BRAIN-MACHINE INTERFACE FOR CONTROL USING AUDITORY FEEDBACK

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

(With Specialization in Measurement & Instrumentation)

By

RAJESH SINGLA

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE-247 667 (INDIA)

JUNE, 2006

I.D. NO. MT-329/2006-24/RS-VK

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in this dissertation entitled, "**BRAIN MACHINE INTERFACE FOR CONTROL USING AUDITORY FEEDBACK**", submitted towards the partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **Electrical Engineering**, with specialization in Measurement and Instrumentation, I.I.T. Roorkee, India is an authentic record of my own work carried out from June 2005 to June 2006 under the supervision of **Dr. Vinod Kumar**, Electrical Engineering Department, Indian Institute of Technology, Roorkee, India.

The matter embodied in this dissertation report has not been submitted by me for the award of any other degree or diploma.

Place: Roorkee
Dated: June 2006

28/06

RAJESH SINGLA

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

Dr. Vinod Kumar
Professor
Electrical Department
IIT Roorkee
Roorkee-247667 (India)

ACKNOWLEDGEMENTS

At the outset, I express my deepest sense of gratitude to ***Dr. Vinod Kumar****, Department of Electrical Engineering, I.I.T. Roorkee, for giving me an opportunity to work on a topic that was so challenging and interesting for me. I remember with great emotion, the constant encouragement and help extended to me by him that went even beyond the realm of academics.*

The department of Electrical Engineering of this institute provided me with all kinds of necessary facilities for carrying out my work. My sincere thanks are due to ***Prof. S.P.Gupta****, Head of Electrical Engineering department and* ***Prof. H.O. Gupta****, Ex-head of the department, for making the opportunities available althrough. My sincere thanks go to all the faculty members of the department for the voluntary help, direct and indirect, extended to me during the course of the work.*

I wish to convey my thanks to ***Mr. Dinesh,*** *Lab attendant, Department of Electrical Engineering, I.I.T. Roorkee for providing me moral support at various stages of the work. I also wish to convey my thanks to M/s RMS Chandigarh for helping me in my work.*

Last, but not least by any means, I wish to acknowledge my wife for giving me the moral strength and constant encouragement. The work could never reach its present status without their constant support and love.

Dated: June 2006 RAJESH SINGLA

LIST OF FIGURES AND TABLES

ABBREVIATION AND ACRONYMS

AEP	Auditory Evoked Potential
BAEP	Brain Stem Auditory evoked potential
BP	Bipolar Electrode
EEG	Electroencephalogram
EMG	Electromyogram
EOG	Electroculogram
ERD	Event related de synchronization
ERP	Event related potential
EP	Evoked potential
IEEE	Institute of Electrical and Electronics Engineering
POSTS	Positive occipital transients of sleep
VEP	Visual evoked potential
PVEP	Pattern visually evoked potential
LPF	Low Pass Filter
HPF	High Pass Filter
TTD	Thought Translation device
RMS	Recorders and Medicare systems
REM	Rapid Eye Movement
SCP	Slow Cortical Potential

CONTENTS

ABSTRACT

A Brain Computer Interface is a communication system in which messages or commands that an individual sends to the external world do not pass through the brain's normal output pathways of peripheral nerves and muscles. Mental activity leads to changes in EEG (Electroencephalogram) signal, which are detected by the BCI and are transformed into a control signal.

The aim of the BCI is to improve the life style of the persons with severe disabilities. The other usage of BCI is in designing and evaluating hand free control i.e. EEG signals are recorded that allows communication with the computers while the operator's hands remained engaged in other activities. In nut shell, the effort is to create methods of BCI that leads to more effective control of the real world applications.

Here in our work we have recorded the changes in EEG pattern taking place due to the variation in the intensity, frequency and location of the click (Auditory stimulus) produced near the ear of the subject. Also changes due to the eye events are noted. These changes are then evaluated and are used to further generate a control action.

The control is switching on and Off of LED's attached to a PC via hardware cable. Software is developed to identify the changes and to use them for further control action.

CHAPTER 1
BASICS OF EEG AND BCI

1.1 Introduction

In this chapter we discuss the basics of EEG and BCI. We first discuss about EEG, its lead systems, recording procedure, feature identification, its artifacts and their removal etc. We also discuss introduction and definition of BCI, block diagram of BCI and types of BCI.

A Brain Computer Interface is a communication system in which messages or commands that an individual sends to the external world do not pass through the brain's normal output pathways of peripheral nerves and muscles. The aim of this research is to create a specialized interface that will allow an individual with severe motor disabilities to have an effective control of devices such as computers, speech synthesizers, assistive appliances and neural prostheses. This type of interface would increase an individual's independence, leading to an improved quality of life and reduced social costs.

BCI research is a multidisciplinary field requiring the knowledge of neuroscience, physiology, psychology and engineering. For the development of BCI, we generally use the Electroencephalogram (EEG). Electroencephalography (EEG) is a method used in measuring the electrical activity of the Brain. This activity is generated by nerve cells, called neurons. When sum of all neuronal activity exceeds a certain potential level called a threshold, the neuron fires nerve Impulse. EEG signal is composed of electrical rhythms and transient discharges. Features like wave shape, amplitude, frequency and power are detected which are typical for a particular act and it can vary from person to person. Once these features are detected, they can be used to generate a control signal using Translation algorithm and can be used to operate some devices.

1.2 EEG (Electroencephalogram)

The EEG is the measurement of the electrical activity of the brain. The electrical activity creates the signal, which depends on following factors:

- Location of Electrodes on the skull

- Age of the subject
- Mental state
- Region of the brain
- Hereditary factors
- Influences on the Brain-injury, stimuli, drugs, diseases etc.
- Artifacts- physiological, biological

Analysis of the EEG is a rational and systematic process involving a series of steps to characterize the electrical activity of the brain in terms of specific descriptors and measurements. These steps are listed as below:

Frequency or Wavelength
Voltage
Waveform
Regulation (Frequency & Voltage)
Manner of occurrence (Random, Serial and Continuous)
Reactivity (eye opening, mental calculation, sensory stimulation, movement)
Inter hemispheric coherence (Symmetry and Synchrony)

Table1.1 Essential characteristics of EEG analysis.

These signals are recorded by placing electrodes on the scalp. Normally two types of activities are measured from the brain:

- Spontaneous activity
- Evoked potentials

Spontaneous activity is measured from the scalp of the brain. The amplitude is about 100microvolt when measured on the scalp. Evoked potentials are those components of the EEG that arise in response to a stimulus which can be electric, auditory, visual etc. While placing electrodes on the brain, the Odd numbered electrodes are placed on left side and even numbered electrodes are place on Right hand side of the brain.

EEG signals are correlated with:-

- Attention
- Memory encoding

- Motor imagery
- Perceived error and/or conflict,
- Perception/recognition.

The average human brain weights around 1400 grams

Main Parts:

- Cerebral cortex
- Cerebellum
- Brain stem
- Hypothalamus and thalamus

Cortical Area	**Function**
Auditory association area	Complex processing of auditory information
Auditory cortex	Detection of sound quality (loudness, tone etc.)
Speech center(Broca's area)	Speech production and articulation
Prefrontal cortex	Problem solving, emotion, complex thought
Motor association cortex	Coordination of complex movement
Primary motor cortex	Initiation of voluntary movement
Primary somatosensory cortex	Receives tactile information from the body
Sensory association area	Processing of multisensory information
Visual association area	Complex processing of visual information
Wernicke's area	Language comprehension

Table 1.2 Description of functional parts of the Brain

EEG wave components include:

- Delta
- Theta
- Alpha
- Beta

Name of the Component	**δ(Delta)**	**θ(Theta)**	**α(Alpha)**	**β(Beta)**
Frequency Range(Hz)	0.5-4	4-8	8-13	13-22
Amplitude Range(μV)	<100	<100	<10	<20
Corresponding Actions	Sleep		Opening of the Eyes and Focusing	High state of wakefulness

Table 1.3 Various EEG Rhythms

- **Delta rhythm:** Infants (around the age of 2 months) show irregular delta activity of 2-3.5 Hz (amplitudes 50-100 V) in the waking state. In adults delta waves (frequencies below 3.5 Hz) are only seen in deep sleep.
- **Theta rhythm:** In normal adults theta waves are seen mostly in states of drowsiness and sleep. During waking hours the EEG contains only a small amount of theta activity and no organized theta rhythm.
- **Alpha rhythm:** It occurs during wakefulness over the posterior regions of the head, generally with higher voltage over the occipital areas. Amplitude is variable but is mostly below 50 μV in adults. Best seen with eyes closed and under conditions of physical relaxation and relative mental inactivity.
- **Beta rhythms:** Beta rhythm amplitudes are seldom larger than 30 microvolts. Beta rhythms can mainly be found over the frontal and central region. It can be blocked by motor activity and tactile stimulation.

These rhythms can generally be considered as general indication of the excitability of Central Nervous System. Normally while recording EEG, two types of Electrodes are used:

- **Referential/Monopolar** recording records the differences between the active electrodes on the scalp and an inactive electrode placed usually away from the scalp. I.e. ear etc.

- **Bipolar recording** involves the differences between two active electrodes. Each channel of EEG machine is connected to two different electrodes and the difference is recorded on one channel. These Montages are arranged in orderly way in chains usually from front to back or side, from one electrode to its neighboring and then to its next.

1.2.1 EEG Lead Systems

The internationally standardized 10-20 electrode system is usually employed to record spontaneous EEG. In this system 21 electrodes are placed on the scalp as shown in the figure. Two electrodes (A1 and A2) are attached on the ear lobes. Also two electrodes Ground and reference are placed on the forehead. The various leads are placed in five columns in a particular manner as follows:

- Cz,C3,C4,T3,T4 –Placed at the centre line of the head
- Fz,F3,F4,F7,F8-Placed in front of centre line electrodes
- Pz,P3,P4,T5,T6-Placed at back of the centre line electrodes
- O1,O2- Placed at the occipital area
- Fp1,Fp2-Placed on the forehead
- Gnd, Reference-Placed on the forehead

Bipolar or unipolar electrodes can be used for EEG measurement. In the first method the potential difference between a pair of electrodes is measured. In the latter method the potential of each electrode is compared either to neutral or the average of all electrodes. Electrodes are the most important link in conducting an EEG. Electrodes can be of surface or sub dermal type. Surface electrodes are applied on the scalp while disc electrodes should be clean metals. These are fine needles which are inserted just behind the skin surface. They can be hollow or solid.

EEG machine consists of following blocks:

- Amplifiers: - These are present in the Head Box of the EEG machine
- Filters: - These are present in the Adaptor Box which is used to filter out the unwanted signals.
- Recorder: - Here signals are recorded on to the PC and are displayed.

The voltage generated by the brain cells are picked up by EEG is extremely small between 10-20 microvolt and amplification is needed of the order of ten thousand times for the realization of the EEG signal.
Following is the figure showing the position of Electrodes on the brain:-

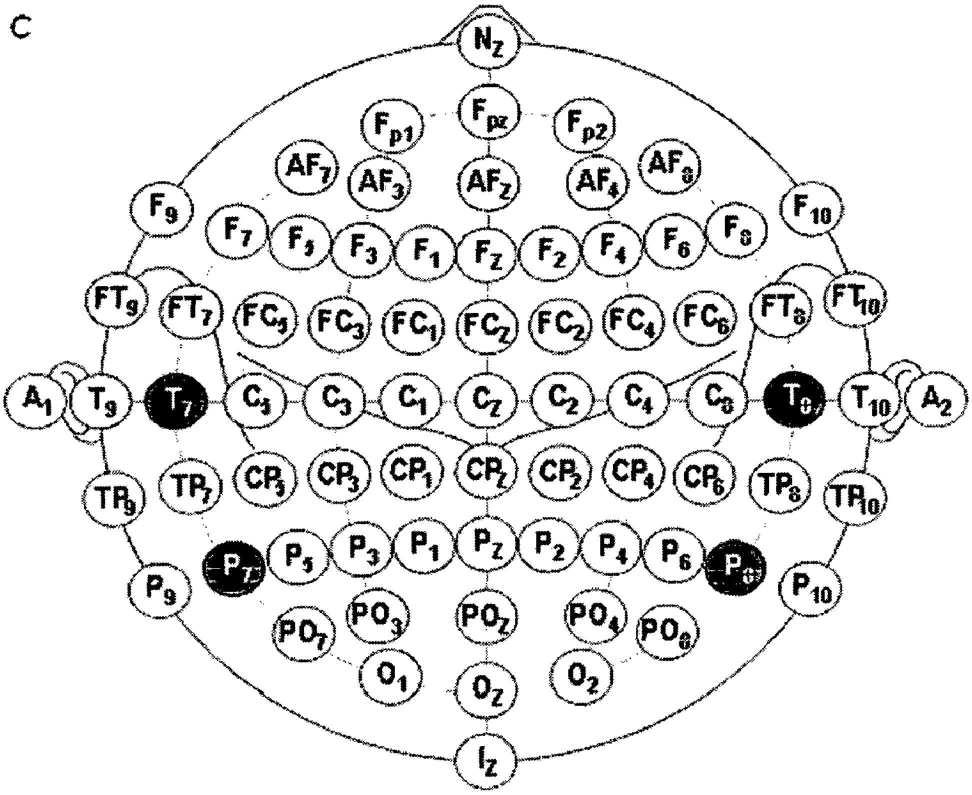


Fig 1.1 10-20/10-10 System of Electrode Placement *(ref Current practice of Electroencephalography, DD Daly and TA Pedley, Raven Press Ltd., New York, 1990)*

Here for recording purposes the international 10-20 system of placement of electrodes is followed. The electrodes are placed on the entire head following 10-20 distance arbitral measuring 100% from nasion to inions. The positions are determined as follows: Reference points are *nasion,* which is the delve at the top of the nose, level with the eyes; and *inion,* which is the bony lump at the base of the skull on the midline at the back of the head. From these points, the skull perimeters are measured in the transverse and median planes. Electrode locations are determined by dividing these perimeters into 10% and 20% intervals. Three other electrodes are placed on each side equidistant from the neighboring points. The locations and nomenclature of these electrodes are standardized by the American Electroencephalographic Society. The view of the electrode positions as seen from side and top is shown in the following figures.

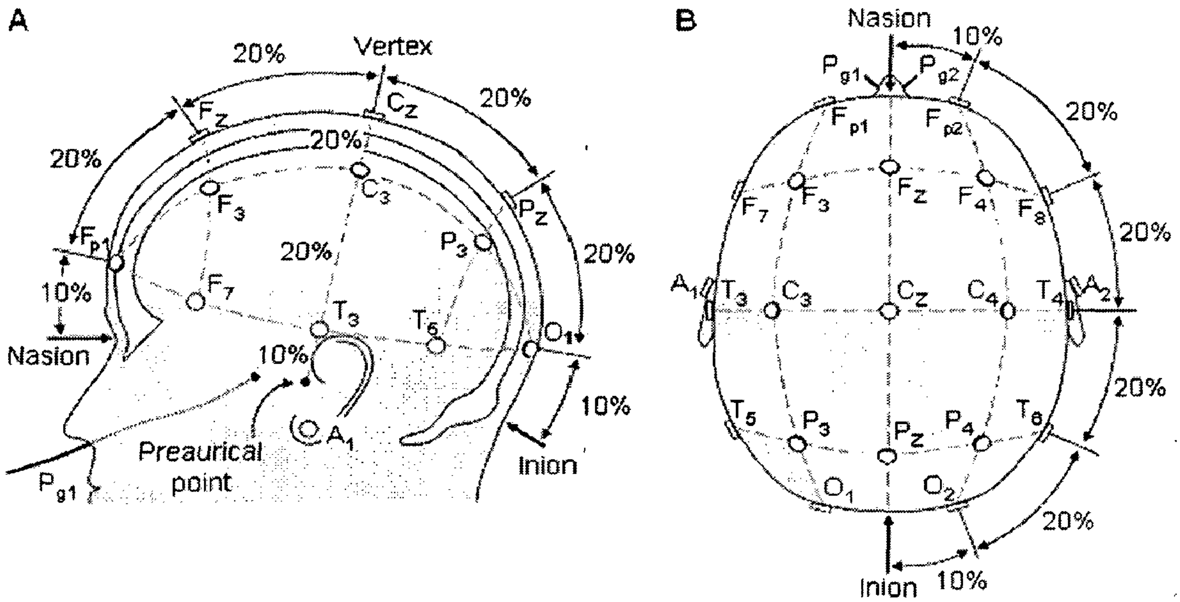


Fig 1.2 The International system of Electrode Placement as seen from the left and above of the head *(ref Current practice of Electroencephalography, DD Daly and TA Pedley, Raven Press Ltd., New York, 1990)*

Montages are the various ways by which an EEG signal can be analyzed on the PC. For an eight channel recorder machine the montages are:

Montages	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Test	O2 O1	O2 O1	O2 O1	O2 O1	O2 O1	O2 O1	O2 O1	O2 O1
Run A	FP2 F4	F4 C4	C4 P4	P4 O2	FP1 F3	F3 C3	C3 P3	P3 O1
Run B	FP2 F8	F8 T4	T4 T6	T6 O2	FP1 F7	F7 T3	T3 T5	T5 O1
Run C	F8 F4	F4 FZ	FZ F3	F3 F7	T4 C4	C4 CZ	CZ C3	C3 T3
Run D	T6 P4	P4 PZ	PZ P3	P3 T5	T6 O2	O2 PZ	PZ O1	O1 T5

Run E	F4 A2	C4 A2	P4 A2	O2 A2	F3 A1	C3 A1	P3 A1	O1 A1
Run F	FP2 A2	F8 A2	T4 A2	T6 A2	FP1 A1	F7 A1	T3 A1	T5 A1
Run G	FP2 C4	C4 O2	FP2 T4	T4 O2	FP1 C3	C3 O1	FP1 T3	T3 O1

Table 1.4 Montages for Eight Channel Recorder

Similarly we can have various montages in our Brain View plus EEG recording machine. These are as follows:-

- BP Longitudinal 1(R)
- BP Transverse (R)
- Monopolar 2(R)
- Padiatric
- BP Longitudinal (L)
- BP Transverse (L)
- Monopolar 2(L)
- Reference Channel
- 32 channel
- 16 channel RMS1
- 16 channel RMS2
- 18 Channel Long
- 18 channel Mono
- Circular/Transverse

We can also determine the voltage between any two electrodes by defining our own montage. Generally we use BP longitudinal and BP transverse to see the variation in the EEG signal. Sometimes Reference montage can also be used.

