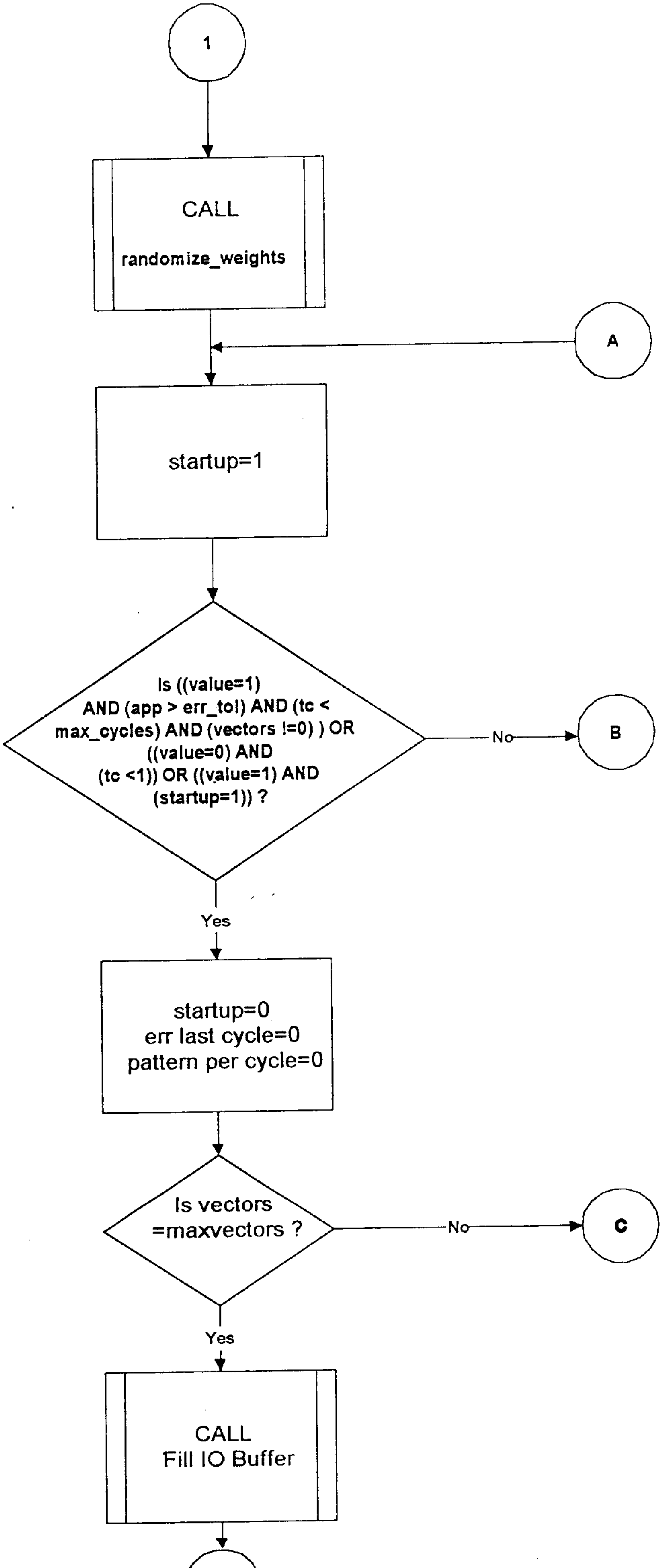
6.4 TRAINING

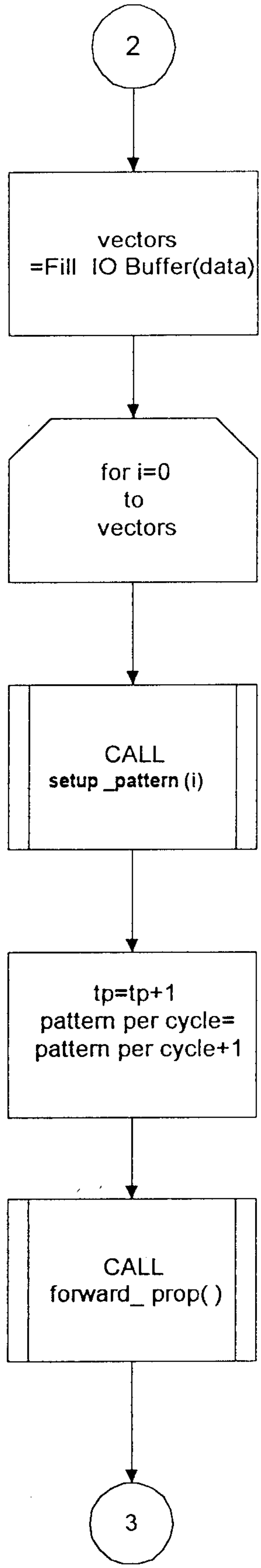
The feedforward backpropagation network undergoes supervised training, with a finite number of pattern pairs consisting of an input pattern and a desired or target output pattern. An input pattern is presented at the input layer. The neurons here pass the pattern activations to the next layer neurons, which are in a hidden layer. The outputs of the hidden layer neurons are obtained by using perhaps a bias, and also a threshold function with the activations determined by the weights and the inputs. The hidden layer outputs become inputs to the output neurons, which process the inputs using an optional bias and threshold function. The final output of the network is determined by the activations from the output layer.

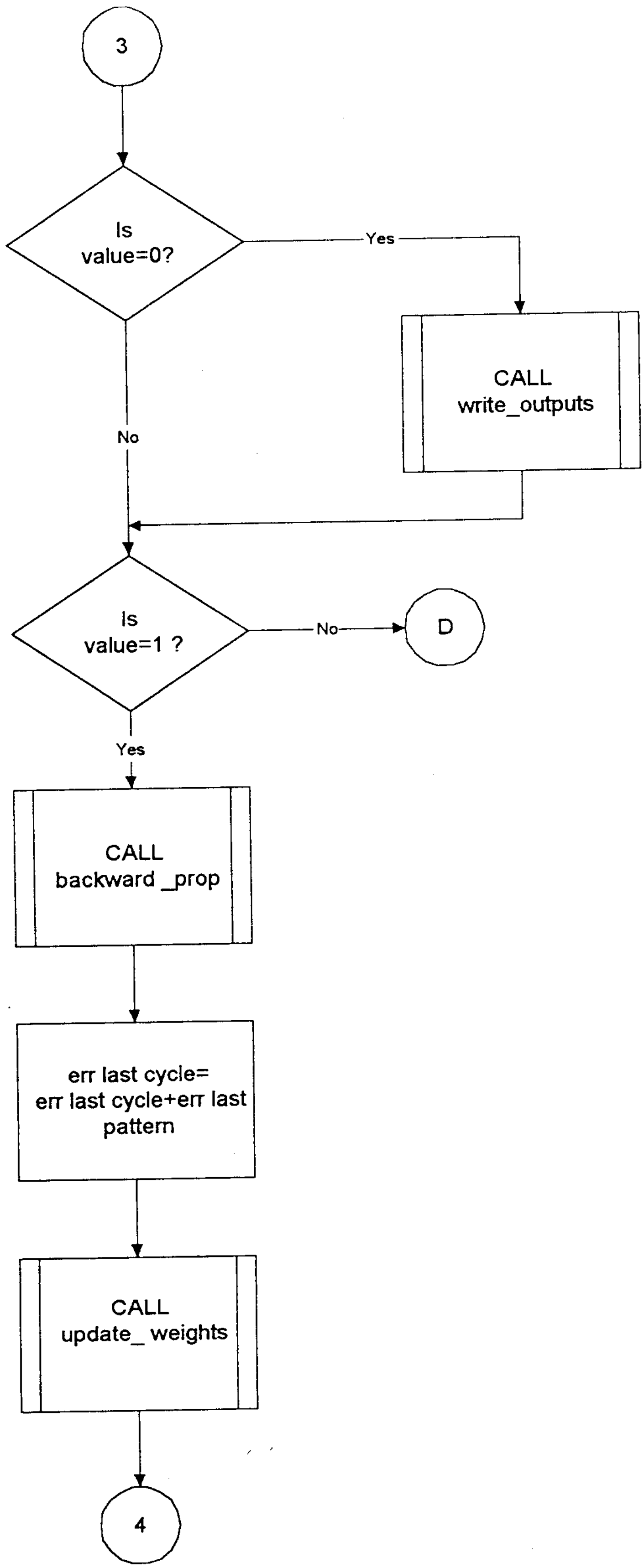
The computed pattern and the input pattern are compared, a function of this error for each component of the pattern is determined, and adjustment to weight of connections between the hidden layer and the output layer is computed. A similar computation, still based on the error in the input, is made for the connection weights between the input and hidden layers. The procedure is repeated with each pattern pair assigned for training the network. Each passing through all the training patterns is called a cycle or an epoch. The process is then repeated as many cycles as needed until the error is within a prescribed tolerance.

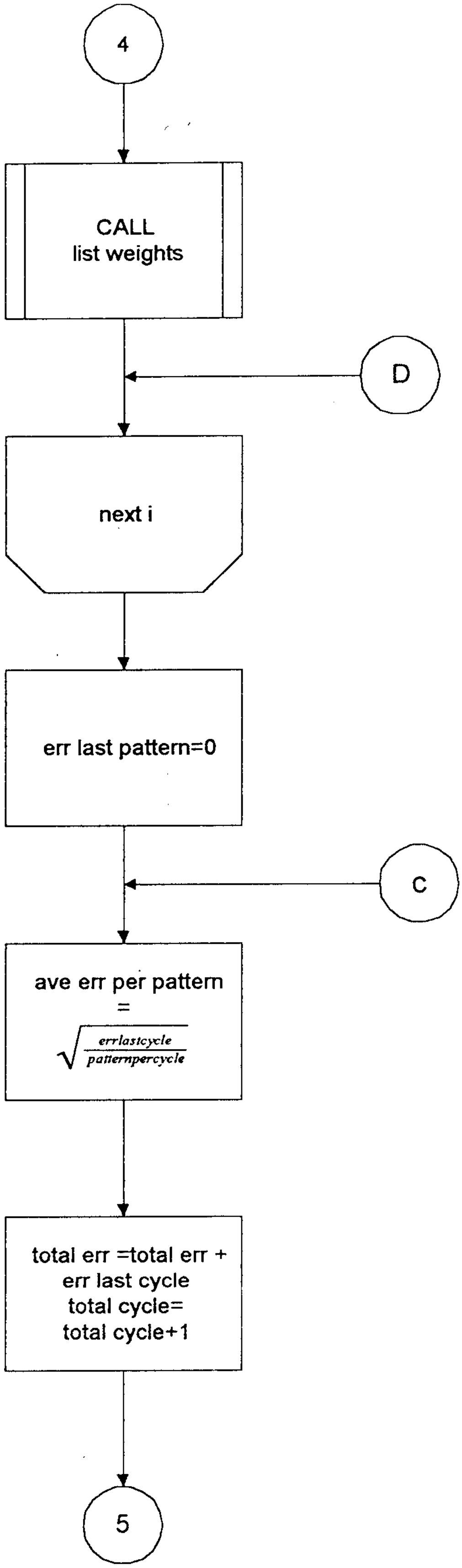
FLOW CHART

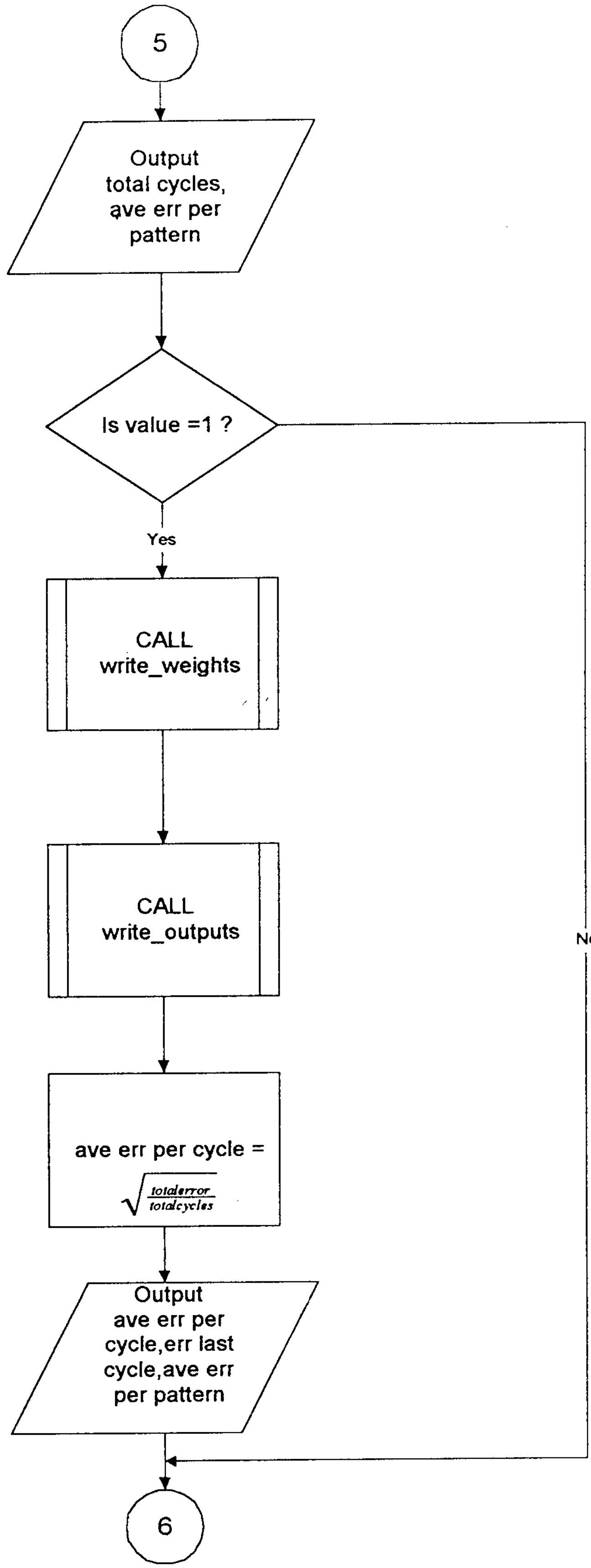

START
INPUT
THE
VALUE
Is
value=1 ?
YES
NO
INPUT
err_tol,
lrn_pmr,
max_cycles.
CALL
get_layer info
CALL
setup_network
Is value = 1 ?
NO
CALL
read_weights
YES
1
A

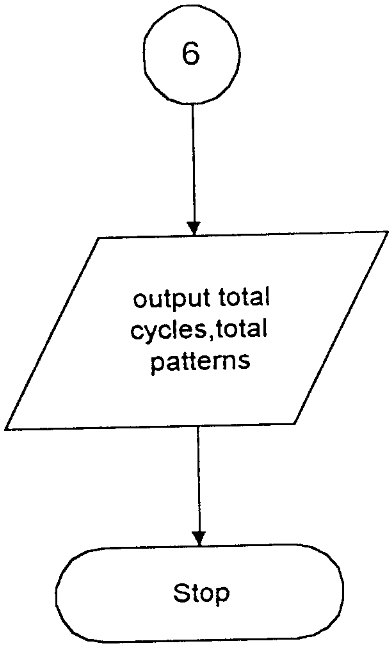

1
CALL
randomize_weights
A
startup=1
Is ((value=1)
AND (app > err_tol) AND (tc <
max_cycles) AND (vectors !=0)) OR
((value=0) AND
(tc <1)) OR ((value=1) AND
(startup=1)) ?
No
B
Yes
startup=0
err last cycle=0
pattern per cycle=0
Is vectors
=maxvectors ?
No
C
Yes
CALL
Fill IO Buffer


2
vectors
=Fill IO Buffer(data)
for i=0
to
vectors
CALL
setup _pattern (i)
tp=tp+1
pattern per cycle=
pattern per cycle+1
CALL
forward_ prop( )
3


3
Is
value=0?
Yes
CALL
write_outputs
No
Is
value=1 ?
No
D
Yes
CALL
backward _prop
err last cycle=
err last cycle+err last
pattern
CALL
update_ weights
4


4
CALL
list weights
D
next i
err last pattern=0
C
ave err per pattern
=
$\sqrt{\frac{errlastcycle}{patternpercycle}}$
total err =total err +
err last cycle
total cycle=
total cycle+1
5


5
Output
total cycles,
ave err per
pattern
Is value =1 ?
Yes
No
CALL
write_weights
CALL
write_outputs
ave err per cycle =
$\sqrt{\frac{totalerror}{totalcycles}}$
Output
ave err per
cycle,err last
cycle,ave err
per pattern
6


6
output total cycles,total patterns
Stop

FUNCTIONS

#void set_ training (constant unsigned &)

for training and 0 for This routine sets the value of private data to the training value and uses 1 test mode.