1.2.2 EEG feature identification

EEG signal is closely related to the level of consciousness of the person. As the activity increases, the EEG shifts to higher dominating frequency and lower amplitude. With the eyes closed, the alpha waves begin to dominate the EEG. When the person falls asleep, the dominant EEG frequency decreases. In certain phase of sleep, rapid eye movement called REM sleep the person dreams and has active movement of eyes, which can be seen as a characteristic EEG signal. In deep sleep, the EEG has large and slow deflections called delta waves.

Waves are recognized by their shapes and forms:-

1.2.2.1Spike and wave

Spike and wave format is seen in all ages but most often in children. It consists of a spike generated in the cortex, and a large amplitude slow wave. They may occur synchronously and symmetrically. They also occur during eye blink. It is characterized by 3 Hz spike.

1.2.2.2Polyspike and wave

It is a form of a spike in which each slow wave is accompanied by two or more spikes. It is often associated with myoclnous or myoclonic seizures. It should not be confused with 6Hz spike or wave, otherwise known as phantom spike and wave.

1.2.2.3Periodic Lateralized Epileptiform Discharges

PLEDS are a form of discharge associated with acute brain injury or damage. This pattern is also said to be more evident when acute brain injury is coupled with some metabolic derangement. It is evolving pattern starting out with a sharp waves occurring at regular intervals over one whole area or side with relative flattening between.

1.2.2.4Triphasic waves

They are illustrated as the 3 waves seen outlined in white. They often occur as long runs causing an appearance of pseudo paroxysmal activity. The wave is found with hepatic encephalopathy.

1.2.2.5Burst Suppression

It is a pattern of burst of slow and mixed waves often of high amplitude alternating with flat baseline. This pattern is bilateral but not always symmetrical. It is usually seen with severe brain injury such as post anoxia. It is also seen in temporary form in deep anesthesia.

1.2.2.6Lambda and POSTS

These are seen morphologically and have a triangular shape. They occur posterior and symmetrically, POSTS stands for 'Positive occipital transients of sleep' and occurs in stage 2 sleep. Lambda occurs in the awake patient when the eyes stare at blank surfaces. Both are normal wave forms.

1.2.2.7K Complexes

K complexes occur in sleep when excited with noises or other stimuli especially in sleep 2 stage. They are followed by run of theta waves.

1.2.2.8V Waves

V waves occur in the parasaggital areas of the two sides and take the form of sharp waves or even spikes which show in the biparietal regions with phase reversal at the midline in the transverse montages or at the vertex in front to back ones. They are seen in stage 2 sleeps along with spindles, K complexes, POSTS etc.

1.2.2.9MU Activity

This is a rhythm in which the waves have a shape suggestive of a wicket fence with sharp tips and rounded bases. It may show phase reversal between two channels.

1.2.2.10Fourteen and Sixteen Rhythms

It is mostly seen in children. It takes the form of 14 or 16 Hz waves sometimes going in the same direction and in others in the opposite direction. It is typically seen in sleep or drowsiness and is seen in monopolar recordings.

1.2.3 EEG Artifacts

1.2.3.1Electromyogram Activity: There are the most common artifacts. These potentials generated in the muscles are of much shorter duration than in the brain and can be identified on the basis of morphology.

1.2.3.2ECG Artifact: ECG artifact can be recognized by the QRS complex wave. The situation is difficult when cerebral abnormal activity appears intermixed with the EEG artifact.

1.2.3.3Pulse: These artifacts occur when an EEG electrode is placed over the pulsating vessel.

1.2.3.4Respiration Artifacts: It produces two types of artifacts. One is slow and rhythmic activity, synchronous with the body movements of respiration and mechanically affecting the impedance of electrode. The other can be slow or sharp waves that occur symmetrically with inhalation or exhalation and involve those electrodes on which the patient is resting.

1.2.3.5Skin artifacts: Biological processes may alter impedance that can cause effects. Sweat is a common cause. Sodium chloride and Lactic Acid from sweat reacting with metals of the electrodes may produce huge baseline artifacts.

1.2.3.6Electrode Artifacts: The most common cause is the electrode popping. This appears as single or multiple sharp wave forms due to abrupt impedance change. It can be identified easily by characteristics appearance and its usual distribution.

1.2.3.7Power Line interference: It also creates the errors which can be removed using notch filters.

1.2.3.8Movements in the Environment: Movements of other persons around the patient can generate artifacts, usually of capacitive of electrostatic origin. These are to be avoided as much as possible.

After recording an EEG signal we can extract the features. Various types of analysis are possible with the EEG signals. They are as follows:

- Analyze
- Amplitude duration
- Single map
- Tri map
- Frequency maps
- Frequency spectra
- Amplitude progressive
- Frequency progressive
- Frequency tables showing absolute and relative powers

There is variety of changes in the EEG signals which takes place due to the events listed below:

- Eye opening
- Eye closing
- Eye blinking
- Motion of hands
- Speaking
- Clinching of teeth
- Photic and Auditory stimulation
- Eye ball motion

1.3 Definition and features of BCI using EEG Signal

The BCI system detects such changes and transforms it into a control signal which can, for example, be used to play a simple video game? One of the main goals is to enable completely paralyzed patients to communicate with their environment. For the development of BCI, two learning systems are to be developed:-

- The machine should learn to discriminate between different patterns of brain activity as accurate as possible.
- The user of BCI should learn to perform different mental tasks in order to produce distinct brain signals.

By training the computer to recognize and classify EEG signals, users can manipulate the machine by merely thinking about what they want it to do within a limited set of choices.

The preparation, actual operation and mutual imagination of limb movements activate similar EEG changes at sensorimotor areas on the scalp. When such regions become activated, EEG activities display an amplitude attenuation of event related desynchronization (ERD). For instance, imagination of right-hand or left hand movement results in the most prominent ERD localized over the corresponding sensorimotor cortex. Similarly we can develop BCI which use multimodal macro qualitative representation to communicate. Multimodality refers to the use of body language, facial expression and thoughts. We can have human movement's estimation system which can translate human physical movements into qualitative linguistic labels.

For development of any BCI, we should be able to answer the following key questions:-

- What signals can be measure from brain? From what regions? With what technology?
- How is the information represented (or encoded) in the brain?
- What algorithms can we use to infer (or decode) the internal state of the brain?
- How can we build practical interfaces that exploit the available technology?

We can measure signals from the brain using an array of chronically implanted microelectrodes. From these we record action potentials of individual neurons and then represent the neural signal using a rate code. We use a simple linear Gaussian model that reconstructs hand motion from neural activity in motor cortex. This reconstruction is sufficiently accurate to permit the control of unconstrained 2D cursor movement or simple robotic functions.

A brain computer interface (BCI) is a real-time communication system designed to allow users to voluntarily send messages or commands without sending them through the brain's normal output pathways .BCI users send information by engaging in discrete mental tasks that produce distinct EEG signatures. These tasks, called cognemes, form the basis of a BCI language .A BCI transforms mental decisions into control signals by analyzing the bioelectrical brain activity. A BCI can also be defined as a non-muscular information channel for sending messages and commands from the brain to the external world.

A brain computer interface (BCI) is a communication or control system in which the user's messages or commands do not depend on the brain's normal output channels. That is, the message is not carried by nerves and muscles, and, furthermore, neuromuscular activity is not needed to produce the activity that does carry the message. The over all configuration of any such system is as shown below

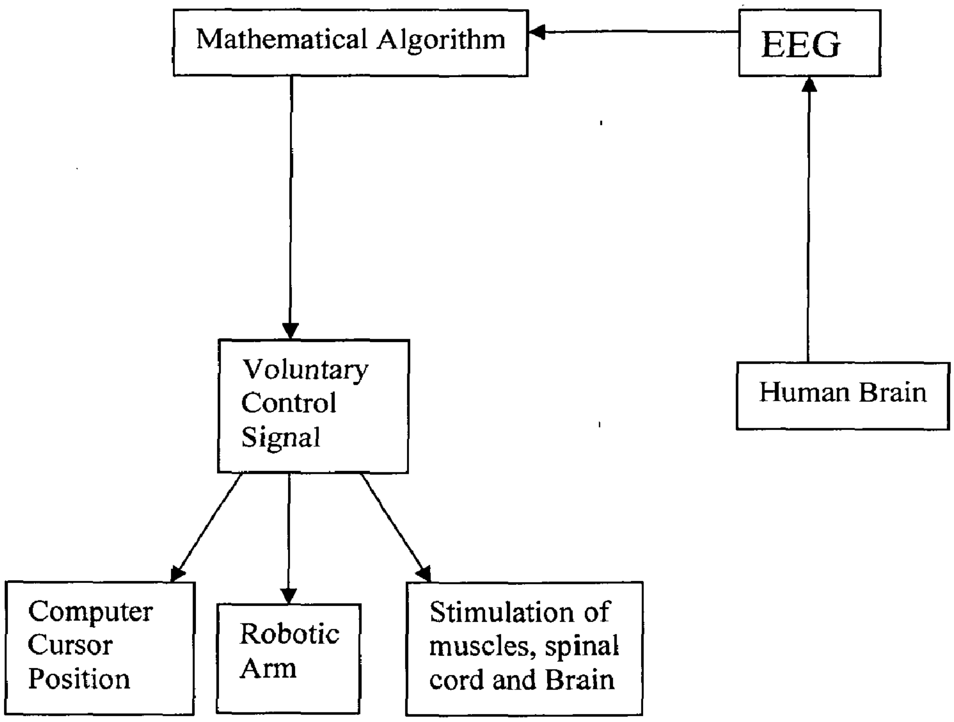


Fig1.3 Brain Computer Interface

One of the most significant obstacles that must be overcome in pursuing the utilization of brain signals for control is the establishment of a signal processing method that can extract event related information from a real-time EEG

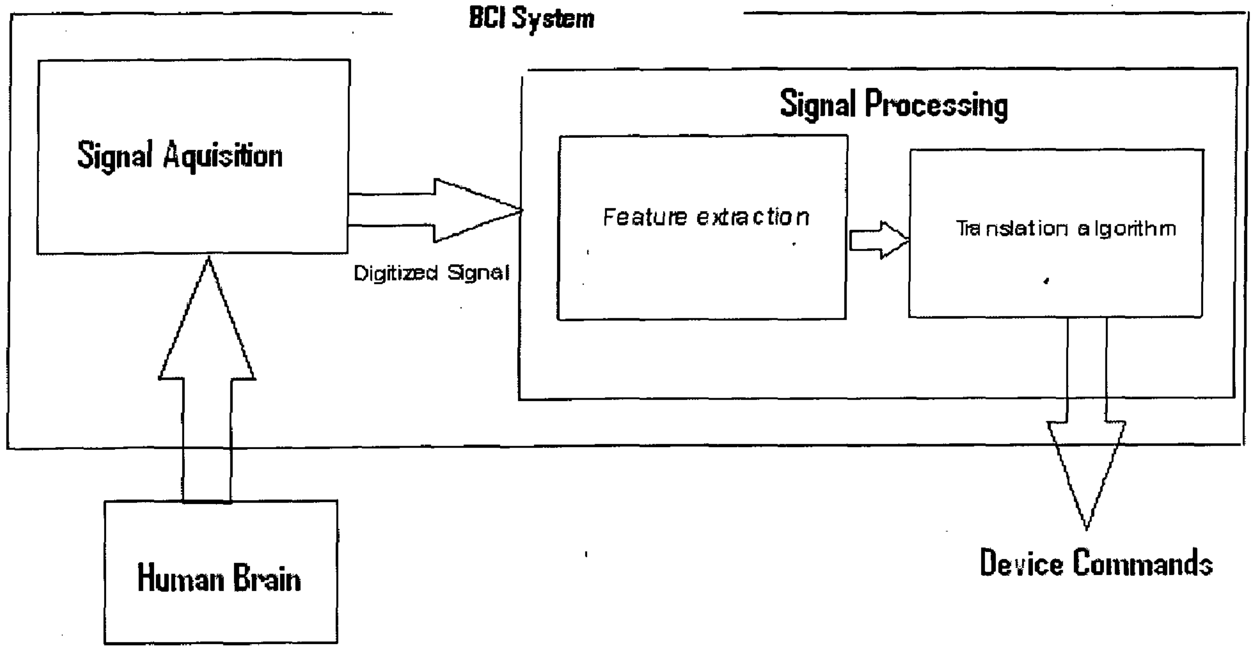


Fig. 1.4 Basic design of a BCI system.

Signals from the brain are acquired by electrodes on the scalp, the cortical surface or from within the brain and are processed to extract specific signal features (eg:- amplitudes, of evoked potentials or sensorimotor cortex rhythms, firing rates of cortical neurons) that reflects user intent. Features are translated into commands that operate a device (a simple word processing program, a wheelchair or a neuroprosthesis)

Through this definition, BCI systems appear as a possible and sometimes unique mode of communication for people with severe neuromuscular disorders like spinal cord injury or cerebral palsy. As a matter of fact, such neural diseases can break the slim and fragile line between thoughts and actions. In these cases, neither medicine nor surgery can be of any use to give back to the person the control of his/her body. However, utilizing the residuals functions of the brain, it seems possible to give back a hope of communication to these people.

BCI s falls into two classes:

- *Dependent:* A dependent BCI does not use the brain's output pathways to carry the message, but activity in these pathways is needed to generate the brain activity that does carry it. For example, one dependent BCI presents the user with a matrix of letters that flash one at a time, and the user selects a specific letter by looking directly at it so that the visual evoked potential (VEP) recorded from the scalp over visual cortex when that letter flashes is much larger than the VEP's produced when the other letters flash. In this case, the brain's output channel is EEG, but the generation of the EEG signal depends on gaze direction, and therefore on extra ocular muscles and the cranial nerves that activate them. A dependent BCI is essentially an alternative method for detecting messages carried in the brain's normal output pathways. While a dependent BCI does not give the brain a new communication channel that is independent of conventional channels, it can still be useful.

- *Independent:* An independent BCI does not depend in any way on the brain's normal output pathways. Peripheral nerves and muscles do not carry the message. For example, one independent BCI presents the user with a matrix of letters that flash one at a time, and the user selects a specific letter by producing a p300 evoked potential when that letter flashes. In this case, the brain's output channel is EEG, and the generation of the EEG signal depends mainly on the user's intent, not on the precise orientation of the eyes. The normal output pathways of peripheral nerves and muscles do not have an essential role in the operation of an independent BCI. Furthermore, for people with the most severe neuromuscular disabilities, who may lack all normal output channels, independent BCIs are likely to be more useful.