 # unsigned get_ training_ value ( )

This routine gets the value of the training constant that gives the mode in use and returns that value.

 # Void get_ layer_ info( )

This routine gets information about the number of layers and the sizes of the layer namely for input & output layers used by the network from the user.

 # Void set_ up_ network ( )

This routine constructs the layers by setting up the connections between the layers by assigning pointers appropriately &also set inputs to previous layer output for all layers except the input layer.

#Void randomize_ weights( ):

This routine is used only in the training node . this routine uses random number generation to randomize all of the weights in the network.

 # Void update_ weights (constant float)

As part of training , this routine updates the weights according to the learning law used in backpropagation.

#Void write_weights(FILE*)

This routine is used to write weights to a file.

#Void read_weights(FILE*)

This routine is used to read weights into the network from a file.

#Void list_weights()

This routine can be used to list weights while a simulation is in progress.

#Void write_outputs(FILE *)

This routine writes the outputs of the networks to a file.

#Void list_outputs( )

This routine can be used to list the outputs of the network while a simulation is in progress.

#Void list_errors( )

This routine lists errors for all layers while a simulation is in progress.

#Void forward_prop( )

Performs the forward propagation.

#Void backward_prop(float &)

Performs the backward propagation.

#int fill_Iobuffer(FILE *)

This routine fills the internal IO buffer with data from the training or test data sets.

#Void set_up_pattern(int)

This routine is used to set up one pattern from the IO buffer for training.

#inline float squash (float input)

This function performs the sigmoid function.

#inline float randomweight (unsigned unit)

This routine returns a random weights between -1 and 1 ; use 1 to intialize the generator, and 0 for all subsequent calls.

7.1 INTRODUCTION

The neural net simulation using the back propagation training algorithm was implemented on a Pentium machine. In neural net optimization process apart from other factors, the data representation strategy was expected to be a dominant one. The current data representation strategy requires the definition of a set of features that adequately describe the waveform (K-complex) to be detected and a pattern matcher to compare the observed value with the ideal values. Linear prediction techniques was used to extract the features which resulted in just 7 terms that describe one second EEG data.

7.2 DISCUSSION

7.2.1 SINGLE CHANNEL IMPLEMENTATION

As a first step, a search was made for the optimum network topology and it was found that 12\18\1 and 12\6\1 configurations offer optimal performance among those tried. Graph 3.1 shows the efficiency of each topology (percentage of correctly identified samples over the total samples) for K-complex, non K-complex and delta activity separately and graph 3.2, shows the same in the combined way. The performance of different topologies tried in this effort is outlined below.

The simulation was started with 9\6\1 ANN which offered efficiency of 71.6%. Another hidden layer was added in this topology to see if this could improve the efficiency. The topology tried was 9\6\3\1, a five layer ANN. Efficiency dropped to 69.6%.

The 12\18\1 ANN with an efficiency of 82.8% emerged as the best topology tried so far. The efficiency of this network (12\18\1) was 77.8% for K-complex , 100% for delta activity and 70.6% for non K-complex activity.

The hidden layers of the 12\18\1 ANN were increased to 12\24\1.The performance dropped to 73.5%. Hidden layers were then decreased to yield a 12\12\1 network that had improved efficiency of 77.2%. Further decrease in the hidden layers led to a topology of 12\6\1 and this offered a combined efficiency of 82.8% that matched the performance of the 12\8\1 ANN.

To analyze the effect of increased number of neurons over the efficiency larger networks were tried. Implementation of the 28\14\1 topology resulted in efficiency of 79.1%. Search for a better network led to the 40\20\1 network that offered best efficiency regarding to the detection of K-complex (94.4%). The efficiency of this ANN was 88.9% for delta activity detection and 64.7% for non K-complex patterns.

Again the hidden layers of this network increased, which resulted in 40\26\1 ANN. It had somewhat poor efficiency when compared to 40\20\1 ANN. The efforts in identifying the best ANN, had yielded to us the following results :

12\18\1 - 82.8%

12\6\1 - 82.8%

Maximum efficiencies for different waves are:

K-complex - 94.4% for 40\20\1

Delta - 100% for 12\18\1

Random Activity - 70.6% for 12\6\1

Thus we see that the basic result is that when there is a K-complex, the probability of correct identification is high but when there is a non K-complex, the probability is low. Hence the false probability is higher.

In the optimal neural network topology 12\18\1, 12\6\1, the neural net parameter settings are as follows:

Sigmoid non- linearity, $f(x) = \dfrac{1}{\left(1+e^{-x}\right)}$

Network topology -- Three layered architecture.

With these topologies, in each cycle of training, K-complex delta activity and random activity were presented cyclically. The previous chapters dealt with the strategies used to identify the EEG patterns. Now let us implement those strategies and classify the K-complex, delta and other waveforms. **Consider the case of 3 waveforms, and it's identification by the neural network.**

7.2.2 INPUT DATA TO NEURAL NETWORK

Consider the case of the following 3 unknown waveforms :
ff1, dd1 & rr2 (the datapoints are included in the Appendix I)
The "LP" coefficients are given by:

Input Data Points	Linear Predictor Coefficients						
ff2	-0.9735	0.0875	0.0268	0.0275	0.0050	-0.0307	0.0705
dd2	-0.2791	0.1692	-0.1085	-0.1534	-0.3152	-0.2822	-0.6122
rr2	-0.9937	0.0666	0.0999	0.0010	-0.0453	-0.0120	-0.0571

These 3 sets of 7 "LP" coefficient are then stored into the file 'test.dat'.

The contents of 'test.dat' is as follows:

-0.9735 0.0875 0.0268 0.0275 0.0050-0.0307 0.0705
-0.2791 0.1692-0.1085-0.1534-0.3152-0.2822-0.6122
-0.9937 0.0666 0.0999 0.0010-0.0453-0.0120-0.0571

This file contains no expected outputs and hence will constitute a set of unknown inputs to the ANN. In order to identify the K-complex waveform among those three wavepatterns, these datas are entered in 'test.dat' file and this file is fed to neural network simulator. This simulator has already been trained with set of known data to identify K-complex wave has `0` and other waveforms (delta & background) as `1`.

7.2.3 OUTPUT FROM THE NEURAL NETWORK

Let us consider four layer Neural Net with the topology 7\12\18\1.The Neural Network Simulator is run and it is tested for the inputs in test.dat file. The results are stored in "output.dat" file

The contents of output.dat file is as follows :

for input vector:

-0.973500 0.087500 0.026800 0.027500 0.005000 -0.030700 0.070500

output vector is:

0.000273

----

for input vector:

-0.279100 0.169200 -0.108500 -0.153400 -0.315200 -0.282200

-0.612200

output vector is:

0.999999

----

for input vector:

-0.993700 0.066600 0.099900 0.001000 -0.045300 -0.012000

-0.057100

output vector is:

0.999998

Thus it is seen that the neural network has successfully identified the K-complex waveforms.

CONCLUSION

By a different way of data representation, a reduction in the number of neurons was achieved and resulted in a significant improvement of network efficiency over 94%. An ill shaped K-complex of a 47 year old patient which was not included in the training set was detected correctly by all these test nets.

The Neural net simulation had resulted in successful identification of K-complex pattern(94.4%). The Delta activity was identified in all the cases. This significant reduction of input points has caused the "learning" process to be much more efficient.

These are the conclusions which are made by the thorough study of the project.

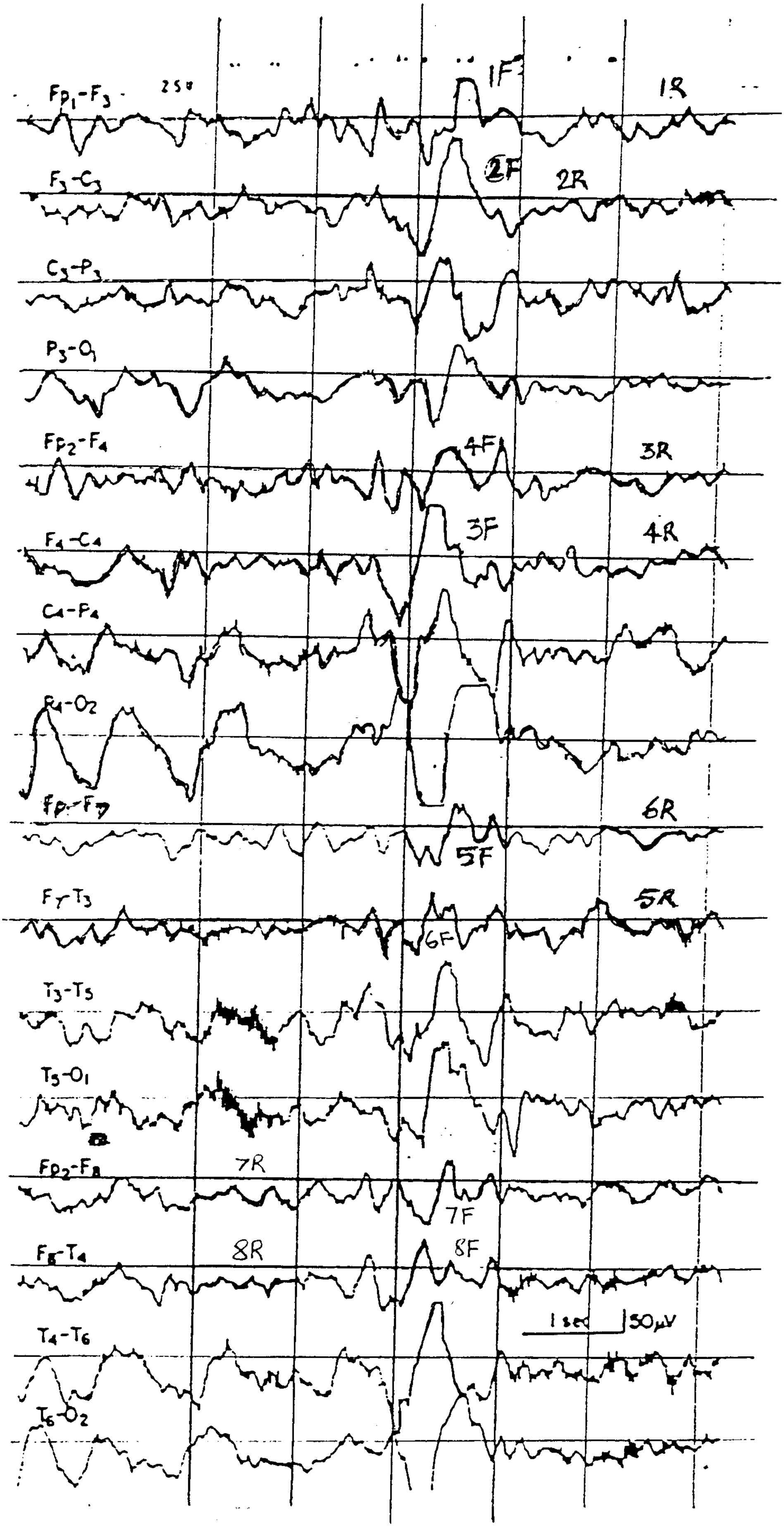
FURTHER DEVELOPEMENTS

In this work, a multichannel approach can be demonstrated by feeding EEG data to two channels parallely .This work could be extended to optimize the other parameters viz. a) gain term and b) type of nonlinearity.

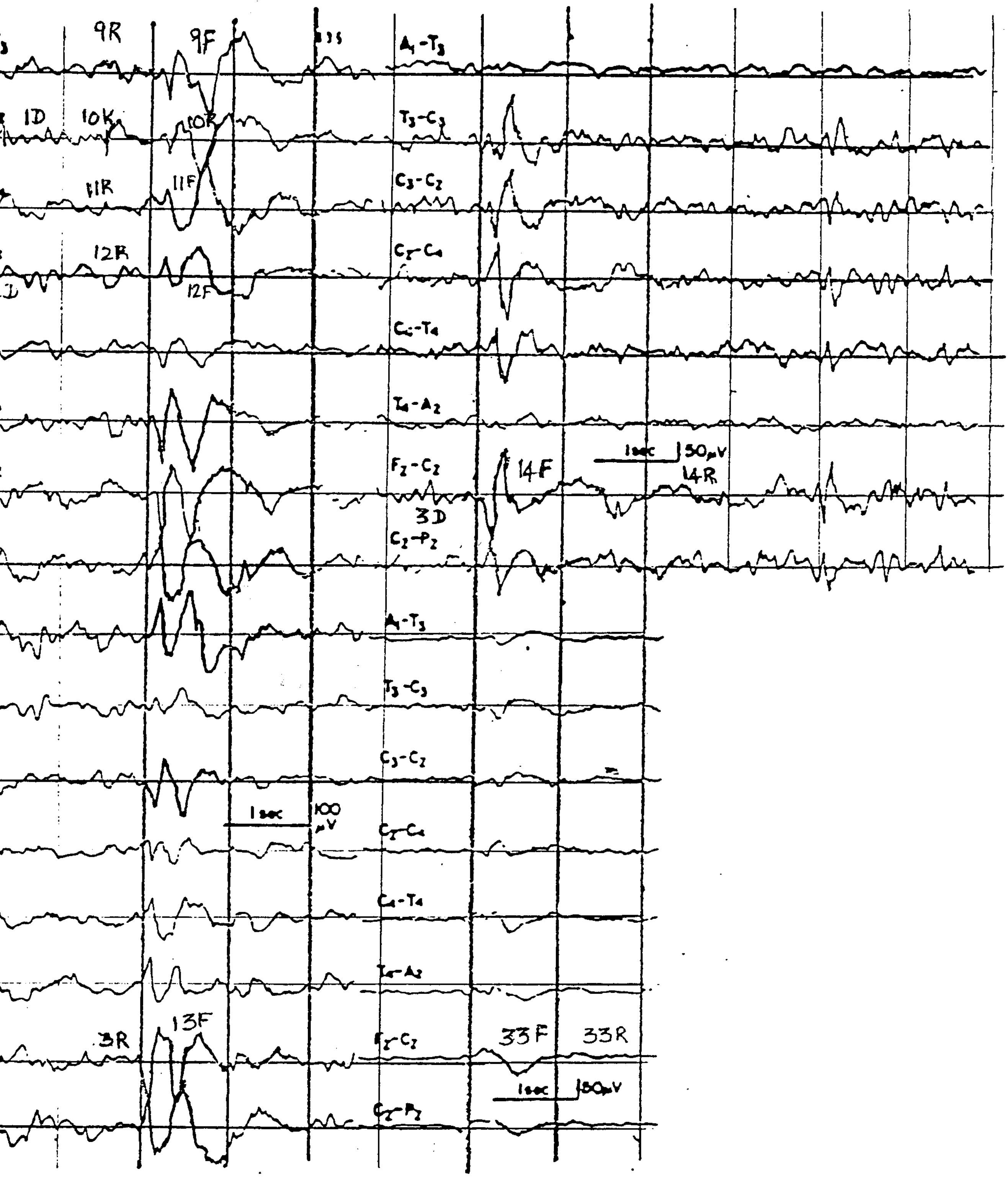
By giving more than two channels parallely to neural net as input.

By using alternate methods of feature extraction other than the linear prediction technique.

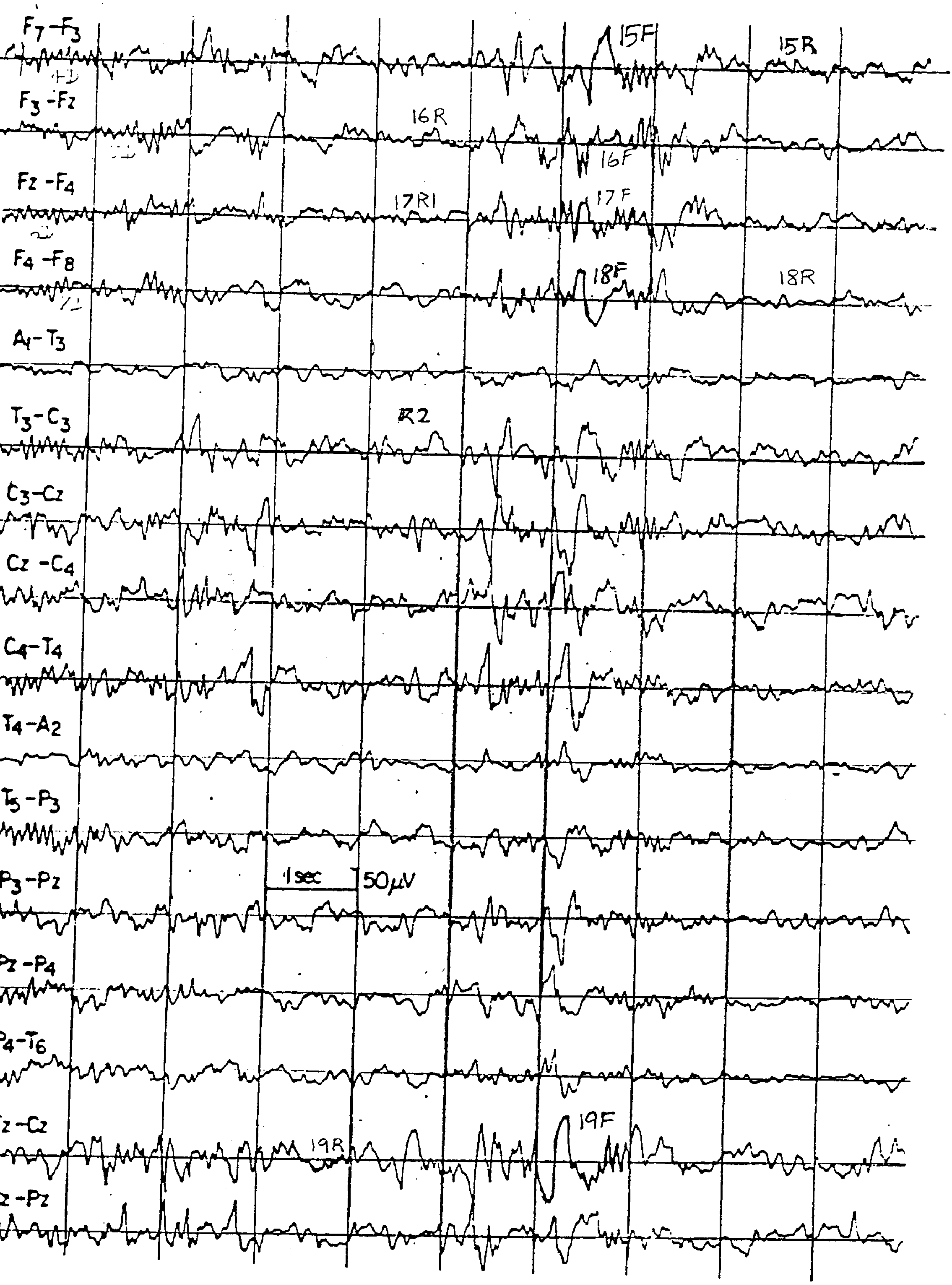
Finally, it is very interesting to note that the neural net designed here may represent a crude model of the visual processing section of the human brain. Even though the inventors of the backpropagation algorithm themselves state that this algorithm will not yield to brain model on the grounds that there is no evidence of leaning by backpropagation of error in brain , the author feels the other way because of the fact that same model can be arrived by many methods. In brain, the mechanism of neural learning may be different but once the net is made , the function and the fundamental units are the same as the neural networks designed in this work as far as the operation of identifying the K-complex is concerned. An investigation in this direction may prove worthy.


Fp1-F3
1F
1R
F3-C3
2F
2R
C3-P3
P3-O1
Fp2-F4
4F
3R
F4-C4
3F
4R
C4-P4
P4-O2
Fp1-F7
6R
5F
F7-T3
5R
6F
T3-T5
T5-O1
Fp2-F8
7R
7F
F8-T4
8R
8F
1 sec
50μV
T4-T6
T6-O2

1



11.17. Evolutional and involutional phases of the K complex. tracing, age 5 years. Prominent initiating sharp component. er right tracing, age 8 years. Note very pronounced sharp ponent of K complex. Farther to the right, a single vertex is shown. Lower right, age 47 years. K complex of moderate ge; the initiating sharp component is markedly blunted. The



g. 11.16 Age 10 REM

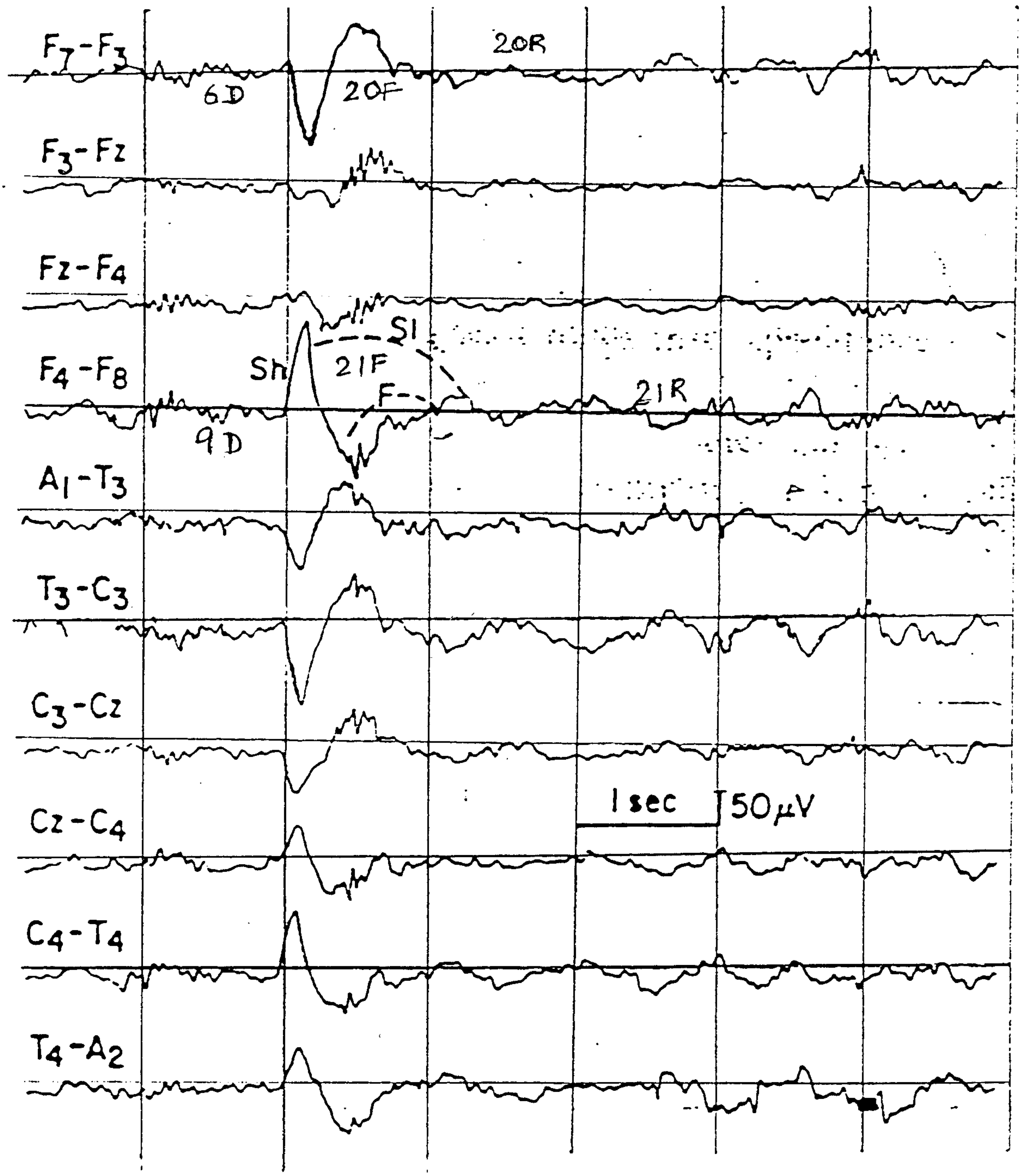


Fig. 10.7. Close-up of a K complex. Note midline maximum (especially Cz: vertex) and the three principal components, the sharp, slow, and fast components. Age 17 years.

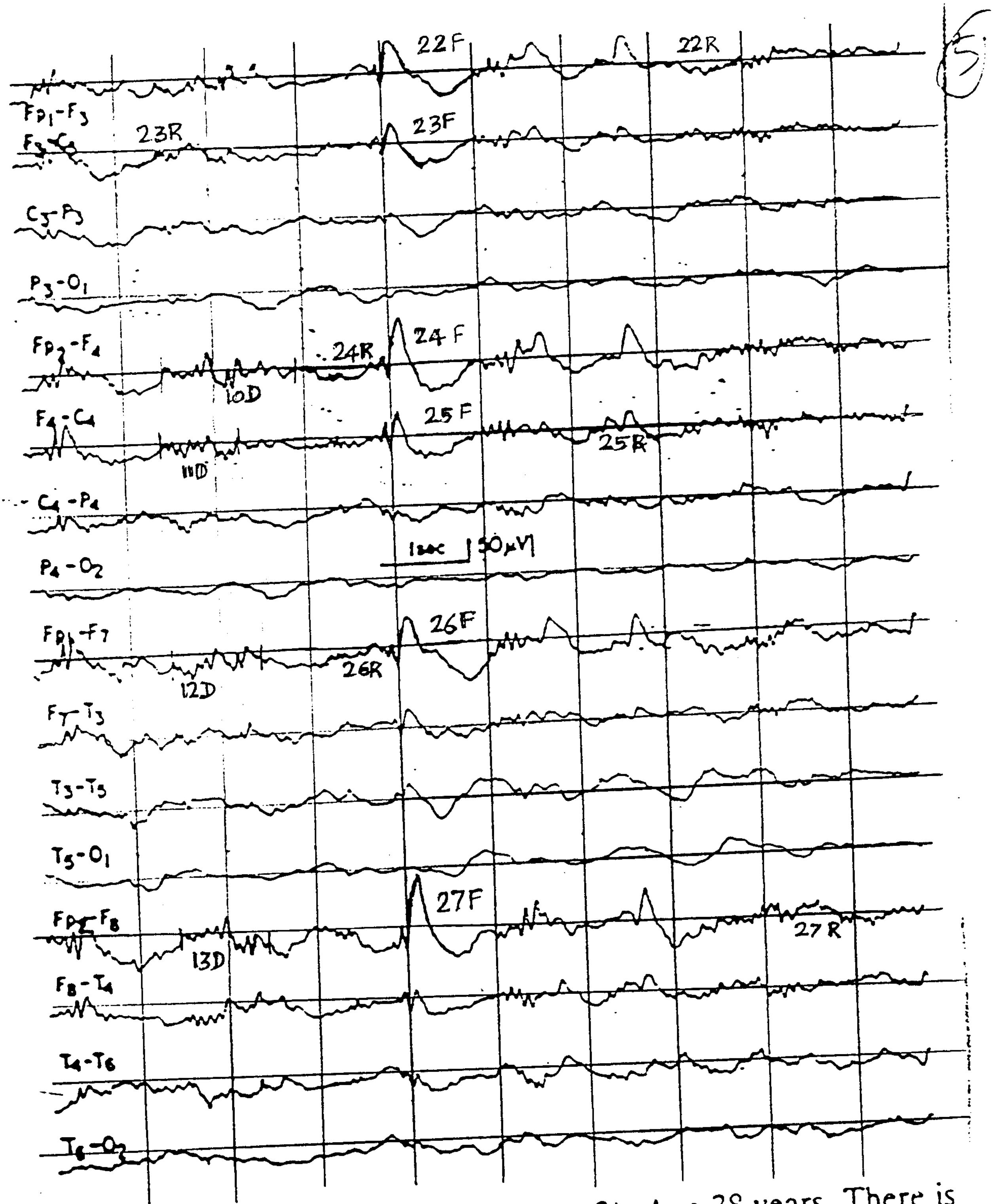
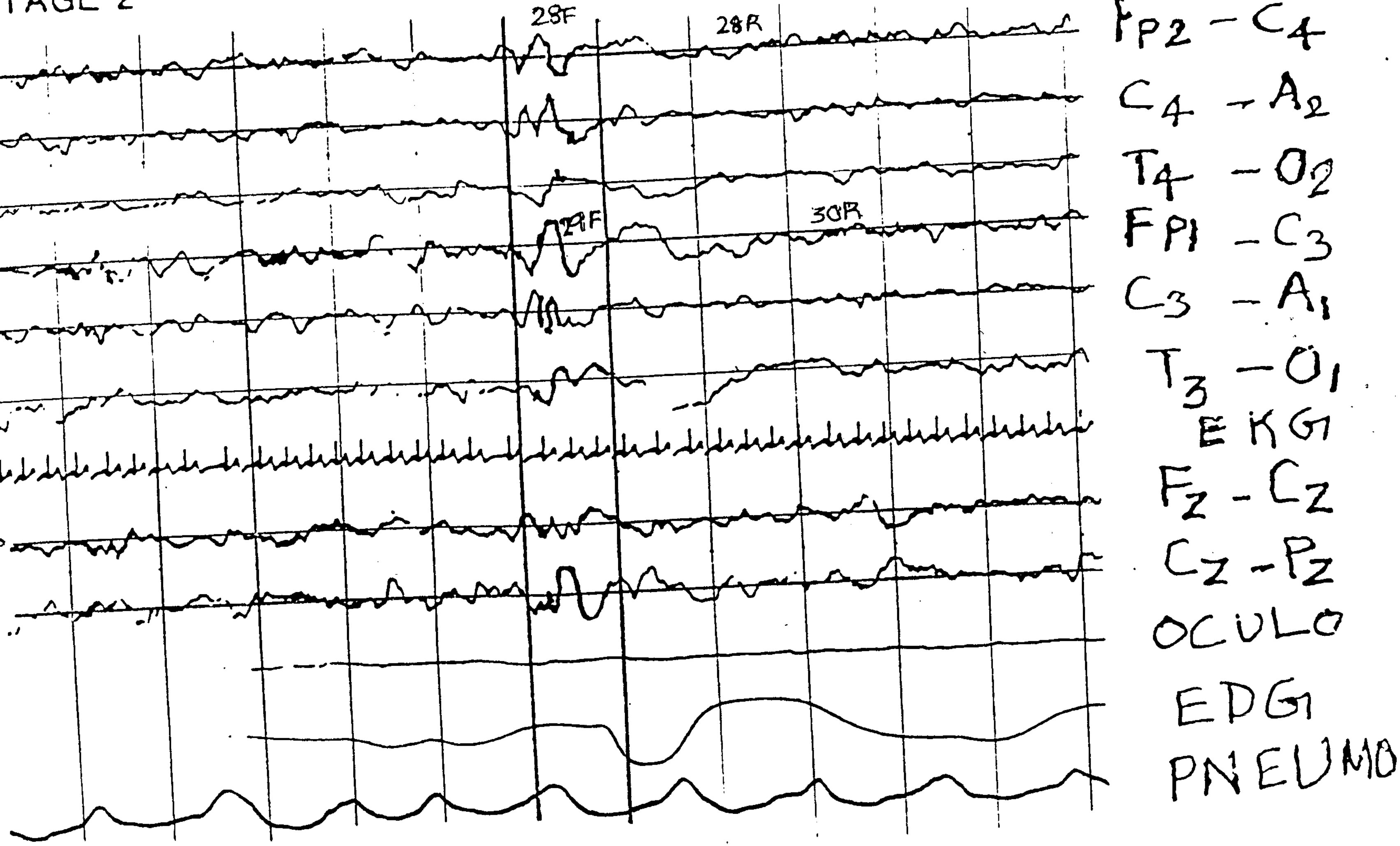


Fig. 10.8. Deep sleep (non-REM Stage 3). Age 38 years. There is a greater amount of slow activity than in Stage 2. Spindles are still abundant but less prominent than in Stage 2. K complexes are ... over anterior areas, forming "mitten" patterns.