Brain activity produces a variety of phenomena that can be measured with adequate sensors and have potential use in a BCI. Among the current monitoring methods scalp recorded EEG constitutes an attractive choice for BCI system because of its noninvasiveness, relative simplicity and low cost. There are two classes of BCIs as described below:

- Asynchronous BCIs allow a user to send messages independent of any external event.
- Synchronous BCIs allow the user to send messages or command by producing one of several different mental responses

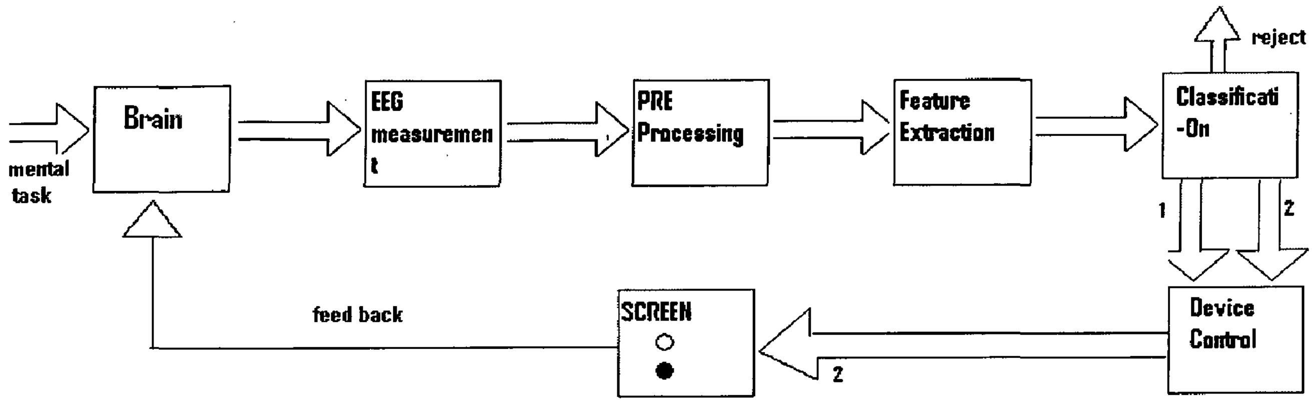


Figure1.5: A BCI based on the classification of two mental tasks. The user is thinking task number 2 and the BCI classifies it correctly and provides feedback in the form of cursor movement

According to Allison there are at least five components necessary for effective BCI system

1) Knowing what to look for
2) Knowing the relevant physiological signals
3) Gathering the data from the user
4) Extracting useful necessary information from the raw signals
5) Interface design

1.4 Different types of BCI

Different types of brain computer interface techniques are

1. EEG Mu-rhythm conditioning/Sensorimotor Rhythm BCI
2. VEP detection/P300 Detection
3. Slow Cortical potentials

1.4.1 EEG mu-rhyhm conditioning/Sensorimotor Rhythm BCI

Scalp EEG is recorded over sensorimotor cortex. Users control the amplitude of 8-12 Hz mu rhythm (or a 18-26 Hz beta rhythm) to move a cursor to a target at the top of the screen or to a target at the bottom (or to additional targets at intermediate locations).

Frequency spectra (top) for top and bottom targets show that control is clearly focused in the mu-rhythm frequency band. Three papers using this technique were reviewed including Wolpaw 1991, McFarland and colleagues at the Wadsworth Center for Laboratories and Research, Albany, NY, and Pfurtscheller and colleagues at the Ludwig Boltzmann Institute of Medical Informatics and Neuro informatics, Department of Medical Informatics, Institute of Biomedical Engineering, and University of Technology Graz, Austria. All three papers describe subjects' abilities to move a cursor toward a target on a computer screen by manipulating their mu-rhythm, a detectable pattern in a great majority of individuals in the EEG 8-12Hz frequency range, centered about 9.1 Hz. Work is based on earlier research efforts by Kuhlman who described the mu-rhythm in normal and epileptic subjects. Wolpaw describes detecting subjects' mu-rhythm amplitude, defined as the square-root of the spectral EEG power at9Hz, using two scalp-mounted electrodes located near location C3 in the International 10/20 System and a digital signal processing board analyzing continuous EEG 333ms segments, and using it to drive a cursor up or down on a screen toward a target placed randomly at the top or bottom. An experiment operator preset the size of the ranges and number of cursor movement steps assigned to each range for each subject during testing prior to each experimental run. Ranges were set so that the commonest mu-rhythm amplitudes (<4 microvolt) left the cursor in place or moved it downwards moderately while higher amplitudes (>4 microvolt) moved it upwards in increasing jumps. Weights were adjusted as subjects exhibited better control of their mu-rhythm amplitudes for up and down targets in repeated trials. Wolpaw substantiates subjects learned intentional control over mu-rhythm amplitude in three ways: by performing frequency analysis up to 192Hz on subjects during cursor movement trials and failing to find any relationship between mu-rhythm changes and the higher frequencies associated with muscular (EMG) activity; by subjects statements about not making contra lateral movements and observing none; and by failing to find any relationship between mu-rhythm changes and posterior scalp recordings of the visual alpha-rhythm. Four out of five subjects acquired impressive control over their mu-rhythm amplitude during 12 45-minute sessions over a period of two months. Accuracies of 80-95% target hits across experimental subjects were achieved and rates of 10-29 hits per minute. Off-line analysis of two subjects' raw EEG data provided good support for Wolpaw's experimental results. McFarland used essentially the same experimental setup and introduced greater precision constraints on four subjects' attempts to position a cursor by means of mu-rhythm control. A vertical bar target appeared in one of five different vertical positions on the left side of the screen and crossed the screen from left to right in 8 seconds. Subjects had to move the cursor (initially in the middle of the right edge of the screen) quickly to the correct one of five different vertical screen positions to intercept the target by controlling their mu-rhythm amplitude. Analysis of the average distance between the center of the target and the cursor during succeeding trials indicated that all subjects reduced the distance and three out of four significantly so. Pfurtscheller used contra lateral blocking of the mu-rhythm during the 1-second period prior to a motor activity (in this case pressing a micro switch using either the right or the left index finger) to predict which response was to follow. An array of 30 electrodes spaced evenly across the scalp (two were at locations C3 and C4 in the International 10/20 System) was used to record EEG activity. An initial training period for each subject involved using data from all 30 electrodes to train the classification network. During experimental trials, a feature-vector of power values from electrodes at positions C3 and C4 was constructed at 5 time points and classified using a Learning Vector Quantizer (LVQ) artificial neural network. The experimenter achieved the best balance of reliability/speed of classification by using the 1/2-second prior to response and performing a multiple-classification and voting process. EEG data from two subjects in the Wolpaw experiment described above were provided to the Graz Institute for Information Processing for additional analysis described by Flotzinger using the Graz LVQ neural net scheme (see above) and a fixed time-segment. Cursor-movement was predicted from raw data with 90% accuracy. Results also implied that frequency bands other than the mu and beta ranges may contain useful (i.e. target-related) information.

1.4.2 VEP Detection

Detection of VEP is the most important phenomenon for the development of BCI. Sutler describes presenting a 64-position block on a computer screen and detecting which block the subject looks at, while Cillier's work uses a series of four lights. In each case, several simultaneously presented stimuli are made to change rapidly in some controlled way (intensity, pattern, color-shift) and the subject has scalp electrodes placed over the visual cortex (back of the head) in a position to detect changes in the evoked potential (VEP) at that location. Sutler used a lengthy binary sequence to switch 64 screen positions between red and green, and in other trials to reverse a checkerboard pattern. Each screen position was shifted 20ms in the binary control sequence relative to its neighbors, and the entire sequence was auto correlated with the VEP in overlapping .Increments (the VHP response components last about 80ms) beginning 20ms apart, with the resultant vector stored in a 64-position array of registers. When a coefficient remains greater than all the others and above a threshold value for a certain amount of time, the corresponding stimulus is considered to have been selected. The 64 positions represent the letters of the alphabet and commonly used words in the English language. The subject can fixate on any word or letter. Whenever the subject fixates on a letter, the commonly used words change to words beginning with that letter, for quick selection of an entire word. Sutler suggests a need to optimize both electrode placement and stimulation mode for each individual subject for good target discrimination. Seventy normal subjects evaluating a prototype system achieved adequate response times ranging from 1 to 3 seconds after an initial tuning process lasting 10-60 minutes. It was also tested on 20 severely disabled persons. Cilliers' technique involves varying the intensity of four LED's modulated with a lO Hz sine wave in phase quadrate and detecting the signal in the subject's VEP using a pair of EEG surface electrodes placed on the occipital lobe. The four flashing LED's are arranged around the edge of a computer screen containing an image of a standard four-row keyboard with each row of keys in a different color. Each LED is associated with one of the colors. Fixating on one LED selects a key row, which is redisplayed in four colors for a more detailed selection. The subject can select any particular key in an average of three selections — about 15 seconds with the current setup. A short initial training period is required where subjects fixate on each LED for 5 seconds.

Technique: P300 detection

A matrix of possible choices is presented on a screen and scalp EEG is recorded over the centro parietal area while these choices flash in succession. Only the choice desired by the user evokes a large P300 potential (i.e. a positive potential about 300ms after the flash). Farwell of the Department of Psychology and Cognitive Psychophysiology Laboratory at the University of Illinois at Urbana-Champaign IL, describes a technique for detecting the P300 component of a subject's event-related brain potential (ERP) and using it to select from an array of 36 screen positions. The P300 component is a positive-going ERP in the EEG with a latency of about 300ms following the onset of a rarely-occurring stimulus the subject has been instructed to detect. The EEG was recorded using electrodes placed at the Pz (parietal) site (10/20 International System), limited with band-pass filters to 02-35Hz and digitized at 50Hz. Electro-oculogram (EOG) data was also recorded from each subject via electrodes placed above and below the right eye. The "odd-ball" paradigm was used to elicit the P300, where a number of stimuli are presented to the experimental subject who is required to pay attention to a particular, rarely-occurring stimulus and respond to it in some non- motor way, such as by counting occurrences. Detecting the P300 response reliably requires averaging the EEG response over many presentations of the stimuli. The experiment presented a 36-position array of letters, plus common typing characters and controls (e.g. space, backspace), made to flash in a random sequence first by rows and then columns. Each trial consisted of a complete set of six column or row flashes.

1.4.3 Slow cortical potentials

Scalp EEG is recorded from the vertex. Users learn to control and monitor SCPs to move a cursor toward a target (e.g. a desired letter or icon) at the bottom (more positive SCP) or top (more negative SCP) of a computer screen among the lowest frequency features of the scalp-recorded EEG are slow voltage changes generated in cortex. These potential shifts occur over 0.5-10.0 s and are called slow cortical potentials (SCPs). Negative SCPs are typically associated with movement and other functions involving cortical activation, while positive SCPs are usually associated with reduced cortical activation. In studies over more than 30 years, Birbaumer and his colleagues have shown that people can learn to Control SCPs and thereby control movement of an object on a computer screen. This demonstration is the basis for a BCI referred to as a 'thought translation device' (TTD).The principal emphasis has been on developing clinical application of this BCI system. It has been tested extensively in people and has proved able to supply basic communication capability. In the standard format EEG is recorded from electrodes at the vertex referred to linked mastoids. SCPs are extracted by appropriate filtering, corrected for EOG activity, and fed back to the user via visual feedback from a computer screen that shows one choice at the top and one at the bottom. Selection takes 4 s. During a 2 s baseline period, the system measures user's initial voltage level. In the next 2 s, the user selects the top or bottom choice by decreasing or increasing the voltage level by a criterion amount. The voltage is displayed as vertical movement of a cursor and final selection is indicated in a variety of ways. The BCI can also operate in a mode that gives auditory or tactile feedback .Users train in several 1-2 h sessions/week over weeks or months.

CHAPTER 2
EVOKED POTENTIALS (AEP & VEP)

Evoked potentials are the potentials generated on the scalp when stimulus acts on the body. Normally we measure evoked potentials generated due to visual or auditory stimulus. Many different AEP's are generated in different areas of the nervous system. The most commonly used AEP are BAEP (Brain Stem Auditory Evoked Potentials) while Visual Evoked Potential (VEP) is the largest evoked potential (EP) in common use, the easiest to record in subjects, and is the most sensitive to alteration by neurological disease.

2.1 Auditory Evoked Potentials

Sound is the change in pressure propagated through an elastic medium by the vibratory motion of its constituent particles. Its three most important characteristics are frequency, intensity and location.

AEPs are generated by the separation of charge across the membranes of cells in the auditory system. Although some early AEPs are generated in the hair cells of the cochela and some late potential may arise in the glial cells, neurons are the major generators. Both action potentials and postsynaptic potentials contribute to the AEP's.

The extent to which evoked potentials are recorded at a distance from their origin depends on four main factors. The first is the number of cells that are active in response to an auditory stimulus. A second factor is the synchronization of activity among responding cells. The greater the synchronization among active cells, the greater the potential field recorded at a distance. Synchronization is one of the major reasons why transient EPs are so prominent. Because different neurons respond to a sound at different rates, they are synchronous only at the onset of the sound.

A third factor determining field spread is the geometrical organization of the active membranes. Synaptic depolarization of dendrites in cortical pyramidal cells results in a separation of charge in the extra cellular fluid such that the surface is negative and the depth is positive. If the dendrites in a group of similarly oriented pyramidal cells are depolarized in this manner, their dipole fields will summate. On the other hand, depolarization of dendrites in a group of stellate cells will generate numerous fields oriented in the multiple directions. The net effect will be cancellation rather than summation.

A fourth factor determining the size of the voltage fields is the impedance of the volume conductor between the generator and the recording electrode. If the conductor is homogenous the field at a distance varies inversely with the impedance. Inhomogeneties in the conductor alter the current paths and thus distort the nearby fields. Low impedance volume located between the generator and the recording electrode characteristics decreases the recorded field. One particular effect of impedance occurs when an action potential traverses a boundary between areas of different impedances. The result is the generation of the stable plot positively at the vertex electrode as an upward deflection.

2.2 Classification of the Auditory Evoked potentials

Many different AEP's can be recorded from human subjects. There occur at different latencies and with various relations to the auditory stimuli. Many different areas of the auditory system (eg. cochlea, auditory nerve, brainstem and cortex) contribute to the recorded potentials. The most commonly used classification of AEP's is based on the latency of the response and upon the response's temporal relationship to the auditory stimulus. The latency of the response is loosely categorized as first, fast, middle, slow and late. Transient responses occur following a change in a stimulus. Sustained responses occur throughout the duration of the continuing stimulus and steady state responses are evoked by rapidly repeating stimuli. The steady state responses contain components which are harmonically related to the frequency of stimulus repetition and which remain constant in amplitude and phase over time. A steady state response is usually generated when the stimulus rate is sufficiently fast than the transient response to one stimulus overlaps the responses to succeeding stimuli.

Other classification can overlay this scheme. For example, some auditory potential can be described in terms of their presumed generators. The first EPs are "cochlear", the fast responses are "Brainstem" and later potentials are largely cortical in origin. EPs can also be classified as "exogenous" or "endogenous". Exogenous EPs are determined by the physical characteristics of the stimulus, whereas endogenous EPs are determined by the psychological significance of the stimulus.

Transient AEPs are usually evaluated by measuring the latencies and amplitudes of the peaks and troughs in the recorded waveforms. These peaks and Troughs do not indicate specific underlying sources, because the fields of different generators may overlap to create scalp waveforms that are quite distinct from the source waveforms. However when source waveforms are not available the peak measurement provide reliable and useful information. Peaks are labeled by their polarity and either by their sequence in a waveform (1,2,3... etc. or a,b,c... etc) or by their typically latency in milliseconds.

Steady state responses are measured by their amplitude and phase. These measurements are objective because no decision has to be made about whether peak is correctly identified. However, phase measurements are sometimes ambiguous and are often difficult to relate to underlying physiology. The most commonly used AEP are BAEP. An electrode located near the human cochlea records the electrocochleogram. The table showing the classification of AEPs is as follows:

Latency	**Transient**	**Steady State**	**Sustained**
First	Cochlear nerve action potential (AP:N1,N2)	Cochlear micro phonic(CM)	Summating Potential(SP)
Fast	Brainstem Auditory Evoked Potentials(BAEP: 1-V111)	Frequency following Potential(FPP)	Pedestal of frequency following potential
Middle	Middle Latency response(MLR: Na, Pa, Nb)	40 Hz potential	
Slow	Vertex Potential(P1,N1,P2,N2)	Slow steady state response	Cortical sustained; Potential contingent jjnegative variation (CNV)

Table2.1 Classification of Auditory Evoked Potentials

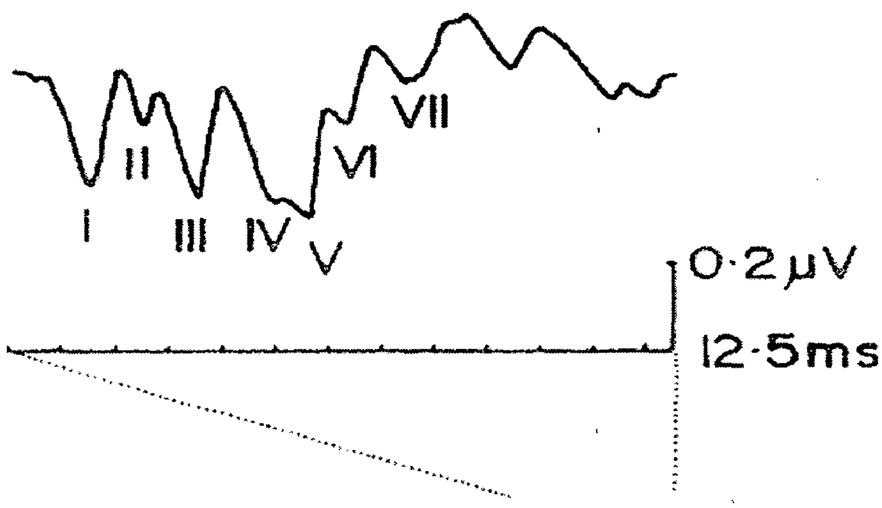


Fig 2.1 Fast Transient Response *(ref Current practice of Electroencephalography, DD Daly and TA Pedley, Raven Press Ltd., New York, 1990)*

For the measurement of fast transient responses clicks were presented at an intensity of 60dB nHL once every second to the right ear.