TAGE 2


28F
28R
29F
30R
Fp2 - C4
C4 - A2
T4 - O2
Fp1 - C3
C3 - A1
T3 - O1
EKG
Fz - Cz
Cz - Pz
OCULO
EDG
PNEUMO

DATA SET :

TABLE I : TRAINING DATA

AGE	K-complex	Delta & other waveforms
1	1F, 3F, 5F, 7F	4R, 6R
5	9F, 11F, 13F	1D, 10R, 13R,
8	4F	3D
10	15F, 17F, 19F	4D, 6D, 16R
17	20F	8D
38	22F, 24F, 26F	10D, 12D, 22R

TABLE II : TEST DATA

AGE	K-complex	DELTA ACTIVITY & OTHER WAVEFORM
1	2F, 4F, 6F, 8F	1R, 2R, 3R, 5R
5	10F, 12F	2D
8	-	14R
10	16F, 18F	5D, 7D, 15R, 17R, 19R
17	21F	9D, 20R, 21R
38	23F , 25F, 27F	11D, 13D, 23R, 26R
UNKNOWN	28F, 29F	7R, 9R, 11R
UNKNOWN	30F, 31F, 32F	14D, 15D, 16D, 24R, 28R, 30R
47	33F	33R

ff1	ff2	ff3	ff4	ff5	ff6
-44.0476	-123.8095	-85.7143	-32.1429	-8.3333	-42.8571
-70.2381	-127.3810	-47.6190	-38.0952	-17.8571	-47.6190
-89.2857	-125.0000	-32.1429	-66.6667	-26.1905	-48.8095
-101.1905	-114.2857	-17.8571	-80.9524	-36.9048	-52.3810
-102.3810	-98.8095	2.3810	-78.5714	-46.4286	-55.9524
-80.9524	-82.1429	25.0000	-46.4286	-55.9524	-63.0952
-45.2381	-59.5238	46.4286	-40.4762	-67.8571	-67.8571
-35.7143	-42.8571	78.5714	-28.5714	-70.2381	-71.4286
-39.2857	-14.2857	101.1905	-3.5714	-70.2381	-46.4286
-38.0952	22.6190	115.4762	9.5238	-65.4762	-39.2857
-33.3333	53.5714	117.8571	25.0000	-47.6190	-7.1429
-27.3810	69.0476	117.8571	34.5238	-45.2381	5.9524
-29.7619	76.1905	117.8571	38.0952	-54.7619	14.2857
-30.9524	88.0952	116.6667	40.4762	-64.2857	29.7619
-30.9524	109.5238	115.4762	44.0476	-72.6190	40.4762
-29.7619	120.2381	113.0952	45.2381	-80.9524	33.3333
-25.0000	121.4286	95.2381	47.6190	-80.9524	14.2857
35.7143	119.0476	30.9524	47.6190	-58.3333	2.3810
71.4286	121.4286	20.2381	47.6190	-38.0952	1.1905
77.3810	120.2381	20.2381	46.4286	-22.6190	3.5714
78.5714	83.3333	25.0000	39.2857	-15.4762	21.4286
77.3810	72.6190	25.0000	29.7619	-4.7619	23.8095
78.5714	69.0476	23.8095	23.8095	15.4762	22.6190
78.5714	46.4286	16.6667	20.2381	32.1429	26.1905
76.1905	29.7619	-13.0952	13.0952	44.0476	28.5714
71.4286	20.2381	-41.6667	2.3810	45.2381	17.8571
63.0952	14.2857	-50.0000	-3.5714	34.5238	-26.1905
44.0476	3.5714	-54.7619	-20.2381	38.0952	-46.4286
-3.5714	-3.5714	-55.9524	-28.5714	44.0476	-58.3333
-9.5238	-14.2857	-59.5238	-35.7143	30.9524	-59.5238
-14.2857	-23.8095	-57.1429	-35.7143	23.8095	-54.7619
-10.7143	-32.1429	-53.5714	-33.3333	19.0476	-45.2381
-9.5238	-39.2857	-40.4762	-29.7619	4.7619	-33.3333
-8.3333	-45.2381	-39.2857	-25.0000	-26.1905	-22.6190
-4.7619	-46.4286	-42.8571	-19.0476	-29.7619	-21.4286
1.1905	-41.6667	-44.0476	-11.9048	-32.1429	-21.4286
3.5714	-34.5238	-36.9048	-4.7619	-29.7619	-17.8571
8.3333	-30.9524	-11.9048	8.3333	-27.3810	-15.4762
11.9048	-36.9048	-10.7143	22.6190	-22.6190	-13.0952
13.0952	-47.6190	-15.4762	38.0952	-11.9048	-16.6667
11.9048	-60.7143	-17.8571	48.8095	0.0000	0.0000
8.3333	-71.4286	-34.5238	55.9524	19.0476	5.9524
7.1429	-83.3333	-53.5714	47.6190	21.4286	11.9048
2.3810	-88.0952	-64.2857	20.2381	5.9524	16.6667
-1.1905	-83.3333	-71.4286	-15.4762	-2.3810	27.3810
-4.7619	-71.4286	-64.2857	-21.4286	-17.8571	21.4286
-13.0952	-61.9048	-55.9524	-29.7619	-33.3333	13.0952
-27.3810	-60.7143	-47.6190	-39.2857	-44.0476	4.7619
-36.9048	-51.1905	-25.0000	-45.2381	-44.0476	-3.5714
-38.0952	-46.4286	-15.4762	-52.3810	-38.0952	-10.7143

ff7	ff8	ff9
0.0000	-69.0476	-7.5000
-10.7143	-73.8095	-10.0000
-19.0476	-79.7619	-8.7500
-35.7143	-76.1905	0.0000
-44.0476	-59.5238	3.7500
-50.0000	-47.6190	8.7500
-53.5714	-39.2857	8.7500
-57.1429	-26.1905	0.0000
-71.4286	-3.5714	-16.2500
-77.3810	11.9048	-32.5000
-80.9524	27.3810	-41.2500
-82.1429	36.9048	-45.0000
-92.8571	45.2381	-15.0000
-96.4286	55.9524	16.2500
-95.2381	50.0000	30.0000
-90.4762	29.7619	42.5000
-73.8095	16.6667	53.7500
-57.1429	-5.9524	48.7500
-47.6190	-20.2381	45.0000
-36.9048	-32.1429	38.7500
-10.7143	-34.5238	31.2500
5.9524	-30.9524	15.0000
20.2381	-28.5714	-8.7500
32.1429	-14.2857	-25.0000
35.7143	-3.5714	-30.0000
34.5238	7.1429	-31.2500
33.3333	11.9048	-30.0000
-22.6190	4.7619	-27.5000
-39.2857	-9.5238	-25.0000
-40.4762	-10.7143	-21.2500
-40.4762	-13.0952	-26.2500
-26.1905	-21.4286	-41.2500
-26.1905	-27.3810	-50.0000
-35.7143	-29.7619	-60.0000
-45.2381	-28.5714	-76.2500
-45.2381	-28.5714	-90.0000
-44.0476	-29.7619	-92.5000
-41.6667	-34.5238	-93.7500
-33.3333	-36.9048	-90.0000
-21.4286	-40.4762	-60.0000
-14.2857	-41.6667	-35.0000
-5.9524	-32.1429	-15.0000
-4.7619	-21.4286	0.0000
8.3333	1.1905	18.7500
8.3333	9.5238	30.0000
3.5714	17.8571	40.0000
-14.2857	13.0952	43.7500
-32.1429	3.5714	43.7500
-44.0476	-5.9524	45.0000
-48.8095	-39.2857	50.0000

ff10	ff11	ff12	ff13	ff14	ff15
-6.2500	28.7500	0.0000	13.7500	-11.2500	-37.7778
-2.5000	31.2500	0.0000	-13.7500	-10.0000	-32.2222
-1.2500	30.0000	-5.0000	-41.2500	-12.5000	-22.2222
-1.2500	26.2500	-2.5000	-53.7500	-23.7500	-18.8889
-1.2500	16.2500	-1.2500	-68.7500	-58.7500	-23.3333
-1.2500	12.5000	6.2500	-85.0000	-76.2500	-13.3333
-1.2500	15.0000	22.5000	-62.5000	-88.7500	1.1111
8.7500	23.7500	37.5000	27.5000	-95.0000	3.3333
12.5000	43.7500	42.5000	46.2500	-82.5000	1.1111
10.0000	41.2500	17.5000	73.7500	46.2500	-6.6667
2.5000	27.5000	-12.5000	71.2500	61.2500	-31.1111
-8.7500	5.0000	-20.0000	62.5000	81.2500	-43.3333
-26.2500	-15.0000	-21.2500	58.7500	96.2500	-51.1111
-13.7500	-31.2500	-22.5000	58.7500	102.5000	-65.5556
-2.5000	-41.2500	-18.7500	57.5000	11.2500	-34.4444
6.2500	-48.7500	-8.7500	57.5000	-10.0000	7.7778
21.2500	-50.0000	17.5000	45.0000	-12.5000	24.4444
36.2500	-47.5000	35.0000	-71.2500	-12.5000	32.2222
41.2500	-40.0000	43.7500	-86.2500	-16.2500	44.4444
41.2500	-38.7500	47.5000	-87.5000	-20.0000	61.1111
42.5000	-33.7500	50.0000	-81.2500	-36.2500	65.5556
21.2500	-11.2500	58.7500	-65.0000	-41.2500	73.3333
18.7500	3.7500	63.7500	-5.0000	-37.5000	78.8889
21.2500	18.7500	71.2500	22.5000	-35.0000	85.5556
21.2500	72.5000	73.7500	32.5000	-32.5000	83.3333
21.2500	92.5000	73.7500	32.5000	-28.7500	43.3333
12.5000	108.7500	61.2500	37.5000	-27.5000	25.5556
-22.5000	116.2500	53.7500	41.2500	-22.5000	7.7778
-36.2500	115.0000	50.0000	60.0000	-12.5000	-7.7778
-48.7500	102.5000	40.0000	68.7500	-12.5000	-2.2222
-58.7500	77.5000	12.5000	71.2500	-13.7500	-8.8889
-70.0000	61.2500	-18.7500	62.5000	-17.5000	-15.5556
-82.5000	37.5000	-25.0000	50.0000	-15.0000	-35.5556
-78.7500	26.2500	-28.7500	42.5000	-6.2500	-28.8889
-70.0000	17.5000	-37.5000	36.2500	2.5000	-20.0000
-61.2500	16.2500	-41.2500	32.5000	6.2500	-35.5556
-56.2500	11.2500	-41.2500	27.5000	7.5000	-52.2222
-38.7500	0.0000	-41.2500	20.0000	10.0000	-17.7778
-30.0000	-22.5000	-41.2500	12.5000	11.2500	-1.1111
-20.0000	-33.7500	-37.5000	2.5000	12.5000	1.1111
-10.0000	-33.7500	-36.2500	-3.7500	17.5000	-18.8889
10.0000	-37.5000	-36.2500	-6.2500	28.7500	-32.2222
21.2500	-42.5000	-45.0000	-15.0000	30.0000	-4.4444
30.0000	-48.7500	-46.2500	-12.5000	27.5000	-5.5556
35.0000	-53.7500	-48.7500	-11.2500	26.2500	-25.5556
35.0000	-55.0000	-47.5000	-5.0000	27.5000	-35.5556
40.0000	-40.0000	-46.2500	-7.5000	27.5000	-13.3333
47.5000	-38.7500	-51.2500	-12.5000	26.2500	-4.4444
52.5000	-36.2500	-51.2500	-7.5000	28.7500	-20.0000
55.0000	-28.7500	-48.7500	18.7500	36.2500	-27.7778

ff16	ff17	ff18	ff19	ff20	ff21
-3.3333	41.1111	12.2222	-26.6667	-7.0000	0.0000
-1.1111	30.0000	6.6667	-38.8889	6.0000	18.0000
6.6667	7.7778	2.2222	-54.4444	-19.0000	51.0000
31.1111	21.1111	12.2222	-67.7778	-60.0000	76.0000
40.0000	37.7778	32.2222	-78.8889	-79.0000	98.0000
0.0000	16.6667	47.7778	-87.7778	-95.0000	118.0000
3.3333	-24.4444	56.6667	-93.3333	-114.0000	144.0000
-3.3333	-24.4444	64.4444	-93.3333	-121.0000	164.0000
-17.7778	-2.2222	62.2222	-85.5556	-122.0000	144.0000
-51.1111	38.8889	62.2222	-23.3333	-117.0000	124.0000
-82.2222	44.4444	62.2222	62.2222	-89.0000	63.0000
-47.7778	44.4444	52.2222	83.3333	-70.0000	27.0000
-45.5556	45.5556	-32.2222	95.5556	-55.0000	8.0000
-57.7778	53.3333	-36.6667	105.5556	-37.0000	-1.0000
-38.8889	30.0000	-42.2222	108.8889	-15.0000	-11.0000
-6.6667	2.2222	-47.7778	108.8889	1.0000	-21.0000
-3.3333	1.1111	-53.3333	97.7778	17.0000	-34.0000
-7.7778	-12.2222	-54.4444	34.4444	36.0000	-44.0000
2.2222	-21.1111	-58.8889	6.6667	45.0000	-53.0000
13.3333	-31.1111	-64.4444	-8.8889	49.0000	-69.0000
22.2222	-16.6667	-58.8889	-7.7778	55.0000	-76.0000
-5.5556	-8.8889	-53.3333	-10.0000	66.0000	-79.0000
-11.1111	-24.4444	-50.0000	-21.1111	77.0000	-88.0000
-6.6667	-26.6667	-40.0000	-30.0000	82.0000	-93.0000
-5.5556	-6.6667	-28.8889	-33.3333	84.0000	-98.0000
-5.5556	1.1111	-15.5556	-28.8889	83.0000	-104.0000
-5.5556	-3.3333	-2.2222	-38.8889	80.0000	-99.0000
-4.4444	-14.4444	1.1111	-52.2222	74.0000	-68.0000
-1.1111	-5.5556	2.2222	-60.0000	71.0000	-89.0000
7.7778	16.6667	2.2222	-43.3333	72.0000	-100.0000
15.5556	27.7778	5.5556	-34.4444	71.0000	-85.0000
12.2222	12.2222	14.4444	-37.7778	71.0000	-77.0000
2.2222	12.2222	17.7778	-45.5556	66.0000	-73.0000
-15.5556	27.7778	22.2222	-30.0000	39.0000	-61.0000
-15.5556	7.7778	22.2222	-11.1111	33.0000	-31.0000
-17.7778	-12.2222	21.1111	93.3333	26.0000	-29.0000
-15.5556	0.0000	17.7778	-21.1111	19.0000	-23.0000
-8.8889	21.1111	20.0000	21.1111	8.0000	-14.0000
1.1111	31.1111	27.7778	47.7778	-4.0000	-20.0000
-10.0000	8.8889	37.7778	47.7778	1.0000	-27.0000
-26.6667	-2.2222	41.1111	12.2222	12.0000	-32.0000
-16.6667	2.2222	35.5556	-12.2222	11.0000	-28.0000
20.0000	7.7778	13.3333	18.8889	12.0000	-30.0000
37.7778	14.4444	3.3333	41.1111	12.0000	-36.0000
38.8889	23.3333	6.6667	15.5556	10.0000	-32.0000
-15.5556	16.6667	12.2222	-5.5556	1.0000	-21.0000
-5.5556	-1.1111	15.5556	-15.5556	-10.0000	-19.0000
25.5556	-17.7778	4.4444	27.7778	-10.0000	-18.0000
42.2222	-27.7778	-15.5556	41.1111	-1.0000	-19.0000
-3.3333	-31.1111	-24.4444	28.8889	-1.0000	-16.0000

ff22	ff23	ff24	ff25	ff26	ff27
-17.0455	-21.5909	17.0455	-19.3182	-26.1364	-19.3182
27.2727	-9.0909	52.2727	18.1818	-22.7273	42.0455
52.2727	9.0909	61.3636	32.9545	22.7273	56.8182
67.0455	21.5909	80.6818	43.1818	35.2273	72.7273
67.0455	35.2273	90.9091	46.5909	52.2727	90.9091
65.9091	40.9091	93.1818	28.4091	59.0909	101.1364
62.5000	37.5000	80.6818	15.9091	57.9545	107.9545
56.8182	31.8182	50.0000	1.1364	53.4091	90.9091
47.7273	25.0000	28.4091	-15.9091	46.5909	55.6818
39.7727	1.1364	13.6364	-25.0000	27.2727	32.9545
30.6818	-4.5455	4.5455	-29.5455	18.1818	12.5000
18.1818	-12.5000	-2.2727	-34.0909	2.2727	0.0000
6.8182	-15.9091	-10.2273	-36.3636	-2.2727	-12.5000
3.4091	-20.4545	-20.4545	-37.5000	-10.2273	-22.7273
2.2727	-23.8636	-37.5000	-34.0909	-11.3636	-28.4091
2.2727	-29.5455	-45.4545	-43.1818	-12.5000	-36.3636
-1.1364	-35.2273	-45.4545	-45.4545	-14.7727	-42.0455
-4.5455	-42.0455	-45.4545	-45.4545	-14.7727	-48.8636
-7.9545	-46.5909	-51.1364	-39.7727	-14.7727	-52.2727
-11.3636	-46.5909	-56.8182	-39.7727	-14.7727	-56.8182
-18.1818	-46.5909	-56.8182	-40.9091	-14.7727	-59.0909
-19.3182	-45.4545	-55.6818	-43.1818	-20.4545	-62.5000
-21.5909	-42.0455	-56.8182	-43.1818	-25.0000	-65.9091
-22.7273	-39.7727	-55.6818	-43.1818	-29.5455	-69.3182
-27.2727	-36.3636	-53.4091	-45.4545	-31.8182	-70.4545
-36.3636	-37.5000	-48.8636	-44.3182	-37.5000	-69.3182
-39.7727	-39.7727	-47.7273	-38.6364	-43.1818	-68.1818
-44.3182	-39.7727	-47.7273	-40.9091	-46.5909	-62.5000
-46.5909	-39.7727	-48.8636	-39.7727	-50.0000	-61.3636
-48.8636	-39.7727	-48.8636	-38.6364	-53.4091	-61.3636
-48.8636	-39.7727	-47.7273	-29.5455	-55.6818	-61.3636
-46.5909	-37.5000	-42.0455	-20.4545	-55.6818	-53.4091
-48.8636	-39.7727	-38.6364	-20.4545	-60.2273	-42.0455
-46.5909	-35.2273	-36.3636	-18.1818	-62.5000	-39.7727
-45.4545	-29.5455	-28.4091	-17.0455	-68.1818	-31.8182
-44.3182	-25.0000	-21.5909	-15.9091	-72.7273	-23.8636
-38.6364	-21.5909	-17.0455	-15.9091	-73.8636	-19.3182
-36.3636	-17.0455	-12.5000	-12.5000	-72.7273	-18.1818
-29.5455	-9.0909	-7.9545	-10.2273	-70.4545	-18.1818
-28.4091	-7.9545	-2.2727	-10.2273	-68.1818	-18.1818
-26.1364	-10.2273	-1.1364	-1.1364	-64.7727	-18.1818
-22.7273	-6.8182	1.1364	0.0000	-59.0909	-17.0455
-19.3182	0.0000	0.0000	0.0000	-53.4091	-19.3182
-17.0455	-1.1364	1.1364	-2.2727	-46.5909	-25.0000
-13.6364	0.0000	1.1364	0.0000	-45.4545	-30.6818
-4.5455	5.6818	-2.2727	7.9545	-42.0455	-23.8636
-7.9545	6.8182	-10.2273	2.2727	-23.8636	-23.8636
-9.0909	3.4091	-12.5000	-3.4091	-22.7273	-30.6818
-10.2273	-1.1364	-9.0909	0.0000	-22.7273	-26.1364
-3.4091	1.1364	-6.8182	11.3636	-21.5909	-20.4545

ff28	ff29	ff30	ff31	ff32	ff33
17.7778	-9.7778	-7.5000	-21.0000	4.0000	18.7500
16.0000	-13.3333	38.5000	0.5000	17.5000	13.7500
12.4444	-16.0000	40.0000	21.5000	18.0000	13.7500
10.6667	-18.6667	43.0000	23.0000	41.0000	12.5000
8.8889	-22.2222	60.0000	26.5000	54.0000	21.2500
0.0000	-24.0000	59.5000	52.5000	54.0000	23.7500
-11.5556	-29.3333	62.0000	47.5000	53.5000	28.7500
-24.8889	-40.0000	61.0000	45.0000	55.5000	32.5000
-16.0000	-44.4444	56.5000	41.5000	53.5000	36.2500
-12.4444	-41.7778	44.5000	39.0000	50.5000	35.0000
0.0000	-30.2222	43.5000	37.5000	47.5000	32.5000
3.5556	-26.6667	48.5000	50.0000	48.0000	28.7500
6.2222	-20.4444	48.0000	50.0000	44.0000	27.5000
16.0000	-6.2222	38.0000	44.0000	35.0000	27.5000
23.1111	9.7778	18.0000	24.5000	20.0000	22.5000
32.0000	20.4444	1.5000	19.0000	11.0000	21.2500
36.4444	32.0000	-2.5000	17.0000	8.0000	17.5000
36.4444	37.3333	-0.5000	16.0000	10.0000	12.5000
32.0000	38.2222	2.0000	15.0000	5.5000	8.7500
24.0000	37.3333	-14.0000	15.0000	0.0000	6.2500
23.1111	37.3333	-10.5000	-6.5000	1.0000	2.5000
-3.5556	33.7778	-7.0000	-8.0000	0.0000	-3.7500
-15.1111	16.0000	-10.5000	-10.0000	-3.0000	-12.5000
-18.6667	-2.6667	-14.5000	-19.5000	-20.0000	-18.7500
-25.7778	-29.3333	-30.0000	-37.0000	-32.0000	-21.2500
-25.7778	-38.2222	-48.0000	-60.5000	-31.5000	-23.7500
-25.7778	-42.6667	-56.0000	-71.5000	-27.5000	-25.0000
-27.5556	-48.8889	-51.0000	-67.5000	-35.0000	-22.5000
-29.3333	-49.7778	-49.0000	-63.5000	-48.0000	-21.2500
-8.8889	-49.7778	-60.0000	-78.0000	-45.5000	-18.7500
0.8889	-42.6667	-62.0000	-78.0000	-38.0000	-16.2500
6.2222	-32.8889	-58.0000	-69.0000	-44.5000	-12.5000
7.1111	-27.5556	-60.0000	-74.0000	-48.5000	-7.5000
9.7778	-26.6667	-68.5000	-76.5000	-31.0000	-2.5000
15.1111	-22.2222	-63.5000	-68.0000	-37.5000	0.0000
16.0000	-16.8889	-51.0000	-57.0000	-45.5000	2.5000
16.0000	-16.0000	-57.0000	-58.5000	-41.5000	6.2500
16.0000	-15.1111	-60.5000	-50.5000	-36.0000	12.5000
19.5556	-8.8889	-48.0000	-37.0000	-41.0000	13.7500
16.8889	-3.5556	-41.0000	-34.0000	-41.0000	13.7500
15.1111	-3.5556	-37.5000	-22.5000	-36.5000	13.7500
12.4444	-3.5556	-32.5000	-17.5000	-32.0000	13.7500
11.5556	-3.5556	-19.0000	-12.0000	-30.0000	13.7500
16.0000	1.7778	-14.5000	-4.0000	-31.0000	17.5000
15.1111	3.5556	-10.0000	-2.0000	-34.5000	17.5000
15.1111	7.1111	-12.5000	-2.5000	-36.5000	18.7500
14.2222	8.0000	-14.0000	-6.0000	-31.5000	20.0000
13.3333	8.0000	-12.0000	-1.0000	-31.0000	20.0000
15.1111	7.1111	-12.5000	0.0000	-33.0000	18.7500
18.6667	7.1111	-14.0000	-9.5000	-34.5000	17.5000

Dd1	Dd2	Dd3	Dd4	Dd5	Dd6
18.7500	-6.2500	1.2500	-3.3333	-10.0000	-13.3333
13.7500	5.0000	-1.2500	-12.2222	0.0000	-10.0000
7.5000	13.7500	-3.7500	-14.4444	3.3333	-8.8889
-7.5000	13.7500	-1.2500	-11.1111	7.7778	-10.0000
-13.7500	10.0000	2.5000	-1.1111	12.2222	-17.7778
-13.7500	6.2500	1.2500	1.1111	3.3333	-22.2222
-3.7500	3.7500	0.0000	-3.3333	6.6667	-7.7778
2.5000	6.2500	-1.2500	-23.3333	12.2222	0.0000
5.0000	15.0000	-11.2500	-11.1111	4.4444	-13.3333
3.7500	21.2500	-16.2500	15.5556	-2.2222	-16.6667
-1.2500	13.7500	-11.2500	20.0000	1.1111	-4.4444
-7.5000	-8.7500	-3.7500	7.7778	7.7778	8.8889
-11.2500	-18.7500	0.0000	-12.2222	3.3333	3.3333
-3.7500	-12.5000	-10.0000	-1.1111	-1.1111	-12.2222
1.2500	-5.0000	-15.0000	7.7778	-10.0000	-15.5556
3.7500	-1.2500	-12.5000	6.6667	-4.4444	-8.8889
2.5000	-1.2500	-5.0000	2.2222	-3.3333	-2.2222
0.0000	-2.5000	2.5000	3.3333	1.1111	-12.2222
-2.5000	-10.0000	10.0000	12.2222	2.2222	-16.6667
-6.2500	-12.5000	6.2500	18.8889	-4.4444	-10.0000
-5.0000	-5.0000	1.2500	4.4444	-3.3333	-1.1111
16.2500	1.2500	-6.2500	-1.1111	13.3333	-10.0000
21.2500	8.7500	-3.7500	7.7778	8.8889	-17.7778
17.5000	0.0000	10.0000	17.7778	-2.2222	-11.1111
0.0000	-2.5000	17.5000	14.4444	-5.5556	-5.5556
-6.2500	0.0000	31.2500	-12.2222	10.0000	-2.2222
-11.2500	12.5000	28.7500	5.5556	26.6667	-26.6667
-6.2500	20.0000	13.7500	11.1111	-1.1111	-25.5556
3.7500	22.5000	-20.0000	15.5556	-18.8889	-3.3333
15.0000	20.0000	-17.5000	-2.2222	-11.1111	1.1111
17.5000	12.5000	-10.0000	-4.4444	-3.3333	-14.4444
10.0000	5.0000	-6.2500	-1.1111	-20.0000	-24.4444
2.5000	2.5000	-1.2500	4.4444	-30.0000	-23.3333
-5.0000	0.0000	-1.2500	-5.5556	-41.1111	-15.5556
-10.0000	-1.2500	-10.0000	-8.8889	-24.4444	-17.7778
-12.5000	-1.2500	-16.2500	10.0000	1.1111	-18.8889
-13.7500	-5.0000	-18.7500	3.3333	-2.2222	-12.2222
-12.5000	-13.7500	-12.5000	-1.1111	-26.6667	-4.4444
1.2500	-25.0000	-5.0000	-11.1111	-28.8889	-13.3333
2.5000	-22.5000	-2.5000	7.7778	4.4444	-14.4444
0.0000	-12.5000	-1.2500	20.0000	11.1111	-5.5556
-5.0000	2.5000	-3.7500	3.3333	-5.5556	4.4444
1.2500	6.2500	-8.7500	-11.1111	-10.0000	-5.5556
6.2500	5.0000	-12.5000	-15.5556	6.6667	-21.1111
7.5000	-1.2500	1.2500	-21.1111	14.4444	-22.2222
1.2500	-28.7500	5.0000	-28.8889	-2.2222	-15.5556
0.0000	-37.5000	3.7500	-35.5556	-8.8889	2.2222
10.0000	-22.5000	-3.7500	-26.6667	3.3333	-2.2222
10.0000	-3.7500	-8.7500	3.3333	24.4444	-5.5556
6.2500	6.2500	-13.7500	7.7778	26.6667	-4.4444

Dd7	Dd8	Dd9	Dd10	Dd11	Dd12
-5.5556	-15.8333	1.6667	-14.7727	-25.0000	-17.0455
-11.1111	-0.8333	2.5000	4.5455	-17.0455	-22.7273
-13.3333	10.8333	8.3333	-2.2727	-13.6364	-26.1364
-14.4444	16.6667	19.1667	-4.5455	-7.9545	-27.2727
-14.4444	10.8333	5.0000	-2.2727	-2.2727	-30.6818
-12.2222	0.8333	-1.6667	18.1818	-1.1364	-39.7727
-12.2222	-8.3333	5.8333	32.9545	-3.4091	-36.3636
-10.0000	-9.1667	10.8333	26.1364	-10.2273	-34.0909
-1.1111	-8.3333	10.8333	13.6364	3.4091	-39.7727
-7.7778	-8.3333	6.6667	-3.4091	-7.9545	-51.1364
-17.7778	-11.6667	0.8333	-19.3182	-19.3182	-43.1818
-11.1111	-10.8333	-2.5000	-23.8636	-12.5000	-26.1364
-15.5556	-5.8333	-0.8333	-26.1364	-2.2727	-21.5909
-20.0000	-8.3333	-0.8333	-27.2727	-18.1818	-23.8636
-27.7778	-12.5000	0.8333	-30.6818	-27.2727	-23.8636
-8.8889	-18.3333	-3.3333	-31.8182	-19.3182	-21.5909
-2.2222	-18.3333	-8.3333	-3.4091	1.1364	-11.3636
-12.2222	-8.3333	-9.1667	-17.0455	3.4091	-18.1818
-20.0000	0.8333	-5.8333	-31.8182	-4.5455	-26.1364
-15.5556	5.0000	-2.5000	-12.5000	-10.2273	-13.6364
-6.6667	-0.8333	-8.3333	6.8182	0.0000	4.5455
-2.2222	-2.5000	-14.1667	18.1818	2.2727	5.6818
-8.8889	-1.6667	-15.8333	10.2273	-11.3636	3.4091
-20.0000	5.0000	-12.5000	-9.0909	-13.6364	1.1364
-8.8889	13.3333	-12.5000	-11.3636	-1.1364	-4.5455
-1.1111	10.8333	-18.3333	-13.6364	4.5455	-13.6364
-27.7778	6.6667	-21.6667	-5.6818	13.6364	-20.4545
-35.5556	5.8333	-15.8333	-2.2727	2.2727	-19.3182
-21.1111	8.3333	-8.3333	-2.2727	1.1364	-28.4091
5.5556	10.0000	1.6667	-1.1364	-13.6364	-32.9545
10.0000	9.1667	4.1667	0.0000	-26.1364	-26.1364
-2.2222	5.8333	1.6667	5.6818	-22.7273	-4.5455
-11.1111	2.5000	2.5000	13.6364	-18.1818	-20.4545
-1.1111	10.0000	0.8333	6.8182	-27.2727	-23.8636
14.4444	12.5000	0.8333	-1.1364	-37.5000	-10.2273
16.6667	7.5000	-1.6667	-7.9545	-19.3182	11.3636
-6.6667	0.8333	-8.3333	-1.1364	-14.7727	7.9545
-7.7778	-0.8333	-11.6667	2.2727	-22.7273	3.4091
3.3333	-1.6667	-7.5000	4.5455	-14.7727	1.1364
7.7778	-4.1667	-2.5000	4.5455	1.1364	-5.6818
7.7778	-6.6667	-0.8333	3.4091	12.5000	-10.2273
5.5556	-9.1667	0.0000	-1.1364	20.4545	-11.3636
4.4444	-9.1667	-0.8333	-12.5000	2.2727	-10.2273
1.1111	-4.1667	-4.1667	-18.1818	-2.2727	-18.1818
-3.3333	2.5000	-6.6667	-14.7727	-6.8182	-19.3182
1.1111	0.0000	-10.8333	-11.3636	-13.6364	-18.1818
2.2222	-0.8333	-15.0000	-6.8182	-11.3636	-12.5000
-1.1111	-6.6667	-16.6667	-3.4091	-10.2373	-15.9091
-3.3333	-6.6667	-16.6667	-1.1364	-7.9545	-18.1818
-8.8889	-5.8333	-15.8333	-2.2727	-7.9545	-18.1818