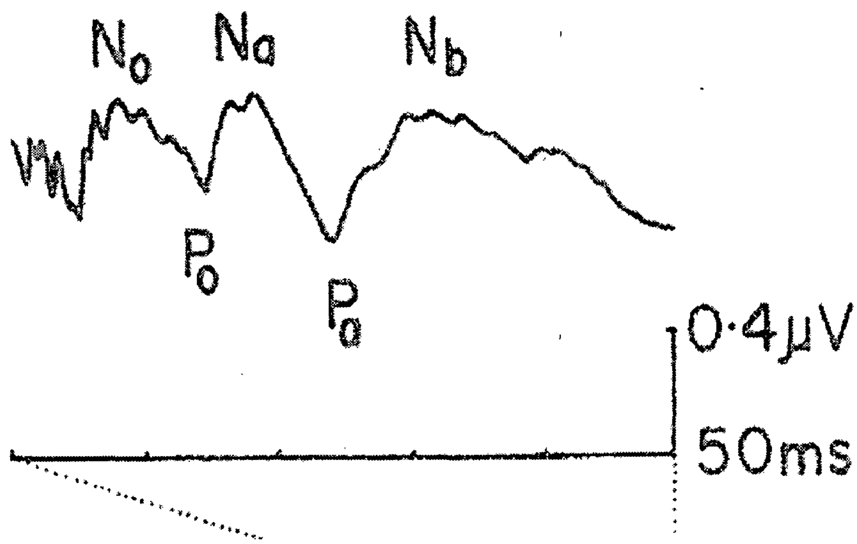


Fig 2.2 Middle Transient Response *(ref Current practice of Electroencephalography, DD Daly and TA Pedley, Raven Press Ltd., New York, 1990)*

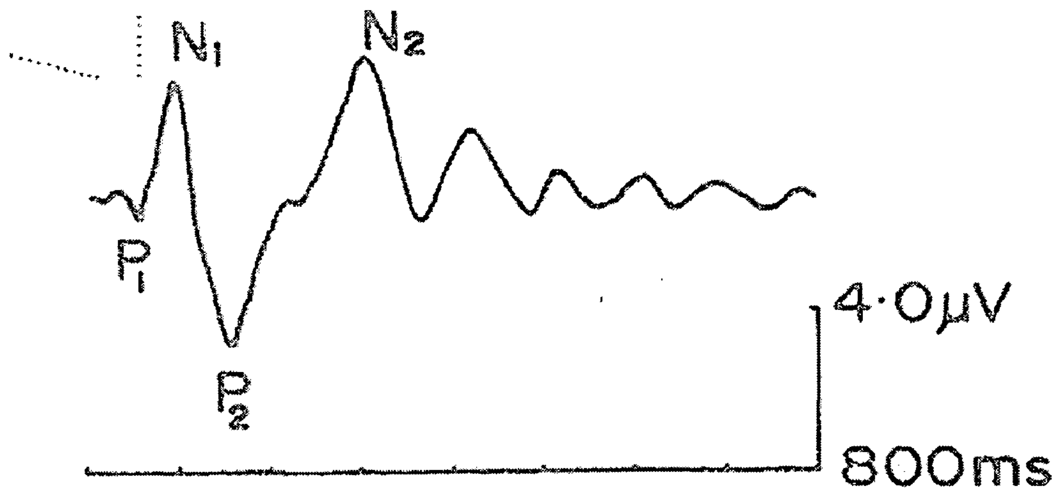


Fig 2.3 Slow Transient Response *(ref Current practice of Electroencephalography, DD Daly and TA Pedley, Raven Press Ltd., New York, 1990)*

Here clicks were presented at an intensity of 60dB once every second to the right ear.

2.2.1 Brain Stem Auditory Evoked Potentials

The BAEP is usually recorded between an electrode at the vertex and one on either the mastoid or the earlobe of the ear being stimulated. The normal response to a click with an intensity of 60 dB or more contains six or seven vertex positive waves that are identified using roman numerals. The most prominent and consistent of these waves is I, III and V. Sometimes it is important to get the recordings of both the ears. The subject is positioned on a reclining chair or bed and is asked to relax and remain still. Electrodes are placed on the scalp and on each earlobe. One hears clicking noises or tone bursts through earphones, and the electrodes pick up the brain's response and record it on a graph. BAEP are very important as they are used in performing Brainstem auditory response test. The brainstem auditory evoked response (BAER) test measures responses in brain waves that are stimulated by a clicking sound to evaluate the central auditory pathways of the brainstem. The response in the form of graphs is as shown below:

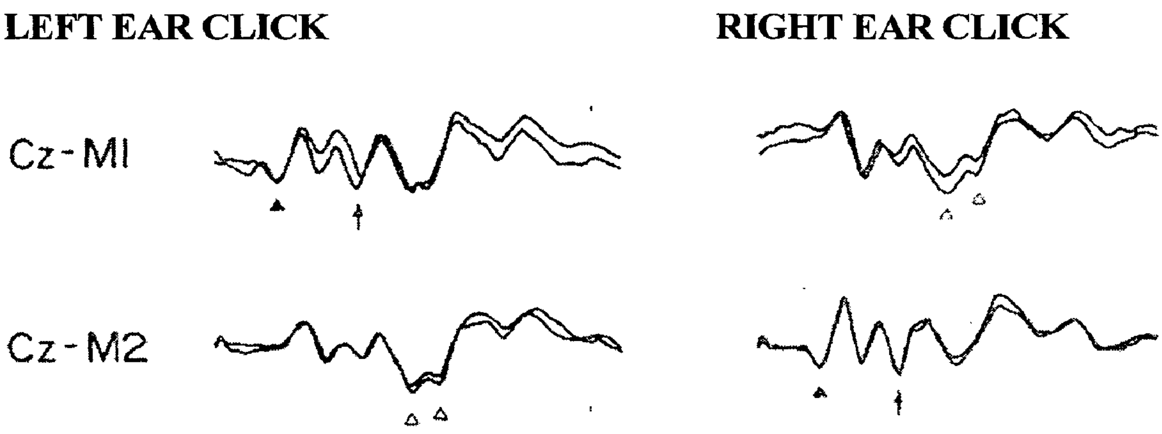


Fig. 2.4 Brain Stem Auditory Evoked potentials (BAEP). Separate responses were recorded from left ear and Right Ear *(ref Current practice of Electroencephalography, DD Daly and TA Pedley, Raven Press Ltd., New York, 1990)*

Many different filters have been used to record BAEP. The frequency spectrum of the BAEP contains three main energy peaks: one near 800-1000 Hz, one near 500 Hz, and one near 100Hz.The most commonly used Band Pass for the BAEP is 100-3000 Hz.

2.3 Visual Evoked Potentials

Under typical test conditions , checkerboard pattern reversal produces a net pattern VEP (PVEP) vector that points diagonally back across the opposite occipital lobe .When the visual field is stimulated , vectors from the two hemispheres sum to produce a VEP maximum at the occipital midline. This full field VEP usually has a negative-positive-negative configuration at between 70 and 140 msec, maximal positivity occurs at around 100m sec. Peaks are labeled using nominal latency values derived from the average in normal subjects: N75, P100 and N145. Depending on test conditions, a smaller positive peak may be recorded between 50 and 60 msec and is usually designated either P50 or P60.

All portions of the VEP are most probably of cortical origin and are classified as mid latency EPs. The earliest definable wave P50 begins within 50 msec after pattern reversal. P100 is the most stable and most commonly measured VEP component. P100 latency measured at the occipital midline is the central parameter of VEP interpretation. It is the one of the most stable and most consistently identified in all normal subjects.

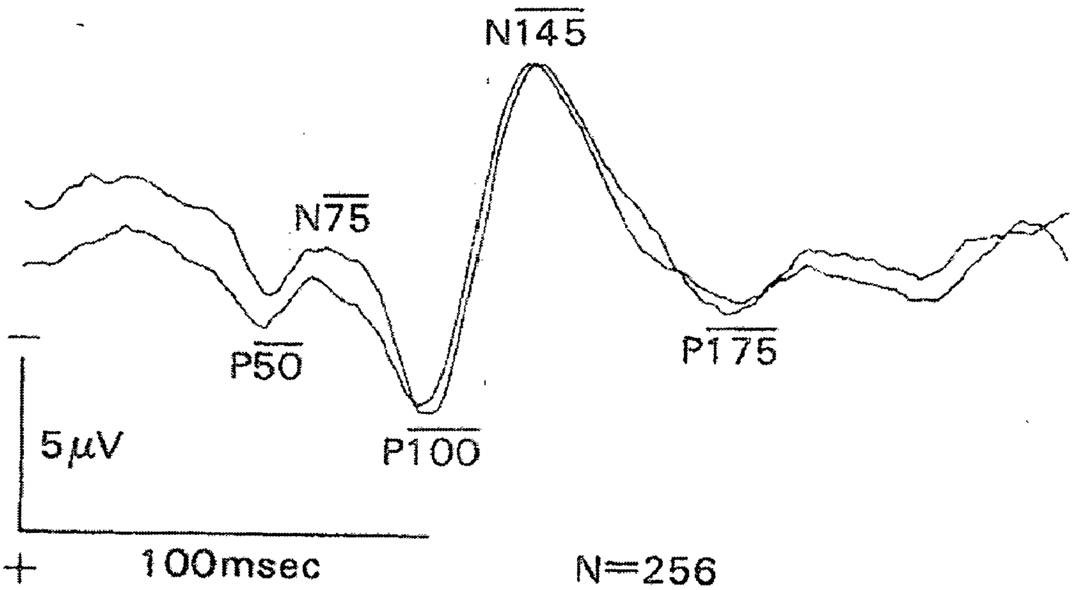


Fig 2.5 The Normal midline PVEP, recorded in an Oz-Cz deviation. The pass band is 1.0-100 Hz. *(ref Current practice of Electroencephalography, DD Daly and TA Pedley, Raven Press Ltd., New York, 1990)*

2.4 P100 latency measurement

P100 latency measured at the occipital midline is the central parameter of VEP interpretation. Given the wide range of VEP variability, it is simply the one of the most stable and most consistently identified in all normal indivuals. P100 may be narrow or broad, and it may be symmetrical or asymmetrical in shape. A broad P100 may appear intuitively suspicious and indeed it has been interpreted as a sign of temporal dispersion in the visual signal. However there are presently no simple and precise criteria by which P100 width can be used as an index of pathology. When the response is noisy or asymmetric, the choice of "peak Latency" is more ambiguous. One technique to detect P100 is to extrapolate the down slopes from N75 and N145 taking P100 latency as the point of intersection. Another is to estimate simply by marking the center of the entire complex from N75 to N145. P100 latencies have a Gaussian distribution in normal subjects.

2.5 P100 Amplitude Measurement

P100 amplitude is considerably more variable than latency. Different laboratories measure amplitude from the peak of N75 to P100, from P100 to N145 as the sum of the two or which ever is best defined in the given subject.

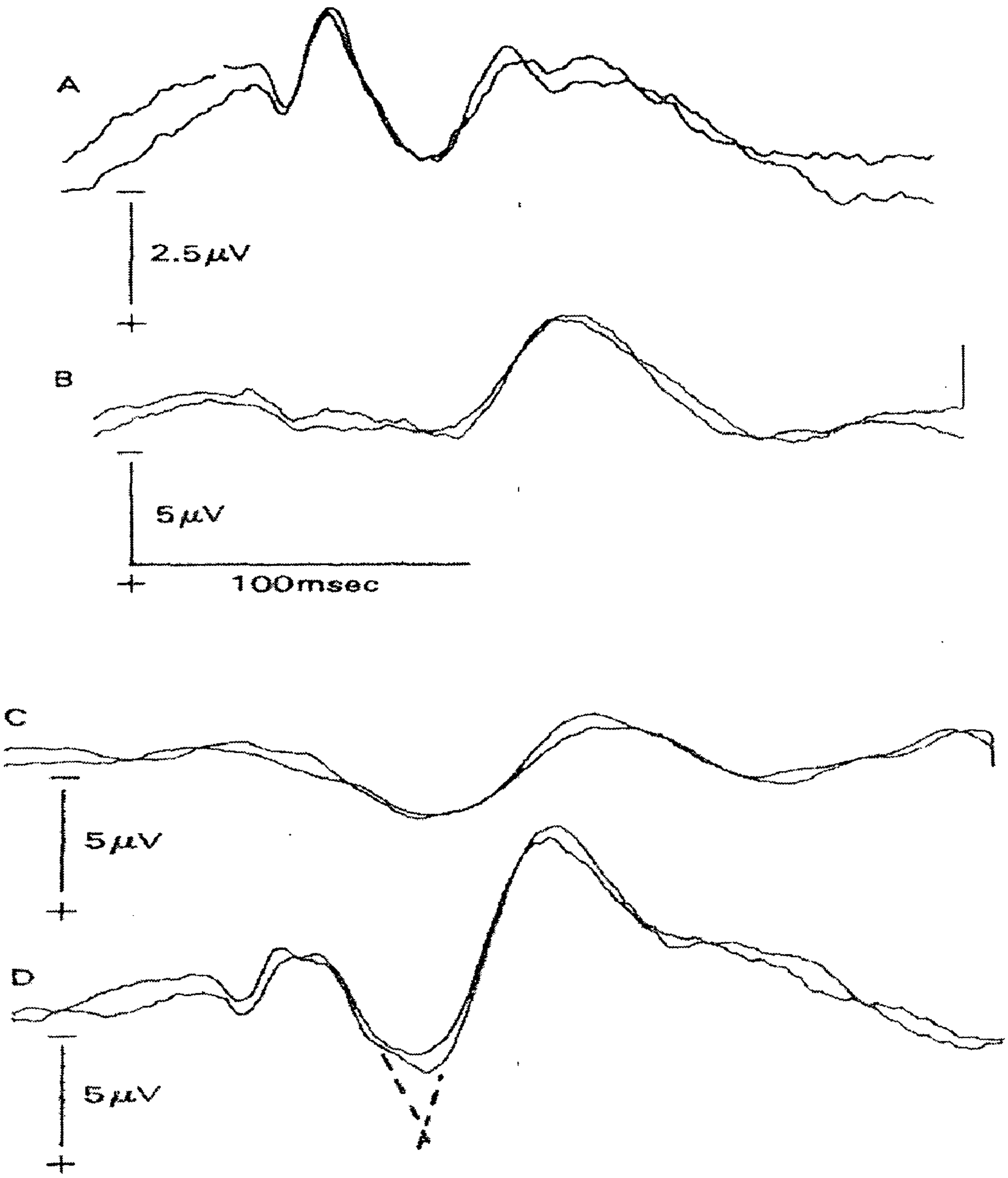


Fig 2.6 Normal waveform variability of the PVEP in four different subjects, showing Oz-Cz deviation. *(ref Current practice of Electroencephalography, DD Daly and TA Pedley, Raven Press Ltd., New York, 1990)*

2.6 Transient and Steady state VEP's

When the interval between visual stimuli is greater than the duration of the VEP and responses are averaged individually, the result is termed as a "transient" VEP. This is type generally used in clinical studies. At stimulus rates faster than about 4/sec sequential VEPs began to run together and form trains of rhythmic activity. Such trains in the form of photic following are classified as Steady State VEPs.

2.7 P100 VEP stimulus parameters

- Check Size
- Field Size
- Patient Distance
- Contrast
- Luminance
- Color
- Reversal Frequency
- Attention of the patient
- Gender
- Age
- Pupils
- Diseases of the Optic nerve
- Diseases of the Eye(Hysteria, Glaucoma and Retinopathies)

2.8PVEP Recording Parameters

- Low Pass Filters (1 Hz): A typical 4^{th} order low pass filter (FIR) is used
- High Pass Filters (260 Hz) : A typical 4^{th} order High Pass filter (FIR) is used
- 50 Hz Notch filter is used to remove power line interference.

CHAPTER 3
GENERAL FRAMEWORK FOR BCI DESIGN

3.1 Introduction

The aim of BCI is to create a specialized interface that will allow an individual with severe motor disabilities to have effective control of devices such as computers, speech synthesizers, assistive appliances, and neural prostheses. This type of interface would increase an individual's independence, leading to an improved quality of life and reduced social costs.

BCI research involves the knowledge from neuroscience, physiology, psychology, engineering, computer science, rehabilitation, and other technical and health-care disciplines. Although the term "BCI system" is not universal, it is considered to be the best term to represent the collection of all BCI components.