Dd13	Dd14	Dd15	Dd16
-34.0909	-10.5000	-7.5000	-3.0000
-28.4091	-6.0000	-9.5000	-6.0000
-26.1364	-6.5000	-11.0000	-7.0000
-6.8182	-9.5000	-12.0000	-7.0000
-1.1364	-11.5000	-11.0000	-8.0000
-4.5455	-9.0000	-9.5000	-10.0000
-12.5000	-6.5000	-9.5000	-5.0000
-11.3636	-2.0000	-13.5000	-4.0000
-14.7727	-10.0000	-15.0000	-4.0000
-14.7727	-9.5000	-11.0000	-4.5000
-4.5455	-6.5000	-13.0000	-5.0000
-2.2727	-5.0000	-17.0000	-6.0000
-7.9545	-12.5000	-19.5000	-9.0000
-3.4091	-18.0000	-12.0000	-12.0000
1.1364	-12.5000	-9.0000	-8.5000
5.6818	-7.5000	-17.0000	-6.5000
6.8182	-10.0000	-22.0000	-9.5000
0.0000	-9.0000	-19.5000	-17.5000
-2.2727	-6.0000	-15.0000	-20.0000
4.5455	-13.0000	-14.5000	-16.5000
12.5000	-17.0000	-9.5000	-12.5000
3.4099	-12.5000	-3.5000	-11.0000
-9.0909	-6.0000	-8.0000	-8.0000
2.2727	-7.5000	-14.0000	-7.0000
26.1364	-11.5000	-16.0000	-13.0000
34.0909	-14.5000	-10.5000	-17.0000
17.0455	-7.0000	-6.5000	-10.5000
-26.1364	-1.5000	-2.0000	-5.0000
-14.7727	2.5000	-9.5000	-4.5000
-35.2273	-7.5000	-2.5000	-12.0000
-28.4091	-4.5000	4.0000	-7.5000
-28.4091	4.0000	-4.5000	1.5000
-36.3636	-5.0000	-12.0000	-5.0000
-44.3182	-10.0000	-18.5000	-8.5000
-23.8636	-14.0000	-13.0000	-12.5000
-12.5000	-11.0000	-12.5000	-7.0000
-22.7273	-10.0000	-14.0000	-6.0000
-40.9091	-9.0000	-11.5000	-6.5000
-26.1364	-14.5000	-6.0000	-3.5000
-7.9545	-8.5000	-9.0000	-1.0000
-10.2273	-7.0000	-12.0000	-4.5000
-14.7727	-5.0000	-10.0000	-7.0000
-21.5909	1.0000	1.0000	-4.5000
-30.6818	2.0000	2.5000	-1.0000
-27.2727	4.5000	-3.5000	4.5000
-26.1364	0.5000	-6.5000	0.5000
-29.5455	-2.0000	-4.5000	-5.5000
-36.3636	-2.5000	-3.0000	-5.0000
-44.3182	1.5000	-6.5000	-5.0000
-48.8636	1.0000	-10.5000	-7.0000

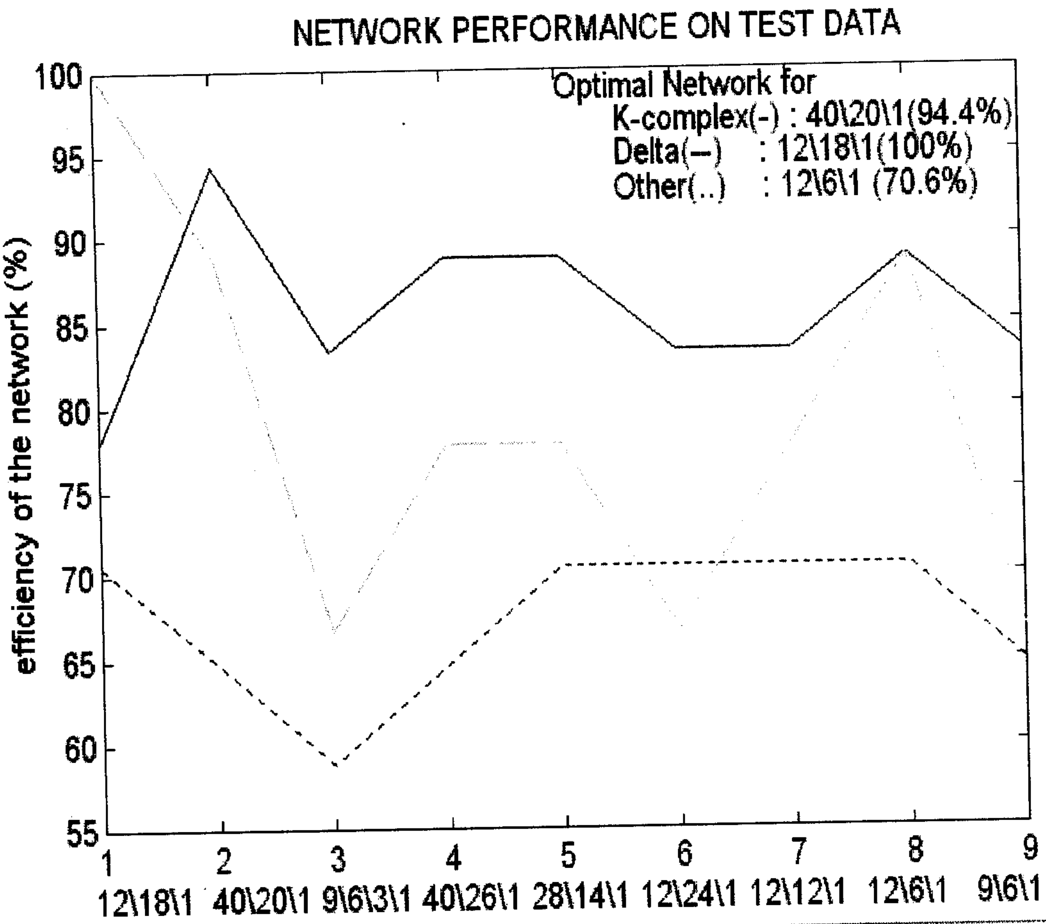
Rr1	Rr2	Rr3	Rr5	Rr7	Rr9
-23.5200	-36.1200	-13.0952	41.6667	-45.2381	7.5000
-31.0800	-30.2400	-15.4762	38.0952	-40.4762	6.2500
-33.6000	-28.5600	-20.2381	38.0952	-39.2857	5.0000
-36.9600	-26.0400	-22.6190	34.5238	-42.8571	8.7500
-36.1200	-21.0000	-23.8095	30.9524	-41.6667	15.0000
-33.6000	-18.4800	-23.8095	11.9048	-42.8571	18.7500
-26.8800	-18.4800	-22.6190	5.9524	-42.8571	20.0000
-19.3200	-20.1600	-23.8095	3.5714	-44.0476	17.5000
-15.1200	-22.6800	-21.4286	2.3810	-44.0476	15.0000
-16.8000	-24.3600	-20.2381	-1.1905	-44.0476	15.0000
-21.8400	-24.3600	-14.2857	-4.7619	-35.7143	10.0000
-24.3600	-24.3600	-13.0952	-5.9524	-33.3333	2.5000
-26.8800	-20.1600	-13.0952	-8.3333	-34.5238	-2.5000
-29.4000	-16.8000	-15.4762	-13.0952	-34.5238	-6.2500
-32.7600	-15.1200	-25.0000	-19.0476	-34.5238	-1.2500
-32.7600	-15.1200	-28.5714	-20.2381	-33.3333	3.7500
-32.7600	-16.8000	-39.2857	-23.8095	-28.5714	13.7500
-32.7600	-19.3200	-44.0476	-28.5714	-21.4286	17.5000
-28.5600	-19.3200	-46.4286	-26.1905	-20.2381	18.7500
-24.3600	-18.4800	-47.6190	-26.1905	-20.2381	22.5000
-20.1600	-13.4400	-46.4286	-26.1905	-27.3810	23.7500
-20.1600	-10.0800	-44.0476	-26.1905	-30.9524	18.7500
-16.8000	-7.5600	-39.2857	-26.1905	-36.9048	17.5000
-12.6000	-5.0400	-35.7143	-28.5714	-42.8571	15.0000
-6.7200	-4.2000	-26.1905	-26.1905	-45.2381	22.5000
-9.2400	-4.2000	-21.4286	-17.8571	-48.8095	23.7500
-14.2800	-5.0400	-15.4762	-9.5238	-52.3810	25.0000
-12.6000	-4.2000	-8.3333	-7.1429	-53.5714	15.0000
-8.4000	-15.9600	-7.1429	-3.5714	-54.7619	1.2500
-2.5200	-23.5200	-5.9524	0.0000	-55.9524	-7.5000
0.8400	-27.7200	-2.3810	0.0000	-53.5714	-5.0000
6.7200	-31.9200	-2.3810	-2.3810	-51.1905	-10.0000
7.5600	-33.6000	-2.3810	-4.7619	-41.6667	-17.5000
2.5200	-31.9200	-10.7143	-9.5238	-33.3333	-17.5000
-1.6800	-29.4000	-13.0952	-9.5238	-27.3810	-5.0000
-7.5600	-16.8000	-14.2857	-7.1429	-25.0000	1.2500
-11.7600	-10.0800	-10.7143	-2.3810	-21.4286	13.7500
-14.2800	-7.5600	-8.3333	0.0000	-21.4286	10.0000
-16.8000	-5.8800	-7.1429	-4.7619	-25.0000	3.7500
-21.0000	-5.8800	-5.9524	-13.0952	-36.9048	0.0000
-25.2000	-11.7600	-1.1905	-32.1429	-46.4286	0.0000
-26.8800	-10.0800	0.0000	-41.6667	-50.0000	0.0000
-26.8800	-8.4000	-2.3810	-34.5238	-51.1905	-1.2500
-23.5200	-3.3600	-3.5714	-33.3333	-51.1905	0.0000
-20.1600	-1.6800	-10.7143	-28.5714	-52.3810	5.0000
-14.2800	0.0000	-21.4286	-14.2857	-59.5238	-2.5000
-10.9200	0.8400	-23.8095	-13.0952	-64.2857	-11.2500
-10.9200	0.0000	-22.6190	-13.0952	-63.0952	-7.5000
-8.4000	-2.5200	-16.6667	-14.2857	-63.0952	-3.7500
-9.2400	-6.7200	-11.9048	-11.9048	-48.8095	2.5000

Rr10	Rr11	Rr13	Rr14	Rr15	Rr16
5.0000	20.0000	-16.2500	-11.2500	8.8889	10.0000
5.0000	20.0000	-12.5000	-11.2500	2.2222	15.5556
6.2500	20.0000	-15.0000	-7.5000	-6.6667	18.8889
7.5000	18.7500	-16.2500	-5.0000	-15.5556	14.4444
12.5000	13.7500	-17.5000	0.0000	-21.1111	1.1111
16.2500	5.0000	-16.2500	-8.7500	-22.2222	4.4444
18.7500	-1.2500	-12.5000	-7.5000	-17.7778	8.8889
18.7500	-3.7500	-5.0000	-3.7500	-7.7778	2.2222
16.2500	-3.7500	-6.2500	2.5000	0.0000	-3.3333
15.0000	-2.5000	-7.5000	8.7500	2.2222	-4.4444
11.2500	-2.5000	-7.5000	11.2500	7.7778	-2.2222
6.2500	2.5000	-7.5000	15.0000	17.7778	-1.1111
2.5000	3.7500	-5.0000	21.2500	21.1111	-2.2222
-1.2500	2.5000	-1.2500	21.2500	22.2222	-4.4444
-5.0000	-7.5000	8.7500	20.0000	17.7778	-4.4444
1.2500	-11.2500	17.5000	20.0000	13.3333	-2.2222
11.2500	-11.2500	20.0000	21.2500	16.6667	4.4444
16.2500	-13.7500	3.7500	18.7500	24.4444	5.5556
20.0000	-15.0000	2.5000	10.0000	17.7778	5.5556
20.0000	-11.2500	-2.5000	8.7500	17.7778	0.0000
26.2500	-2.5000	-2.5000	10.0000	16.6667	-12.2222
26.2500	8.7500	-7.5000	15.0000	10.0000	-13.3333
21.2500	7.5000	-7.5000	22.5000	3.3333	-13.3333
16.2500	-1.2500	-6.2500	23.7500	1.1111	-13.3333
20.0000	-1.2500	-1.2500	23.7500	1.1111	-7.7778
27.5000	-1.2500	10.0000	21.2500	4.4444	10.0000
27.5000	-1.2500	13.7500	20.0000	23.3333	13.3333
23.7500	1.2500	13.7500	11.2500	22.2222	14.4444
8.7500	1.2500	8.7500	-1.2500	15.5556	10.0000
-5.0000	1.2500	6.2500	-6.2500	10.0000	11.1111
-6.2500	1.2500	6.2500	-8.7500	6.6667	18.8889
-10.0000	1.2500	10.0000	-16.2500	4.4444	24.4444
-12.5000	0.0000	12.5000	-7.5000	5.5556	23.3333
-17.5000	-1.2500	12.5000	-7.5000	3.3333	15.5556
-16.2500	-2.5000	11.2500	-13.7500	-3.3333	1.1111
-1.2500	-2.5000	12.5000	-16.2500	-3.3333	-5.5556
8.7500	-6.2500	11.2500	-15.0000	-4.4444	-6.6667
12.5000	-12.5000	7.5000	-10.0000	-4.4444	-3.3333
8.7500	-15.0000	2.5000	-10.0000	-2.2222	-3.3333
0.0000	-5.0000	0.0000	-10.0000	-2.2222	-11.1111
-1.2500	2.5000	0.0000	-13.7500	-4.4444	-10.0000
2.5000	6.2500	7.5000	-20.0000	-5.5556	-8.8889
-1.2500	17.5000	11.2500	-20.0000	-11.1111	-6.6667
0.0000	21.2500	6.2500	-1.2500	-21.1111	-11.1111
3.7500	28.7500	-30.0000	3.7500	-14.4444	-15.5556
3.7500	30.0000	-41.2500	0.0000	-3.3333	-16.6667
-10.0000	23.7500	-46.2500	-2.5000	6.6667	-16.6667
-11.2500	20.0000	-45.0000	-25.0000	13.3333	-16.6667
-6.2500	13.7500	-41.2500	-23.7500	10.0000	-11.1111
0.0000	10.0000	-31.2500	-23.7500	8.8889	-14.4444

Rr17	Rr19	Rr20	Rr21	Rr22	Rr23
-1.1111	20.0000	-8.3333	17.5000	-9.0909	-45.5556
0.0000	22.2222	-5.8333	17.5000	-5.6818	-50.0000
0.0000	20.0000	-15.8333	12.5000	-4.5455	-44.4444
0.0000	-5.5556	-11.6667	10.8333	-1.1364	-42.2222
4.4444	-22.2222	-1.6667	15.8333	0.0000	-34.4444
4.4444	-23.3333	-1.6667	24.1667	-1.1364	-30.0000
3.3333	-18.8889	-5.0000	25.8333	-1.1364	-27.7778
1.1111	-14.4444	-14.1667	18.3333	-1.1364	-31.1111
2.2222	5.5556	-23.3333	15.8333	-1.1364	-32.2222
3.3333	25.5556	-21.6667	12.5000	-6.8182	-32.2222
-1.1111	17.7778	-19.1667	7.5000	-6.8182	-32.2222
0.0000	15.5556	-16.6667	4.1667	-5.6818	-32.2222
1.1111	24.4444	-15.0000	4.1667	-2.2727	-32.2222
3.3333	37.7778	-14.1667	3.3333	0.0000	-32.2222
2.2222	33.3333	-11.6667	0.8333	0.0000	-27.7778
-4.4444	26.6667	-2.5000	1.6667	-1.1364	-25.5556
-2.2222	18.8889	-2.5000	5.0000	-5.6818	-23.3333
-4.4444	14.4444	-3.3333	8.3333	-13.6364	-23.3333
-6.6667	24.4444	-5.8333	5.0000	-14.7727	-21.1111
0.0000	34.4444	-1.6667	-0.8333	-19.3182	-15.5556
15.5556	28.8889	-0.8333	0.0000	-21.5909	-6.6667
16.6667	20.0000	1.6667	2.5000	-20.4545	-6.6667
17.7778	12.2222	-0.8333	-8.3333	-15.9091	-6.6667
12.2222	2.2222	-0.8333	-18.3333	-13.6364	-7.7778
8.8889	-1.1111	2.5000	-19.1667	-14.7727	-11.1111
0.0000	-4.4444	6.6667	-19.1667	-15.9091	-20.0000
-5.5556	-7.7778	3.3333	-20.0000	-22.7273	-12.2222
-5.5556	-6.6667	1.6667	-22.5000	-28.4091	-11.1111
-6.6667	-11.1111	-0.8333	-18.3333	-27.2727	-14.4444
-8.8889	-13.3333	-5.8333	-16.6667	-22.7273	-16.6667
-6.6667	-18.8889	-6.6667	-15.8333	-19.3182	-3.3333
-4.4444	-24.4444	-6.6667	-15.0000	-18.1818	-1.1111
-3.3333	-26.6667	-6.6667	-13.3333	-17.0455	2.2222
-5.5556	-25.5556	-6.6667	-10.0000	-14.7727	2.2222
0.0000	-24.4444	-6.6667	-2.5000	-14.7727	5.5556
1.1111	-22.2222	-7.5000	2.5000	-18.1818	8.8889
-2.2222	-17.7778	-7.5000	3.3333	-18.1818	11.1111
-5.5556	-11.1111	-6.6667	2.5000	-14.7727	7.7778
-4.4444	-16.6667	-5.0000	2.5000	-10.2273	3.3333
-4.4444	-18.8889	-2.5000	3.3333	-10.2273	1.1111
-1.1111	-16.6667	-12.5000	8.3333	-10.2273	1.1111
6.6667	-4.4444	-15.0000	20.0000	-4.5455	1.1111
14.4444	-4.4444	-14.1667	15.0000	-4.5455	0.0000
15.5556	-7.7778	-12.5000	0.0000	-1.1364	-2.2222
16.6667	-2.2222	-8.3333	6.6667	1.1364	-7.7778
14.4444	1.1111	-10.8333	11.6667	4.5455	-21.1111
17.7778	5.5556	-13.3333	18.3333	-6.8182	-22.2222
15.5556	5.5556	-13.3333	21.6667	-11.3636	-23.3333
12.2222	-1.1111	-13.3333	0.0000	-6.8182	-23.3333
11.1111	-11.1111	-11.6667	-6.6667	-11.3636	-25.5556

Rr24	Rr26	Rr28	Rr30	Rr33
-3.4091	-31.8182	-11.5556	-6.5000	4.5000
-5.6818	-32.9545	-10.6667	-8.5000	5.0000
-6.8182	-31.8182	-9.7778	-8.0000	4.5000
-7.9545	-31.8182	-8.8889	-7.0000	5.0000
-9.0909	-31.8182	-8.8889	-9.0000	5.0000
-9.0909	-34.0909	-9.7778	-9.5000	6.0000
-12.5000	-32.9545	-10.6667	-16.5000	6.5000
-20.4545	-36.3636	-10.6667	-24.5000	7.5000
-21.5909	-34.0909	-11.5556	-23.5000	7.5000
-22.7273	-32.9545	-10.6667	-23.0000	7.0000
-23.8636	-31.8182	-6.2222	-21.0000	6.5000
-23.8636	-35.2273	-1.7778	-8.5000	6.0000
-17.0455	-31.8182	0.8889	-1.5000	5.5000
-19.3182	-30.6818	1.7778	-1.5000	5.5000
-19.3182	-30.6818	1.7778	-0.5000	6.5000
-17.0455	-22.7273	0.0000	1.0000	9.0000
-17.0455	-18.1818	-3.5556	6.0000	9.5000
-15.9091	-15.9091	-9.7778	8.0000	9.0000
-15.9091	-18.1818	-10.6667	-1.0000	9.0000
-19.3182	-17.0455	-11.5556	-1.5000	8.5000
-22.7273	-15.9091	-11.5556	-2.5000	8.5000
-22.7273	-14.7727	-12.4444	-3.5000	8.0000
-22.7273	-14.7727	-13.3333	-5.5000	8.5000
-23.8636	-12.5000	-16.8889	-8.5000	7.5000
-25.0000	-11.3636	-17.7778	-8.0000	6.0000
-25.0000	-13.6364	-14.2222	-8.0000	5.5000
-20.4545	-18.1818	-13.3333	-8.5000	5.0000
-15.9091	-15.9091	-11.5556	-9.5000	5.0000
-15.9091	-17.0455	-8.8889	-10.5000	4.5000
-11.3636	-13.6364	-7.1111	-13.0000	4.5000
-4.5455	-9.0909	-2.6667	-15.0000	4.5000
-1.1364	-7.9545	-0.8889	-15.5000	5.5000
4.5455	-10.2273	0.8889	-6.5000	7.0000
3.4091	-11.3636	1.7778	-8.0000	6.5000
0.0000	-7.9545	1.7778	-8.5000	5.5000
-1.1364	1.1364	-2.6667	-6.0000	6.0000
1.1364	3.4091	-4.4444	-4.0000	6.0000
6.8182	6.8182	-3.5556	-10.0000	7.5000
15.9091	7.9545	-0.8889	-11.5000	7.0000
2.2727	6.8182	1.7778	-18.0000	6.0000
-13.6364	1.1364	2.6667	-22.0000	6.5000
-5.6818	1.1364	2.6667	-21.0000	7.5000
-4.5455	-2.2727	2.6667	-16.0000	8.0000
-2.2727	0.0000	5.3333	-14.5000	6.0000
-2.2727	-5.6818	6.2222	-17.5000	5.5000
7.9545	-13.6364	6.2222	-18.5000	5.5000
0.0000	-4.5455	5.3333	-21.0000	5.5000
-4.5455	1.1364	6.2222	-20.0000	6.0000
-1.1364	-15.9091	1.7778	-18.0000	6.5000
-2.2727	-23.8636	-0.8889	-16.0000	6.0000

GRAPH 3.1


NETWORK PERFORMANCE ON TEST DATA
Optimal Network for
K-complex(-) : 40\20\1(94.4%)
Delta(--) : 12\18\1(100%)
Other(..) : 12\6\1 (70.6%)
efficiency of the network (%)
100
95
90
85
80
75
70
65
60
55
1
12\18\1
2
40\20\1
3
9\6\3\1
4
40\26\1
5
28\14\1
6
12\24\1
7
12\12\1
8
12\6\1
9
9\6\1

GRAPH 3.2

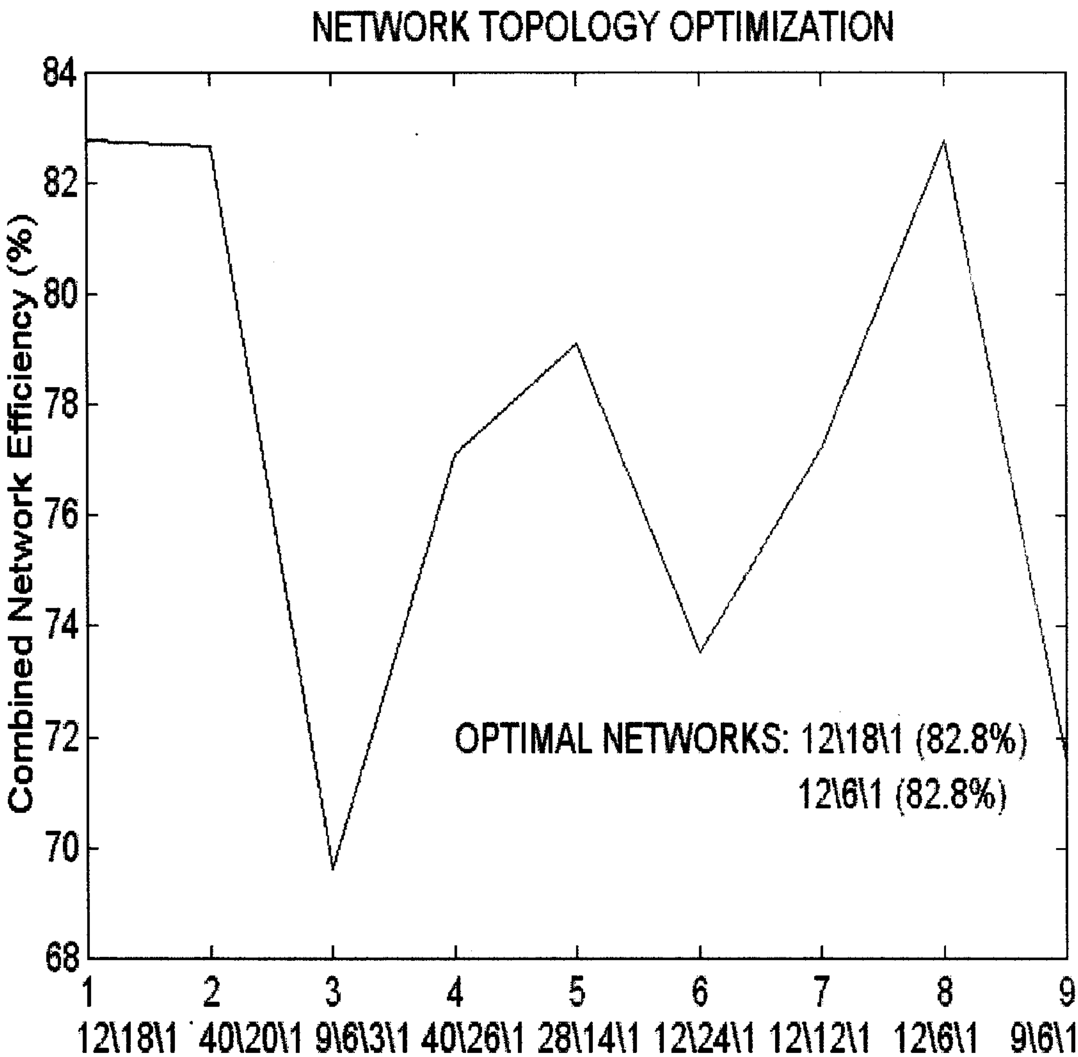
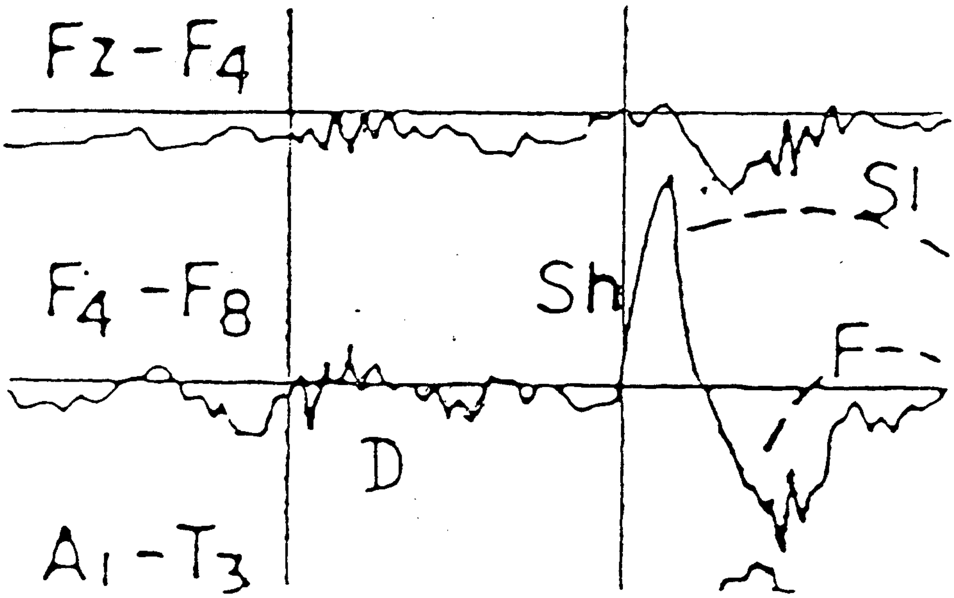
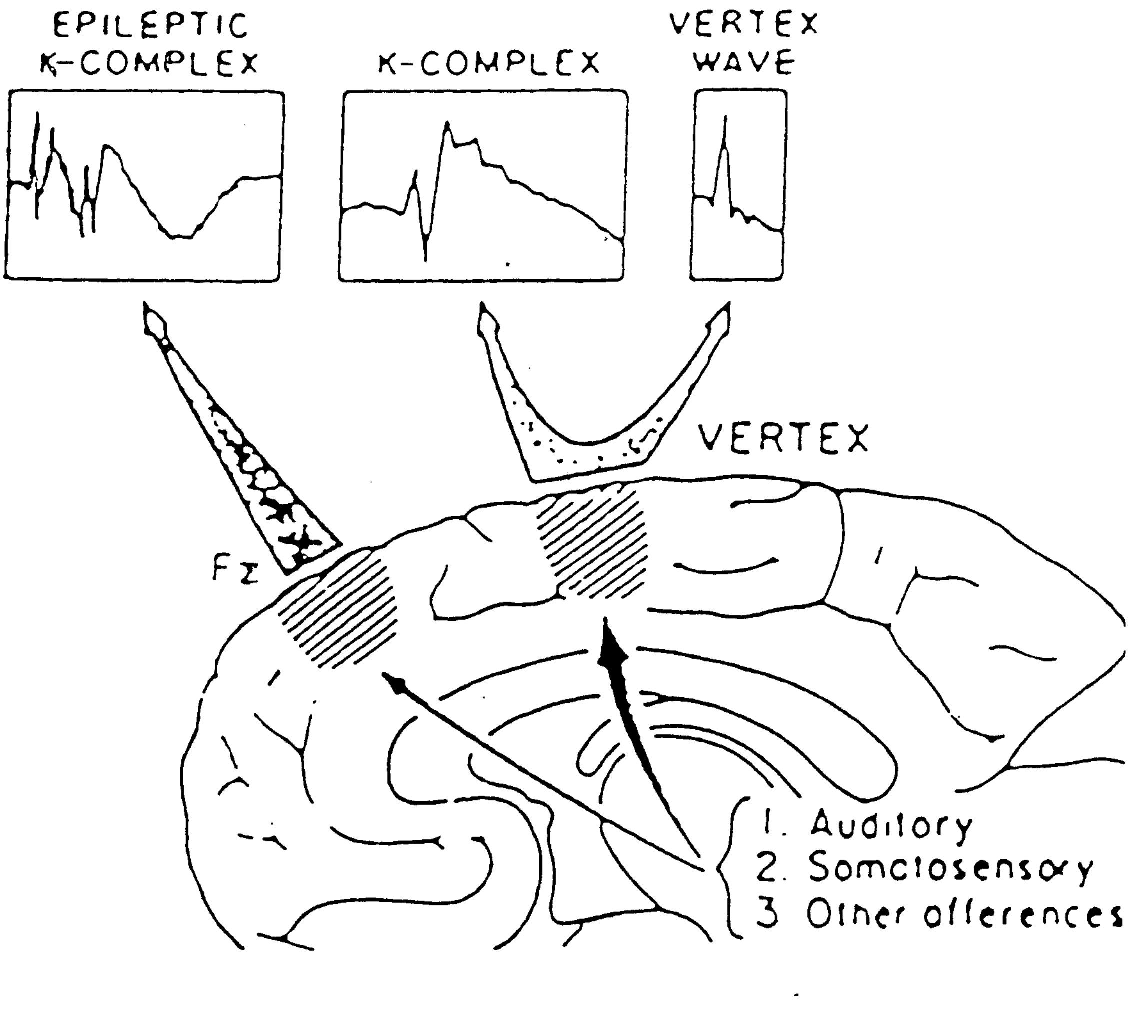

NETWORK TOPOLOGY OPTIMIZATION
84
82
80
78
76
74
72
70
68
Combined Network Efficiency (%)
OPTIMAL NETWORKS: 12\18\1 (82.8%)
12\6\1 (82.8%)
1
2
3
4
5
6
7
8
9
12\18\1
40\20\1
9\6\3\1
40\26\1
28\14\1
12\24\1
12\12\1
12\6\1
9\6\1