3.2 Functional model of a BCI system

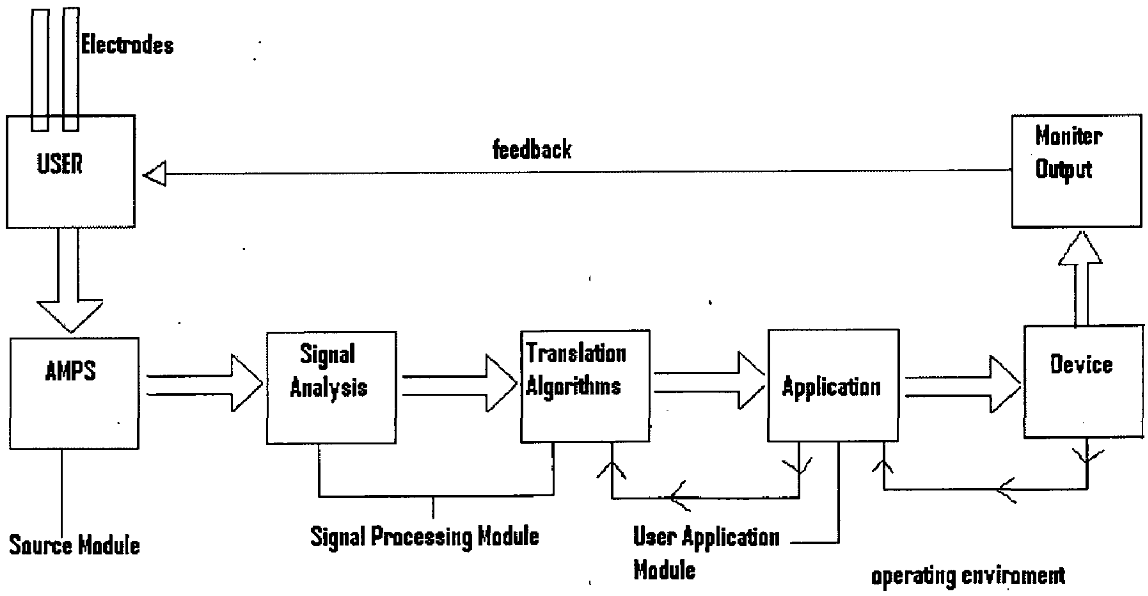


Fig.3.1 Functional model of the BCI system

3.3 Modules

1) *Source Module*: This module digitizes and stores Brain Signals and passes them on without any further preprocessing to signal processing. It consists of data acquisition and data storage component. Data storage stores the acquired brain signal samples along with the relevant system variables in a data file. The documented file format consists of an ASCII header followed by a binary signal sample and the event marker values. The file format can accommodate any number of signal channels, system parameters or event markers.

2) *Signal Processing Module*: This module converts signals from the Brain into signals that control an output device. The conversion has two stages: feature extraction and feature translation. In the first stage the digital signal received from the source module is subjected to procedures that extract signal features. In the second stage, a translation algorithm translates these signal features into control signals that are sent to the user application module. Each of the two stages of Signal processing consists of signals of cascade of signal operators each of which transforms an input signal into an output signal. The individual signal operators are themselves independent of each other and can thus be combined or interchanged without affecting others.

3) *User application Module:* The user application module receives control signals from signal processing and uses them to drive an application. In present day BCIs the user application is presently visually on a computer screen and consists of the selection of the targets, letters or icons.

4) *Operator Module:* The operator module defines the system parameters and the onset and offset of the operation. The user can also control the experiment and can receive real time information about online events.

5) *Offline Analysis Module:* There are number of offline tools available for analysis. They are software options that provide frequency spectra for amplitude and for statically measure.

This model is to be reworked for various reasons. First, the function of the translation algorithms component is extremely general. The Translation Algorithms component appears to contain all translation algorithms in the system, which includes algorithms for feature-to-logical-control translation, logical-control-to-semantic-control translation, and semantic-control-to-physical-control translation. Second, the function of the Application component is vaguely defined. This could lead to confusion for those attempting to apply the model to BCI Systems. Third, the component name "Application" implies algorithms used in a computer to control a computer monitor. This name makes it awkward to describe BCI Systems that control devices other than computers. Fourth, the model does not define all the principle feedback paths in a BÇI System.

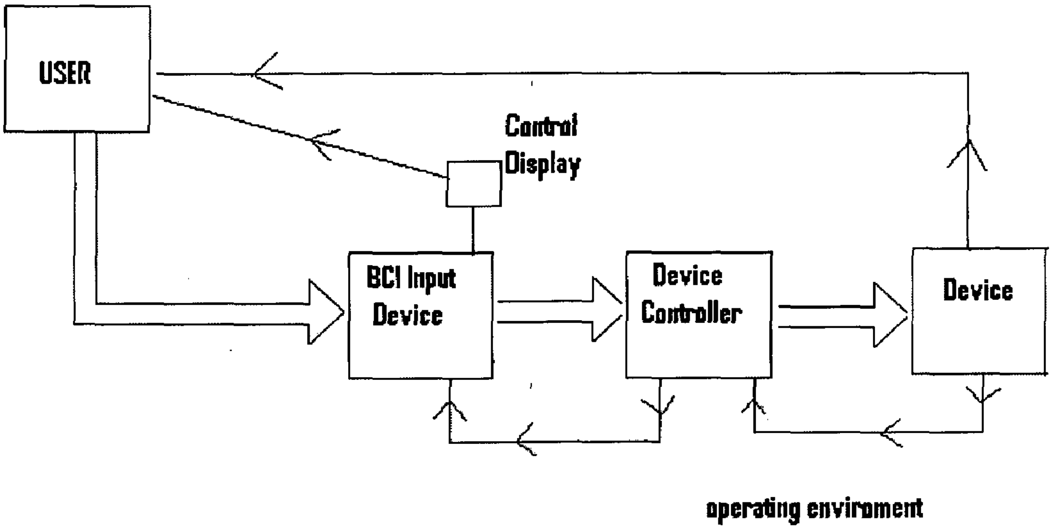


Fig 3.2 View of the functional model suitable for Input device emulation

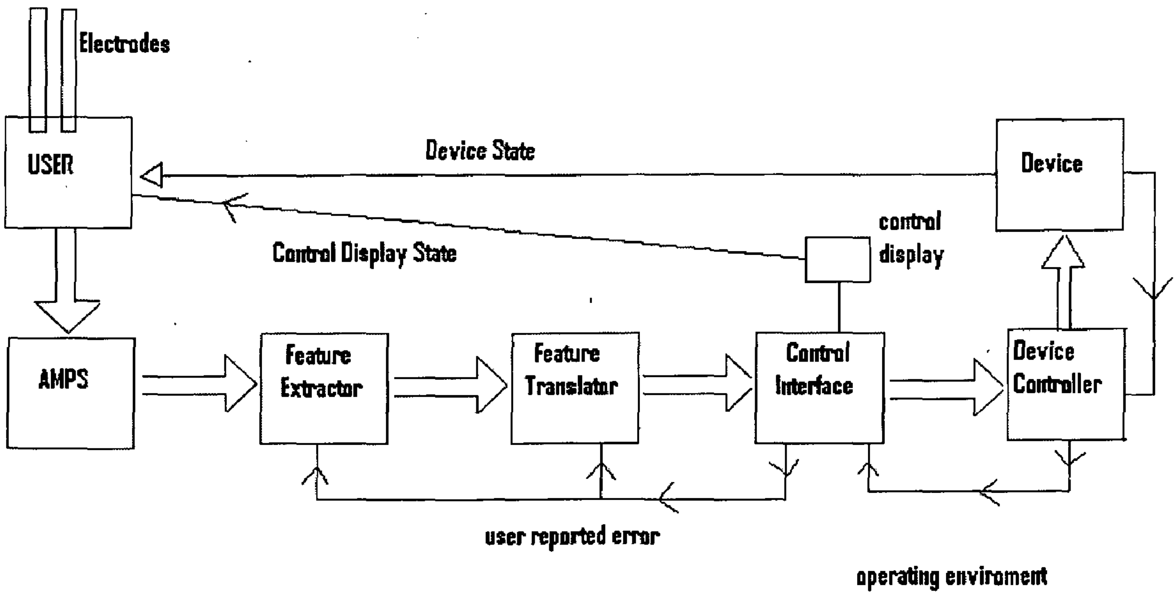


Fig 3.3 Improved Functional model of a BCI system

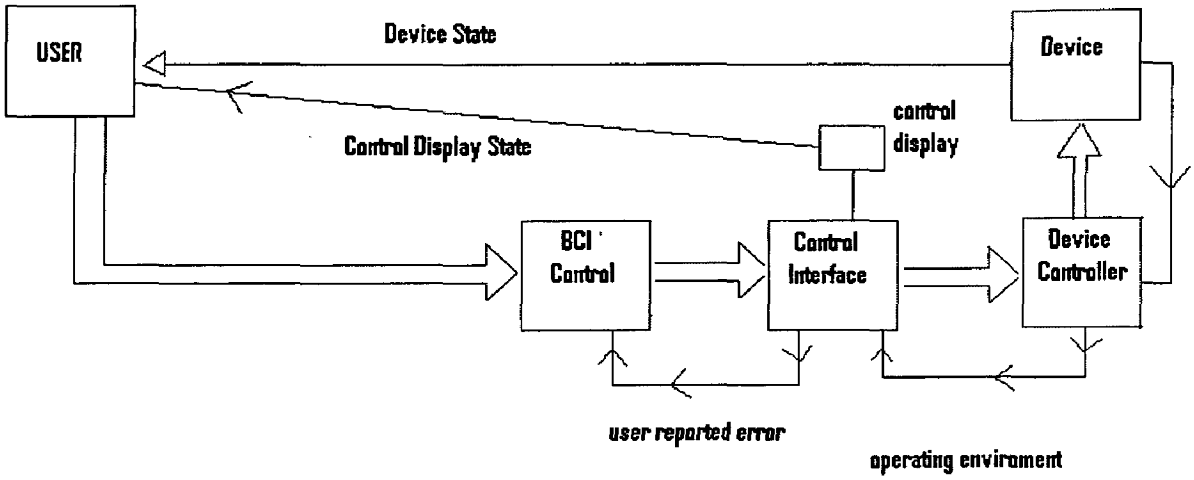


Fig3.4 Simplified version of the Functional Model

3.4 Improved functional model of the BCI system

The improved functional BCI System model is presented in the figure 3.3. The figure depicts a generic BCI System in which a person (the User) controls a Device in an operating environment through a series of functional components. The User monitors the state of the Device to determine the result of his or her control efforts. In some systems, the User may also be presented with a Control Display, which displays his or her control inputs within a semantic application-Specific context. The set of functional components between the User and the Device Controller will be considered BCI interface technology, or simply BCI technology. (Even though a User could potentially control multiple Devices with combinations of interface technologies in various environments, the functional model in Fig. 3.3 has been restricted to one Device, one interface technology, and one operating environment to simplify the presentation.) Like other interface technologies, a BCI technology is developed to help a target population with specific abilities perform certain tasks with a Device within an operating environment. The function of each component of the proposed model is discussed in Table 3.1 and related feedback loops are defined in Table 3.2. The component definitions and the functional boundaries between components were selected to meet several design objectives:

1) The components in the model should be a minimal but sufficient set to effectively represent existing and future BCI Systems.

2) The boundaries between the functional components should align as much as possible with existing research disciplines such as pattern recognition to maximize the use of existing knowledge and technology and the boundaries between the functional components should align as much as possible with existing interface technology to facilitate comparisons between BCI technologies and non-BCI user-interface technologies.

The model in Fig. 3.3 does not show the external sensory stimulator used by some BCI Systems to evoke brain activity in the User. In some systems, the stimulator may be integrated into the Control Display. By treating the device-independent components (i.e., the electrodes, amplifiers, Feature Extractor, and Feature Translator) as a single entity, which we will call a BCI Control, the functional model reduces to the model depicted in Fig. 3.4. This new construct, the BCI Control, is analogous to a physical transducer such as a potentiometer or a switch. The output of the BCI Control, like that of a physical transducer, consists of either sequences of discrete states or a continuous signal.

Component	**Functional Description**
User	The user is a person controlling the device in the BCI system. The user intentionally modifies his or her brain state in order to generate the control signals that operate the BCI system.
Electrodes	The electrodes convert the User's brain state into electrical signals. Several types of electrodes (e.g. scalp, inter-cranial and interocortical) have been used in various configurations.
Amplifier	The amplifiers amplify and band pass filters the electrical signals from the user's brain
Feature Extractor	The Feature Extractor transforms the amplified signals into feature values that correspond to the underlying neurological mechanism used by the user for control. For example, if the user controls the power of their mu and Beta rhythms, a Feature Extractor can be

	designed to continually generate a feature vector containing the power estimates of the user's mu and Beta rhythms.
Feature Translator	The Feature Translator translates the feature vector into logical control signals. For example, a Feature Translator may produce a 2 state discrete output.
Control Interface	The control interface translates the logical control signals from the Feature translator into semantic control signals that are appropriate for a particular type of device. This mapping may be instantaneous or by integrating inputs over time. The semantic mappings in Control Interfaces are usually dynamic and not static. The role of the control display is to display the interpretation of the User's control signals within a semantic context. As an example, the control display may depict a virtual keyboard and the user's control signals may be seen as movements of a cursor over this keyboard. The user monitors this display and dynamically adjusts his or her brain state to achieve the desired response.
Device Controller	The Device controller translates the semantic control signals from the control Interface into physical control signals that are used within the device. It also controls the overall behavior of the device. For example, the Device controller is responsible for initializing and resetting the device when required.
Device	There is an unlimited range of devices that can be used in a BCI system. Computers, speech synthesizers, neural prostheses and other objects can be used. These devices are usually physically present but can also be virtual, existing only on a computer monitor.
Operating Environment	This term refers to the physical environment (e.g. walls, floors, ambient temperature and noise) and objects and people in the environment. These environment factors are usually controlled in a laboratory setting.

Table3.1 Definition of functional components

Information	Feedback Paths
Device State	The device state is fed back to the user through one or more sensory channels. The User correlates changes in Device State with their control attempts. This information is used by the user to adjust his output. The Device state may be fed back to the device Controller if the device supports this type of output. This information is used to keep the device Controller synchronized with the Device.
Control Display state	The Control Display state is fed back from the Control interface to the user through one sensory channel. This information is used by the user to dynamically adjust his or her output.
Device Controller State	The device controller state is feedback from the Device Controller to the Controller interface. This information is used to synchronize the semantic mapping of the control interface to the state of the device controller.
User-reported errors	If a feature Extractor or the Feature Translator is adaptive, user reported errors can be fed back from the control interface to the feature extractor or the feature translator so that they can modify their function.
User State	The user's self perception of his or her state is an internal source of information fed back to the user. For example, the user may notice change in energy, fatigue, frustration, interest in the task, or body pains and may adapt his or her control to this new state.
Environmental state	The state of the physical environment and the people and objects in the environment are fed back to the User through one or more sensory channels.

Table 3.2 Definition of Functional Components (feedback elements)

CHAPTER 4
EXPERIMENTAL SETUP

4.1 Introduction

In our experimental setup, the EEG patterns are recorded and the variations in these patterns due to various factors are studied. The changes can be due to auditory stimulus, Visual stimulus and Eye motion. These changes are then utilized further for the generation of the control action.

4.2 Generalized Block diagram of the BCI developed

The various blocks used in the development of BCI are as follows:

Electrodes: The electrodes used are circular electrodes which are pasted on the head using an adhesive paste. We used here **Detachable EEG Electrodes.** Generally for our use we require 7 to 8 electrodes. They are Fp1, Fp2, F4, F2, A1, A2, CZ, Gnd and reference electrodes. We are interested in waveforms originating at Fp2-F4, Cz-A1, Fp1-F3, and Cz-A2. We can also use variety of other electrodes. They are as listed below:

- Disposable EEG Needle electrodes
- EEG single disc electrodes
- Detachable EEG disc electrodes and leads
- Ribbon strand electrodes
- Quick disconnect Ribbon strand electrodes

Amplification and Signal Conditioning Unit: The EEG signal generated is in the range of microvolt, so the signal needs to be amplified for the further use. Also hardware filters are applied to remove unwanted noise signals and disturbances. The amplifiers are present in the Head Box of the unit, while Filters are present in the Adaptor Box.

Multiplexer and A/D unit: The multiplexer is used to convert the parallel data coming into a single router and ADC further converts Analog signal into Digital Signal. We

4.3 EEG Hardware

The standard items of the EEG hardware are as follows:

- Adaptor Box
- Head Box
- Photic Flash
- Connecting Cable
- Spike Protector
- Paste Jar
- PC
- Head Box and Photic Stand

While installing the hardware for EEG measurements we should keep in mind that the surface where the SSEEG is to be installed should be smooth, level and sturdy. The room should be preferably air conditioned. A wash basin may be installed in the EEG lab. To minimize the electromagnetic interference, the EEG lab should not be located near transformers, DC motors or other power appliances. There should be proper grounding of the AC outlets used for EEG. Wires carrying large currents should not pass through the EEG lab. The EEG Electrode paste is a low impedance highly conductive gel, specially formulated to stick the electrodes on the skin without additional adhesive disks. The EEG paste composes of Water / Polyoxyellylene Oleyiether Phosphate / Glycerin / Calcium Carbonate / Liquid Patrolatum / Propylene Glycol / Lanolin Alcohol / Sodium Chloride/ Sodium Hydroxide / Polyoxyethylene Hydrogenated Lanolin / Coconut Fatty Acid Diethanolamide / Polyoxyethylene Stearylether / Polyoxyethylrne Oleylether / Egg Yolk Oil / Dibutylhydroxytoluene / Methl Parahydroxybenzoate / Propyl Parahydroxybenzoate.