FIG-2.1



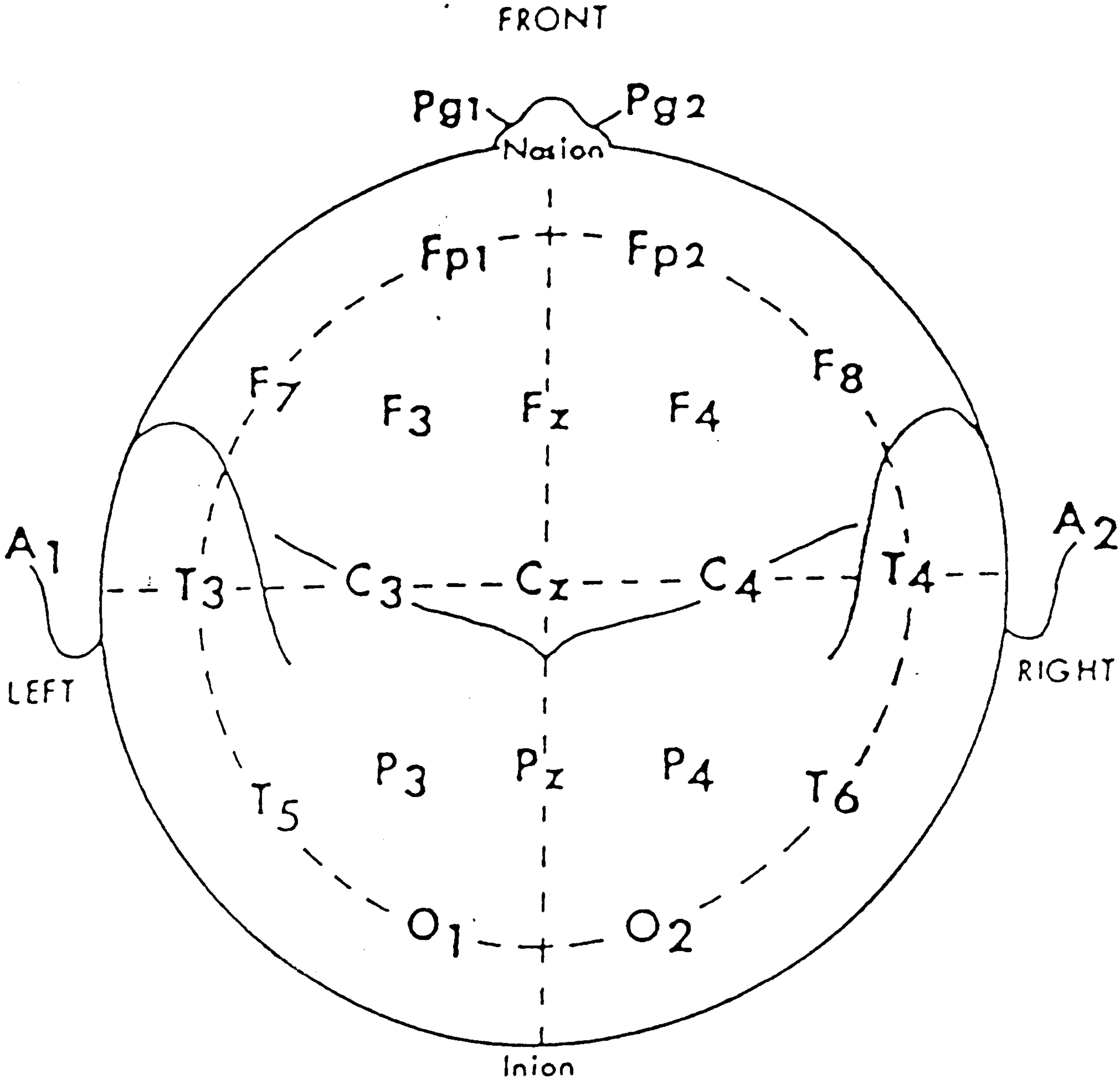
An ideal k-complex showing sharp, slow and fast components along with the neighbouring delta activity (sleep spindle)

FIG-2.2



Classification of k-complex based on the site of origin

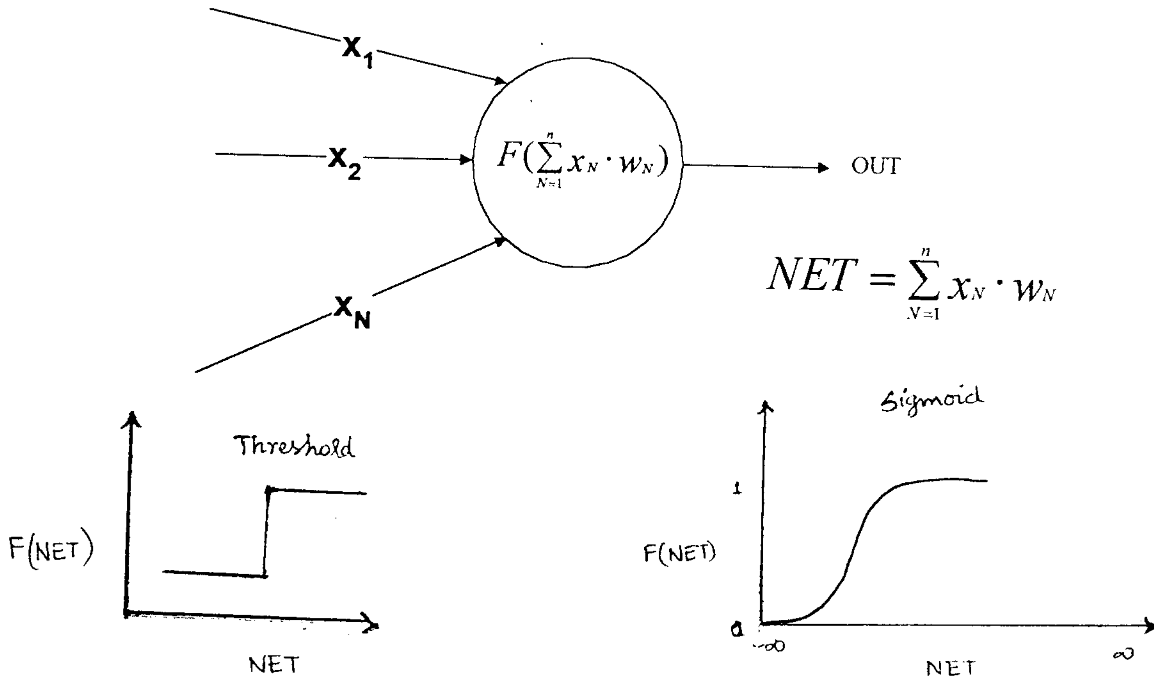
FIG-2.3



TOP OF HEAD

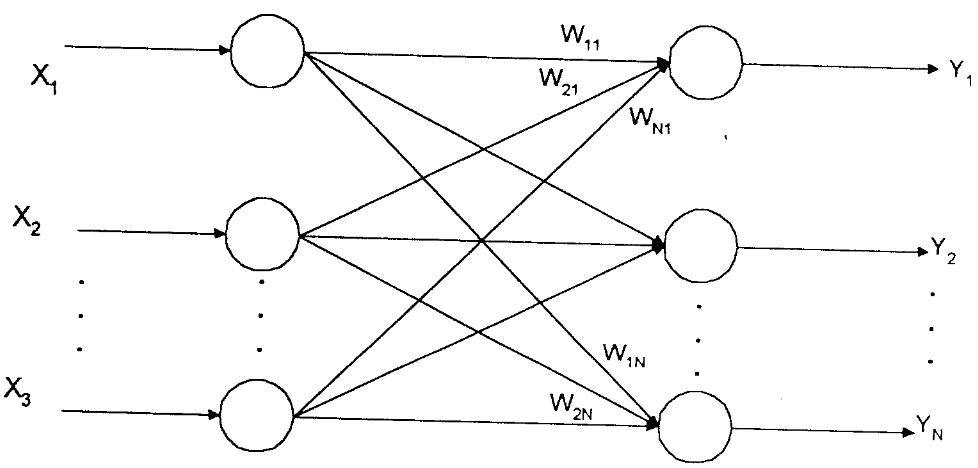
EEG electrode positions
F - Frontal, C - central

FIG - 3



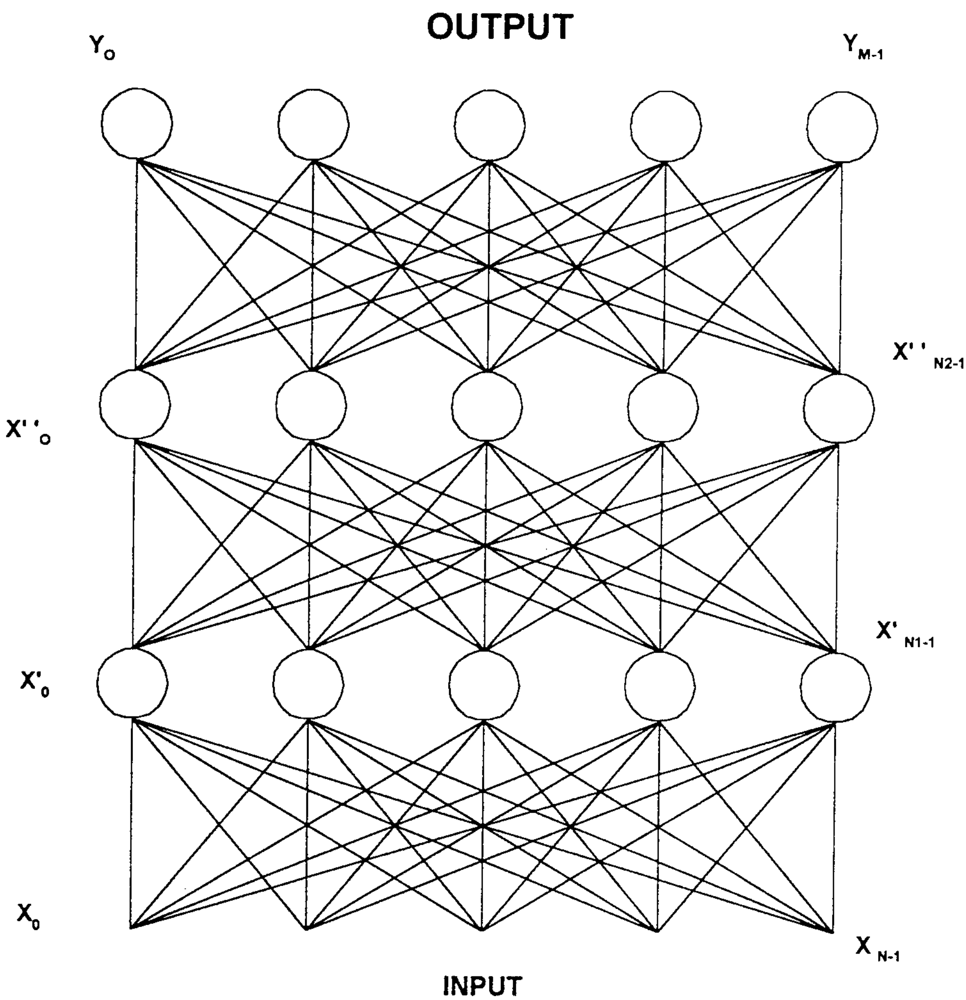
X1
X2
XN
$F(\sum_{N=1}^{n} x_N \cdot w_N)$
OUT
$NET = \sum_{N=1}^{n} x_N \cdot w_N$
Threshold
F(NET)
NET
Sigmoid
1
F(NET)
0
-∞
NET
∞

FIG - 3.2



X1
X2
X3
W11
W21
WN1
W1N
W2N
Y1
Y2
YN

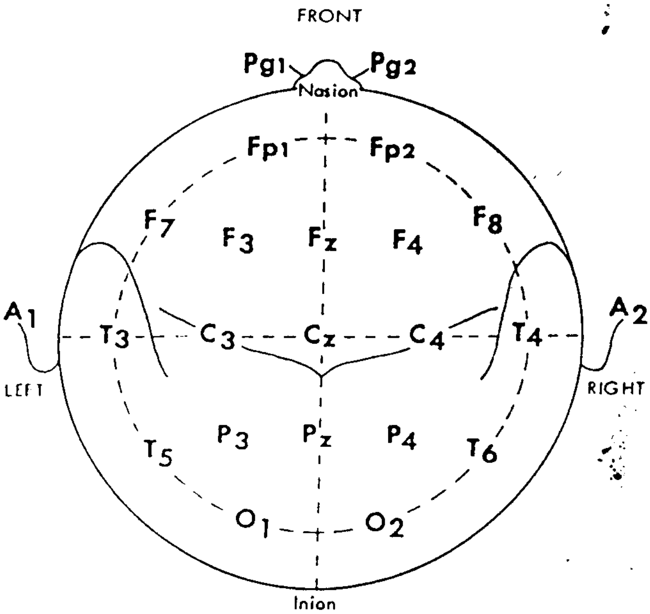
FIG 3.3



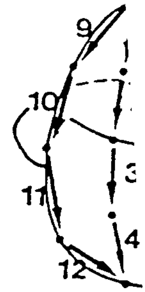
THREE LAYERED NEURAL NET ARCHITECTURE

N = NUMBER OF INPUTS
N1 =NUMBER OF INPUT LAYER NEURONS
N2 =NUMBER OF HIDDEN LAYER NEURONS
M = NUMBER OF OUTPUT LAYER NEURONS
(NUMBER OF OUTPUTS)

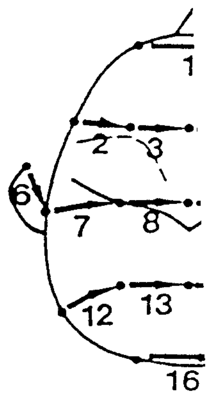
EEG QUICK REFERENCE CHART



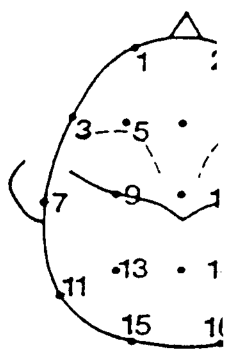
TOP OF HEAD



A representation of bipolar longitudinal or AP direction. This m comparison of left-right differences in area, but a montage with strict left-to-r could provide the same information.



This is a typical bipolar (scalp- transverse or coronal direction



IPSILATERAL REFERENC

This is a reference (monc

This particular sequence is

a front-to-back sequenc to provide anatomic

EEG ELECTRODE POSITIONS*

10-20 SYSTEM

BRAIN AREA	LEFT HEMISPHERE	MIDLINE	RIGHT HEMISPHERE
RONTAL POLE	Fp1	-	Fp2
RONTAL	F3	-	F4
NFERIOR FRONTAL	F7	-	F8
ID-FRONTAL	-	Fz	-
NTERIOR TEMPORAL	T1	-	T2
ID-TEMPORAL	T3	-	T4
OSTERIOR TEMPORAL	T5	-	T6
ENTRAL	C3	-	C4
ERTEX OR MID-CENTRAL	-	Cz	-
ARIETAL	P3	-	P4
ID-PARIETAL	-	Pz	-
CCIPITAL	O1	-	O2
URICULAR	A1	-	A2

[1]. Leslie Cromwell & Fred J. Weibell & Erich A. Preiffer : "Biomedical Instrumentation And Instruments ",Second Edition.

[2]. Wasserman : "Neural Computing :Theory and practice " Van Nostrand

[3]. Ben H.Jansen :"Artificial Neural Nets for K-complex Detection " , University Of Houston.

[4]. Reddy D C: "Recent Advances In Biomedical Engineering", Osmania University.

[5]. John G. Proakis & Dimitris G. Manolakis :"Digital Signal Processing" Principles , Algorithms , and Applications . Second edition(1992) .

[6]. Simon Haykin : "Digital Communications". Mc Master University. 1988 Edition .

[7]. Paul A. Lynn : "Electronic Signals And Systems ". University Of Bristol . 1986 Edition

[8]. Lawerence R. Rabiner & Bernard Gold : "Theory And Application Of Digital Signal Processing ", 1993.

[9]. John Laidlaw & Alan Richens & David Chadwick : " A Text book Of Epilepsy", Fourth Edition (1993).

[10]. M.A.B. Brazier: Electrical Activity Of The Nervous System , Pitman , London,1951.

[11]. Lippan RP : "An Introduction to Computing with Neural nets", IEEE ASSP Magazine , April 1987, PP.4-22 .

[12]. Robert Lafore :" Object - Oriented Programming In TURBO C++ ",1994 Edition.

[13]. Dr. Valluru B. Rao & Hayagriya V. Rao : "Neural Networks & Fuzzy Logic In C++ ", Second edition .

[14]. Meeta Gandhi & Tilak Shetty & Rajiv Shah : " The 'C' Odyssey - C++ &GRAPHICS - The Future Of C ", First Edition ,1992.

[15]. Arthur .C. Guyton : "Textbook of medical physiology ", seventh edition.

[16]. Limin Fu: " Neural Networks In Computer Intelligence ",University Of Florida , 1994 Edition .

[17]. Stephen Prata : " C++ Premier Plus ",1994 Edition .