The Head Box is used for connecting electrodes from the scalp to the hardware unit. The signal generated is amplified and then sent to adaptor Box for signal conditioning. The digital signal generated then, passes to the PC where it is displayed on the screen on Super Spec software.

The detailed block diagram of the EEG hardware is as follows:

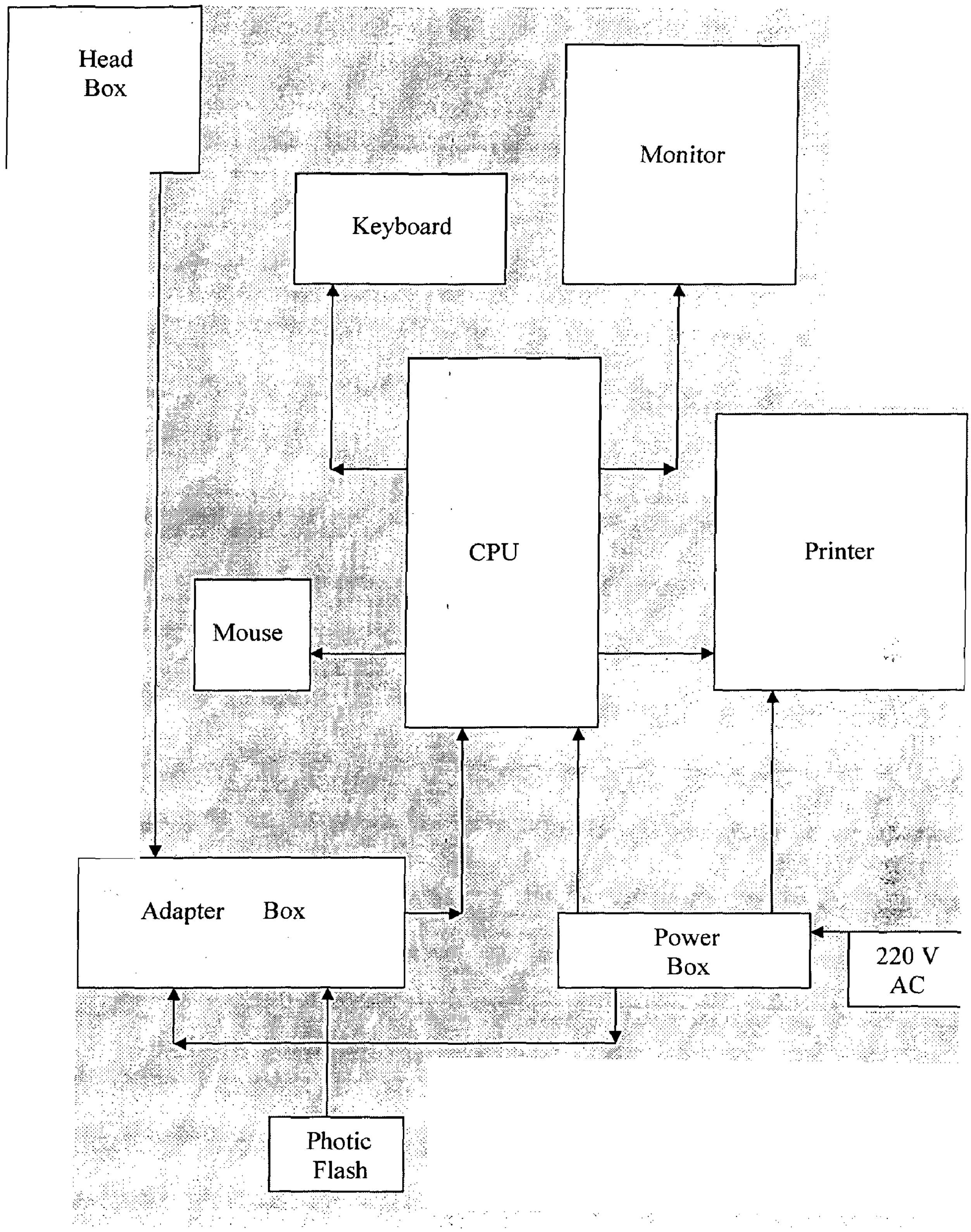


Fig4.1 ***Interconnection diagram of the EEG machine with peripherals***

4.4 EEG Recording Procedures

Usually the brain waves are recorded for about 20 minutes. The hairs are washed and then recording is done .First the measurement of the head is done so that the electrodes can be placed in the correct position. The electrodes are held in place by a paste that can be washed off easily when the test is over. The particular area where electrode is to be kept is firstly washed with spirit and then electrode is kept using the paste. This helps in better contact as the impedance is lowered. Ideally the impedance should be less than 5 K . Preferably EEG is recorded in a quiet room, which often is dimly lit. Sometimes photic simulation is used to check for the abnormality in the EEG. In this brief flashes of light (2-5 seconds in duration) at a number of different frequencies are delivered to the patient with both eyes open and closed and changes are noted.

4.5 EEG Feature Extractions

For the development of any BCI, the most important thing is the feature extraction. The various changes in the EEG patterns are noted following the effect of various stimuli. We get changes for different stimuli at different montages. For the detecting of auditory evoked potentials, the changes are best viewed at Cz-A1, Cz-A2. The most important detection is the BAEP (Brain Stem auditory evoked potential). The most important is the detection of peaks I, III and V. When subjected to acoustic stimuli i.e. clicks (100 microseconds square wave) there are changes in the EEG at montages Cz-A1 and Cz-A2..We normally used a frequency rate of 1click/sec and the intensity is 60 dB nHL. We normally used 256 samples as the data variation for peaks detection lie in 100 msec. The detection of Peaks I, III and V does give us useful information regarding the patient hearing system but sometimes the major difficulties arise when some components are missing. The main waves to be recognized are I, III and V. Sometimes wave I may be small and difficult to measure. We do certain manipulations like auditory stimuli intensity is made high i.e. 90 dB nHL and frequency is reduced to 1 click per 2 second to clearly identify wave I. To identify wave V we decrease the intensity to 30 dB nHL and we the increase in the latency as shown in figure 4.3. Once the peaks I and V are detected, the peak midway is peak III. To identify the peaks I , III and V we use low pass filter(4^{th} order FIR) with cutoff 4000Hz and high pass filter of cut off 40 Hz.(4^{th} order FIR). Also notch Filter for 50 Hz power line interference removal is also used.

The waveform is as shown below:

CHAPTER 4

EXPERIMENTAL SETUP

4.1 Introduction

In our experimental setup, the EEG patterns are recorded and the variations in these patterns due to various factors are studied. The changes can be due to auditory stimulus, Visual stimulus and Eye motion. These changes are then utilized further for the generation of the control action.

4.2 Generalized Block diagram of the BCI developed

The various blocks used in the development of BCI are as follows:

Electrodes: The electrodes used are circular electrodes which are pasted on the head using an adhesive paste. We used here **Detachable EEG Electrodes.** Generally for our use we require 7 to 8 electrodes. They are Fp1, Fp2, F4, F2, A1, A2, CZ, Gnd and reference electrodes. We are interested in waveforms originating at Fp2-F4, Cz-A1, Fp1-F3, and Cz-A2. We can also use variety of other electrodes. They are as listed below:

- Disposable EEG Needle electrodes
- EEG single disc electrodes
- Detachable EEG disc electrodes and leads
- Ribbon strand electrodes
- Quick disconnect Ribbon strand electrodes

Amplification and Signal Conditioning Unit: The EEG signal generated is in the range of microvolt, so the signal needs to be amplified for the further use. Also hardware filters are applied to remove unwanted noise signals and disturbances. The amplifiers are present in the Head Box of the unit, while Filters are present in the Adaptor Box.

Multiplexer and A/D unit: The multiplexer is used to convert the parallel data coming into a single router and ADC further converts Analog signal into Digital Signal. We are using 14bit ADC which converts the signal of -5 to +5 into the digital format. A 5V is converted into 32767 and -5V is converted to -32767.

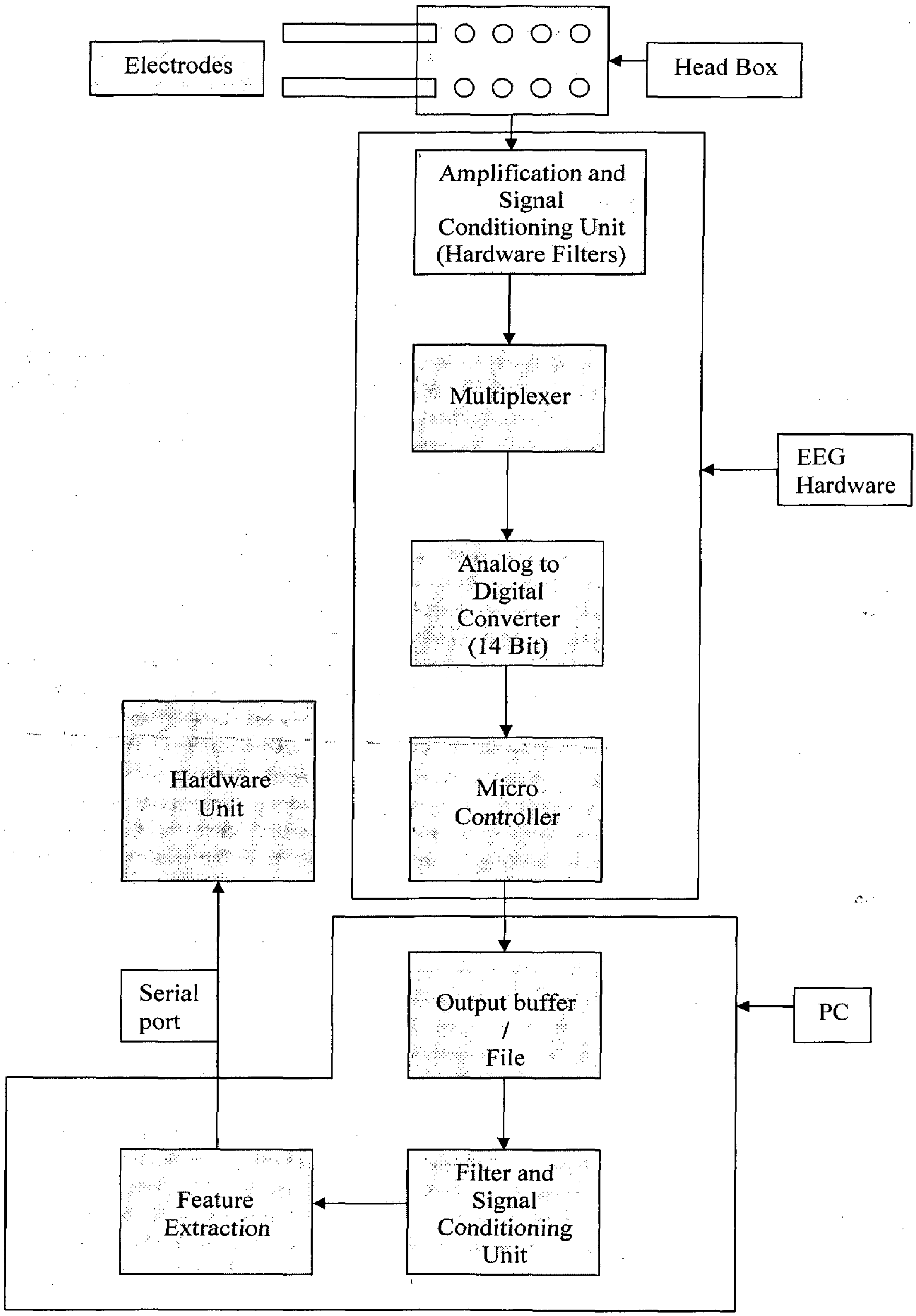
Microcontroller unit: This unit receives the signals and are then are processed which are further sent to the display unit. This particular unit lies in the adaptor box of the EEG Machine

Output Buffer/File: This is online file generated which contains the samples of the channel selected. Normally the sampling frequency is 256. They are recorded 8 at a time in a block of 32 for 1 second. In our Super Spec software, we can get a data of 4 channels at a time. These 4 channels can be selected from the various montages and we can make our own montages. The sampled data has to pass through the signal conditioning unit and the filtered data can be used further.

Filter and Signal conditioning unit: This particular unit acts on the online data generated. The signal is first passed through Low Pass Filter (4th order FIR filter with cut off 99Hz), then through High Pass Filter (4^{th} order FIR filter with cut off 0.1Hz) and a notch filter of 50 Hz for removal of power line interference. The signal is then differentiated to highlight the changes. Here the filters used are the digital filters.

Feature Extraction: This unit then analyses the signal for the detection of events. Once the event is extracted the software sends an interrupt signal to the hardware unit via COM port. The further control action is taken at the hardware unit.

Hardware Unit: The hardware unit contains the microcontroller AT85S52, which decodes this interrupt signal and takes the necessary control action i.e. switching ON of the corresponding LED. The hardware unit consists of Micro controller, MAX 232 for connecting microcontroller to PC via COM port. A power supply section is there to provide supply to Microcontroller and MAX 232. There is a crystal oscillator to provide clock pulses to the Microcontroller. The detailed block diagram and functioning of the hardware unit is described later. A printer is also attached to the unit for recording rhythms on the paper.


Electrodes
Head Box
Amplification and Signal Conditioning Unit (Hardware Filters)
Multiplexer
EEG Hardware
Analog to Digital Converter (14 Bit)
Micro Controller
Hardware Unit
Serial port
Output buffer / File
PC
Feature Extraction
Filter and Signal Conditioning Unit

4.3 EEG Hardware

The standard items of the EEG hardware are as follows:

- Adaptor Box
- Head Box
- Photic Flash
- Connecting Cable
- Spike Protector
- Paste Jar
- PC
- Head Box and Photic Stand

While installing the hardware for EEG measurements we should keep in mind that the surface where the SSEEG is to be installed should be smooth, level and sturdy. The room should be preferably air conditioned. A wash basin may be installed in the EEG lab. To minimize the electromagnetic interference, the EEG lab should not be located near transformers, DC motors or other power appliances. There should be proper grounding of the AC outlets used for EEG. Wires carrying large currents should not pass through the EEG lab. The EEG Electrode paste is a low impedance highly conductive gel, specially formulated to stick the electrodes on the skin without additional adhesive disks. The EEG paste composes of Water / Polyoxyellylene Oleyiether Phosphate / Glycerin / Calcium Carbonate / Liquid Patrolatum / Propylene Glycol / Lanolin Alcohol / Sodium Chloride/ Sodium Hydroxide / Polyoxyethylene Hydrogenated Lanolin / Coconut Fatty Acid Diethanolamide / Polyoxyethylene Stearylether / Polyoxyethylrne Oleylether / Egg Yolk Oil / Dibutylhydroxytoluene / Methl Parahydroxybenzoate / Propyl Parahydroxybenzoate.

The Head Box is used for connecting electrodes from the scalp to the hardware unit. The signal generated is amplified and then sent to adaptor Box for signal conditioning. The digital signal generated then, passes to the PC where it is displayed on the screen on Super Spec software.
The detailed block diagram of the EEG hardware is as follows:

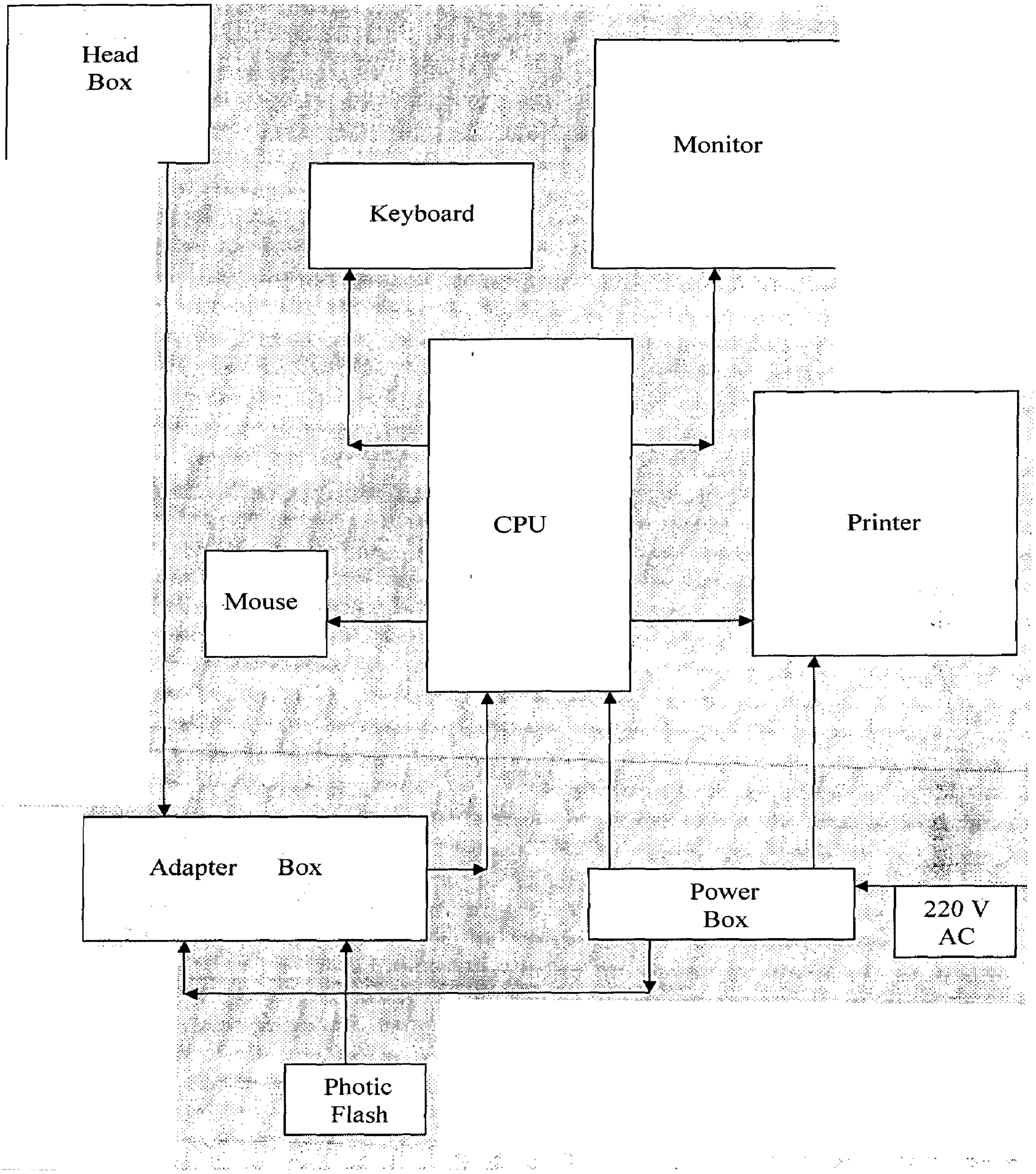


Fig4.1 ***Interconnection diagram of the EEG machine with peripherals***

4.4 EEG Recording Procedures

Usually the brain waves are recorded for about 20 minutes. The hairs are washed and then recording is done .First the measurement of the head is done so that the electrodes can be placed in the correct position. The electrodes are held in place by a paste that can be washed off easily when the test is over. The particular area where electrode is to be kept is firstly washed with spirit and then electrode is kept using the paste. This helps in better contact as the impedance is lowered. Ideally the impedance should be less than 5 K . Preferably EEG is recorded in a quiet room, which often is dimly lit. Sometimes photic simulation is used to check for the abnormality in the EEG. In this brief flashes of light (2-5 seconds in duration) at a number of different frequencies are delivered to the patient with both eyes open and closed and changes are noted.

4.5 EEG Feature Extractions

For the development of any BCI, the most important thing is the feature extraction. The various changes in the EEG patterns are noted following the effect of various stimuli. We get changes for different stimuli at different montages. For the detecting of auditory evoked potentials, the changes are best viewed at Cz-A1, Cz-A2. The most important detection is the BAEP (Brain Stem auditory evoked potential). The most important is the detection of peaks I, III and V. When subjected to acoustic stimuli i.e. clicks (100 microseconds square wave) there are changes in the EEG at montages Cz-A1 and Cz-A2..We normally used a frequency rate of 1click/sec and the intensity is 60 dB nHL. We normally used 256 samples as the data variation for peaks detection lie in 100 msec. The detection of Peaks I, III and V does give us useful information regarding the patient hearing system but sometimes the major difficulties arise when some components are missing. The main waves to be recognized are I, III and V. Sometimes wave I may be small and difficult to measure. We do certain manipulations like auditory stimuli intensity is made high i.e. 90 dB nHL and frequency is reduced to 1 click per 2 second to clearly identify wave I. To identify wave V we decrease the intensity to 30 dB nHL and we the increase in the latency as shown in figure 4.3. Once the peaks I and V are detected, the peak midway is peak III. To identify the peaks I , III and V we use low pass filter(4^{th} order FIR) with cutoff 4000Hz and high pass filter of cut off 40 Hz.(4^{th} order FIR). Also notch Filter for 50 Hz power line interference removal is also used.

The waveform is as shown below:

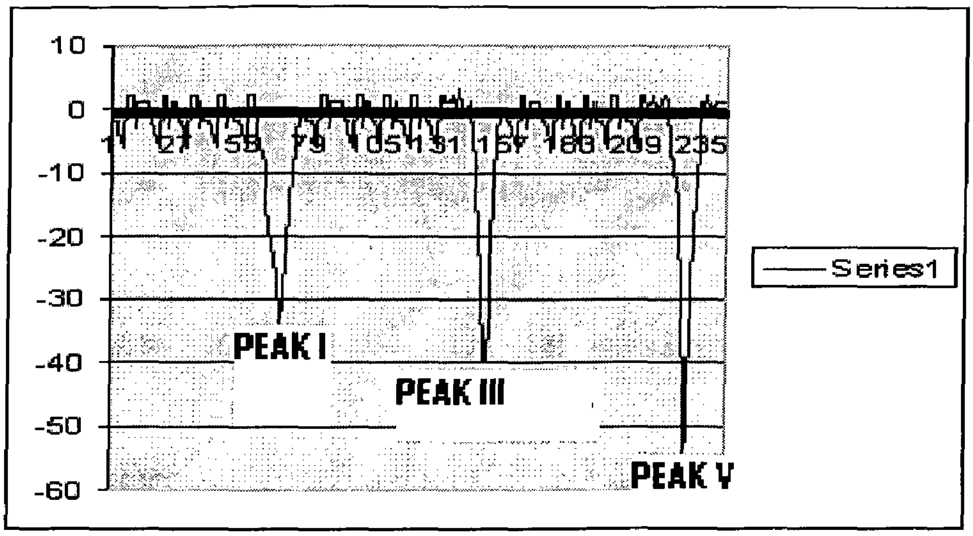


Fig 4.2 Plot of various instantaneous amplitudes versus samples of subject 1 of variations in Cz-A2 when subjected to Auditory Stimuli (Click) of frequency 1 and intensity 60 dB nHL subjected to Right Ear.

Wave I is the vertex negative peak occurring immediately before the waveform crosses the baseline to become positive. Waveform V is the negative peak occurring immediately before the last large waveform. Wave III is the most prominent wave between wave I and wave V. The variations are also studied when stimulus is presented on Left Ear.

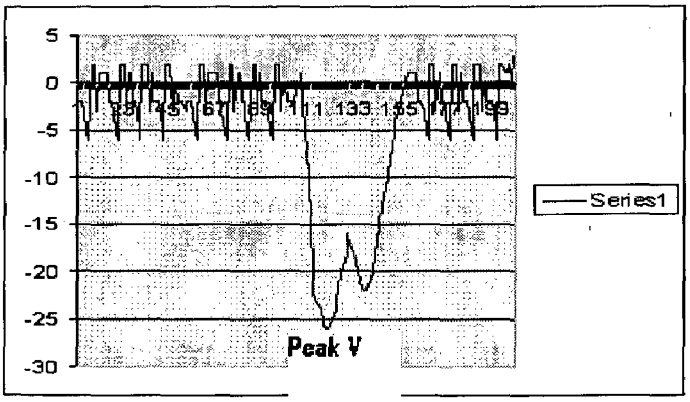


Fig 4.3 Plot of various instantaneous amplitudes versus samples of subject 1 of variations in Cz-A2 when subjected to Auditory Stimuli (Click) of frequency 1 and intensity 60 dB nHL subjected to Left Ear.

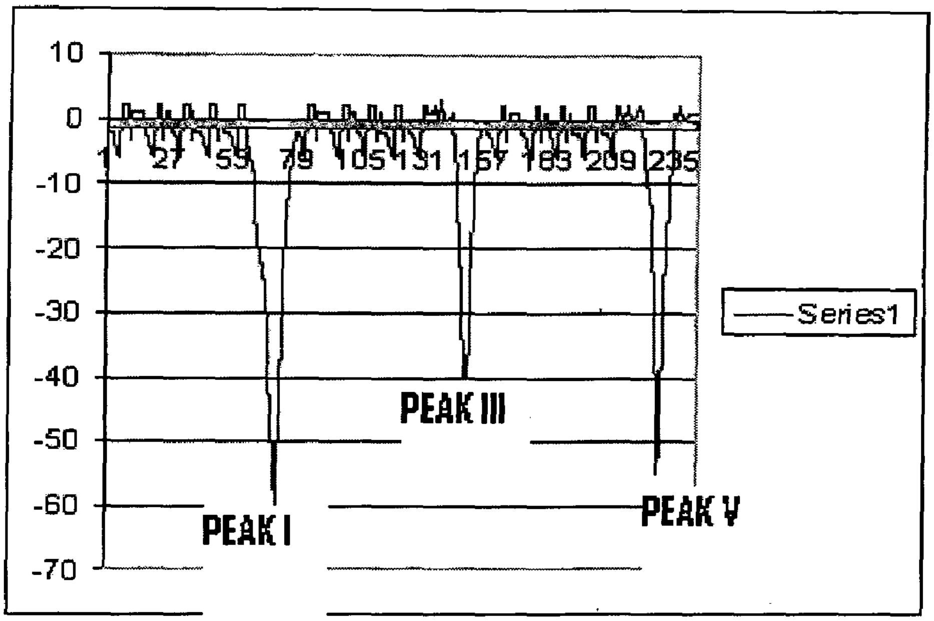


Fig 4.4 Plot of various instantaneous amplitudes versus samples of subject 1 of variations in Cz-A2 when subjected to Auditory Stimuli (Click) of frequency 0.5 and intensity more than 60 dB nHL subjected to Right Ear.

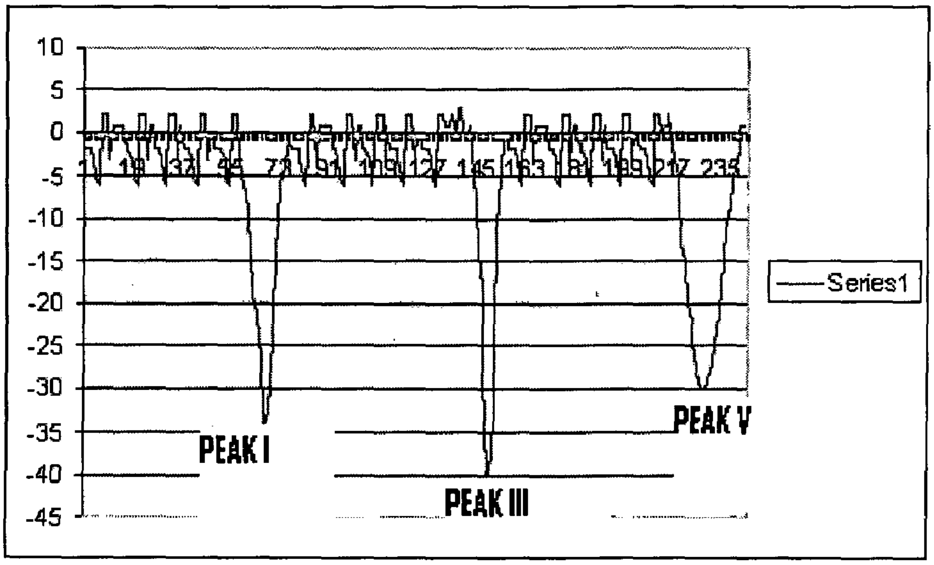


Fig 4.5 Plot of various instantaneous amplitudes versus samples of subject 1 of variations in Cz-A2 when subjected to Auditory Stimuli (Click) of frequency 1 and intensity less than 60 dB nHL subjected to Right Ear.

Eye movements are observed on all EEGs and are useful in identifying sleep stages. Vertical eye movements are observed with blinks. A blink causes the positive pole (ie, cornea) to move closer to frontopolar (Fp1-Fp2) electrodes, producing symmetric downward deflections. During downward eye movement the positive pole (ie, cornea) of the globe moves away from frontopolar electrodes, producing an upward deflection. Similarly changes in the EEG patterns due to eye activity are also noted. They are mostly detected at Fp2-F4, Fp1-F3. For the development of BCI, we used these changes.

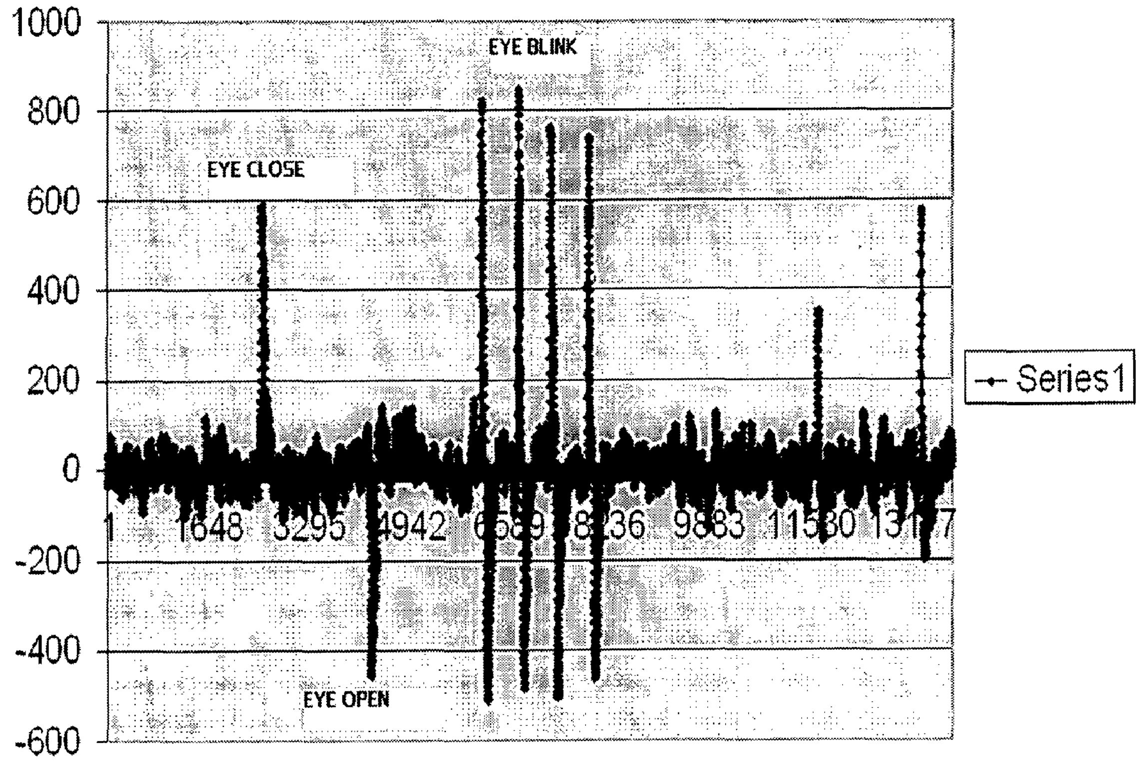


Fig 4.6 Plot of various instantaneous amplitudes versus samples of subject 1 of variations in FP2-F4

The type of variation we get for different subjects for eye open, eye close and eye blink is different so it is important to design a generalized system for the detection of the eye events. For that we have given a sensitivity selector button in the on line analysis of the EEG. The actual EEG patterns recorded from the EEG machine are also attached. 3

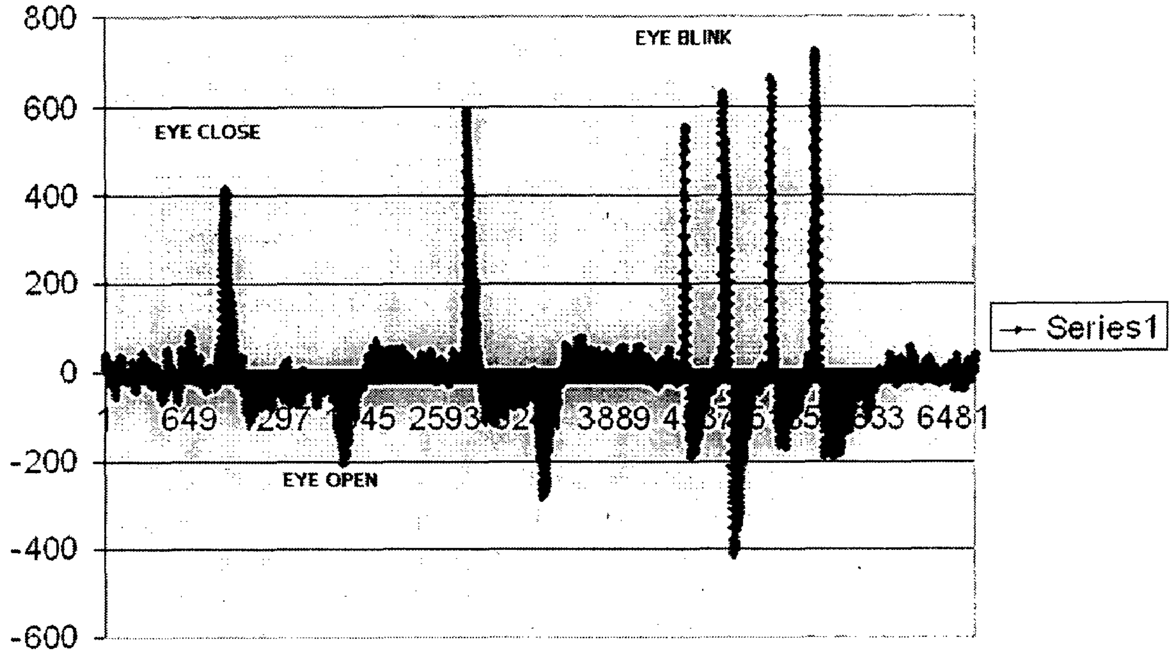


Fig 4.7 Plot of various instantaneous amplitudes versus samples of subject 2 of variations in FP2-F4

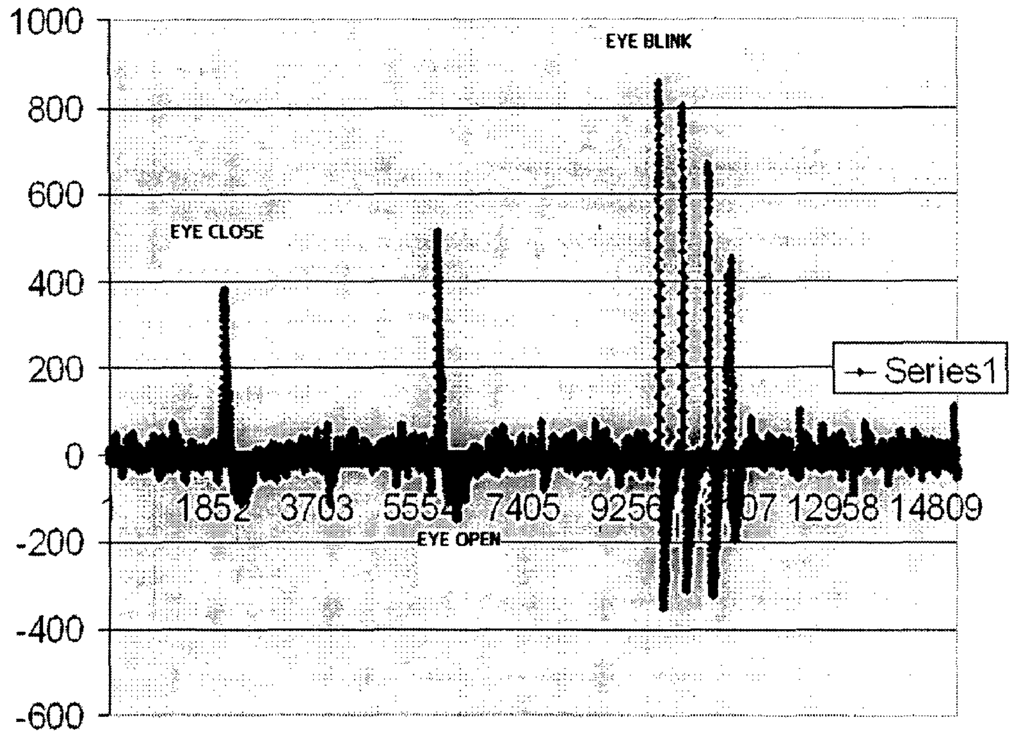
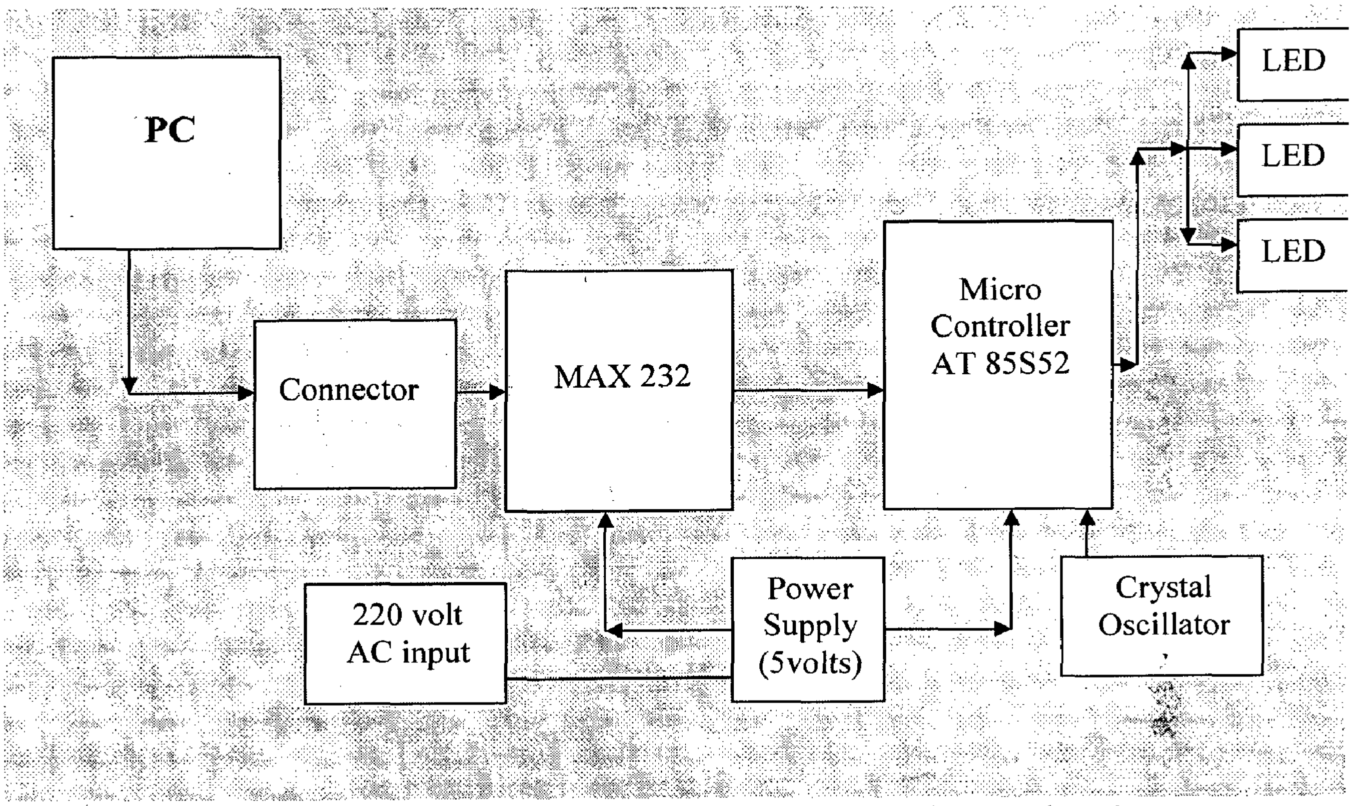


Fig 4.8 Plot of various instantaneous amplitudes versus samples of subject 3 of variations in FP2-F4

4.6 Introduction and generalized Block diagram of the Hardware unit attached

We wish to use the hardware attached to the COM port of the PC for generating and executing the control action. The hardware is a PCB designed and it contains mainly 3 LEDs for generation and execution of the control action.



In the above hardware the heart of the system is microcontroller AT 85S52. There is a crystal oscillator for the generation of the clock pulse used for the operation of micro controller. At pins 21, 22 and 23, there are 3 LED's attached to the ground via current limiting resistor. The input to the microcontroller is via MAX 232. The 3 wires from the MAX 232 are going via serial cable to the COM port of the PC. There is a section for the power supply which is a transformer (Step Down) along with a bridge rectifier followed by capacitor for filtering; voltage regulator 7805 for proper voltage regulation of 5V DC and again a capacitor for proper filtering. The microcontroller operates in the range of (0-5) V. For interfacing the COM port to the microcontroller we need MAX232 as RS232 operates in the range of -3 to -25 Volts and 3 to 25 volts. A charge pump circuitry with the help of capacitors in MAX232 converts 5V to +/- 10V which lies in the range of RS232. There is a reset switch to reset the microcontroller normally. When power is switched on, it automatically resets the microcontroller. There is also a facility to manually reset the Microcontroller. The programming of the microcontroller is accomplished using developer's notepad IDE (Integrated Development Environment) which incorporates GNU's, SDCC Compiler, Simulator and Program Burner.

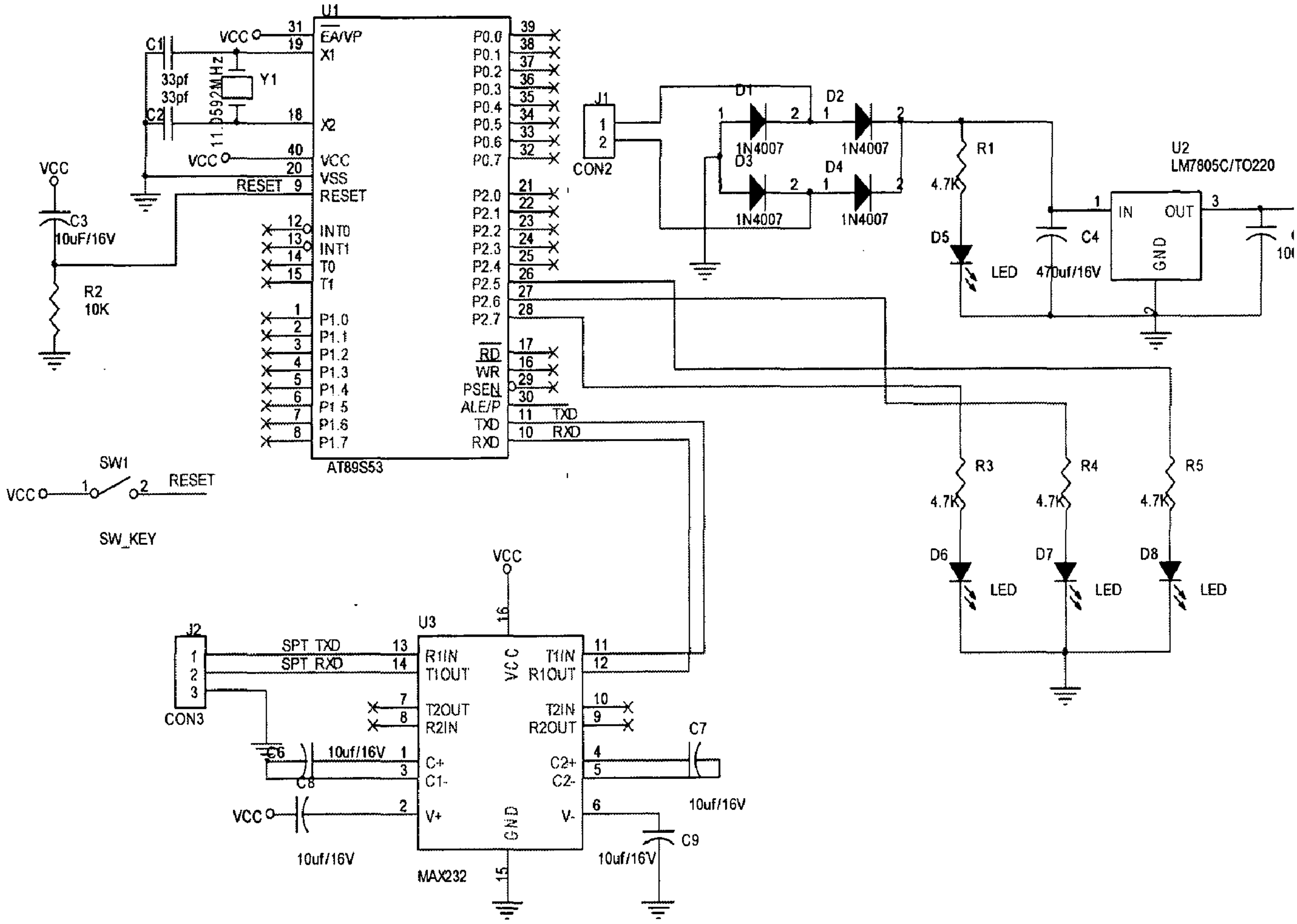


Fig 4.9 Connection diagram of the hardware unit attached

1	2	C2,C1	33pf
2	5	C3,C6,C7,C8,C9	10uf/16V
3	1	C4	470uf/16V
4	1	C5	100uf/16V
5	4	D1,D2,D3,D4	1N4007
6	4	D5,D6,D7,D8	LED
7	1	J1	CON2
8	1	J2	CON3
9	4	R1,R3,R4,R5	4.7K
10	1	R2	10K
11	1	SW1	SW_KEY
12	1	U1	AT89S53
13	1	U2	LM7805C/TO220
14	1	U3	MAX232
15	1	Y1	11.0592MHz

Fig 4.10 Specifications of the various components on the hardware unit

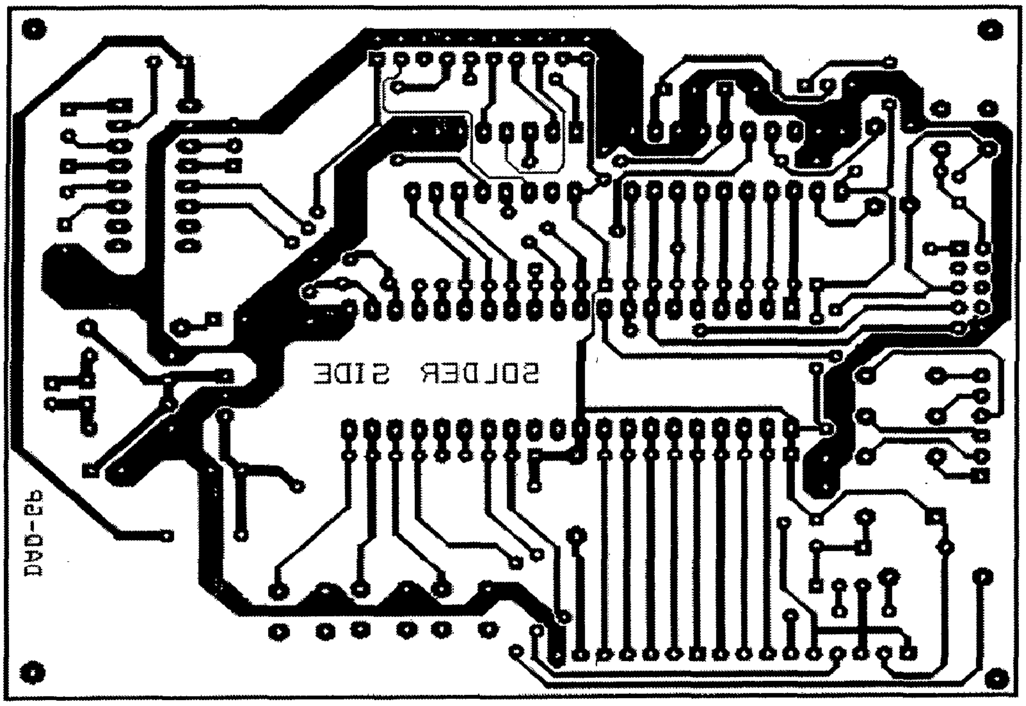


Fig 4.11 Diagram showing tracks of the solder side of the PCB

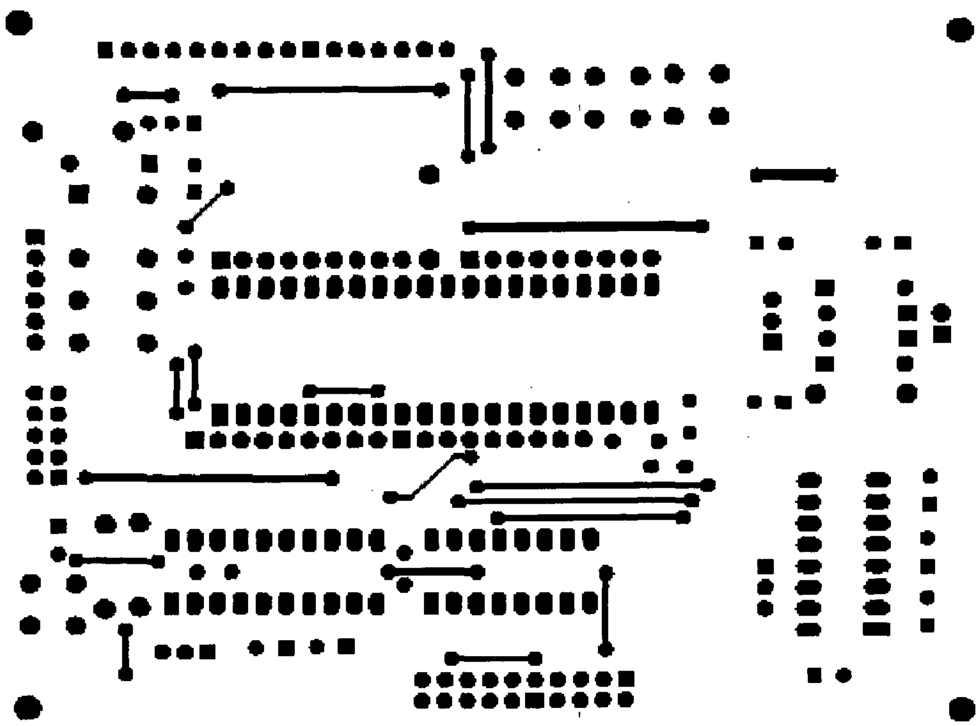


Fig 4.12 Diagram showing the jumper connections of the PCB

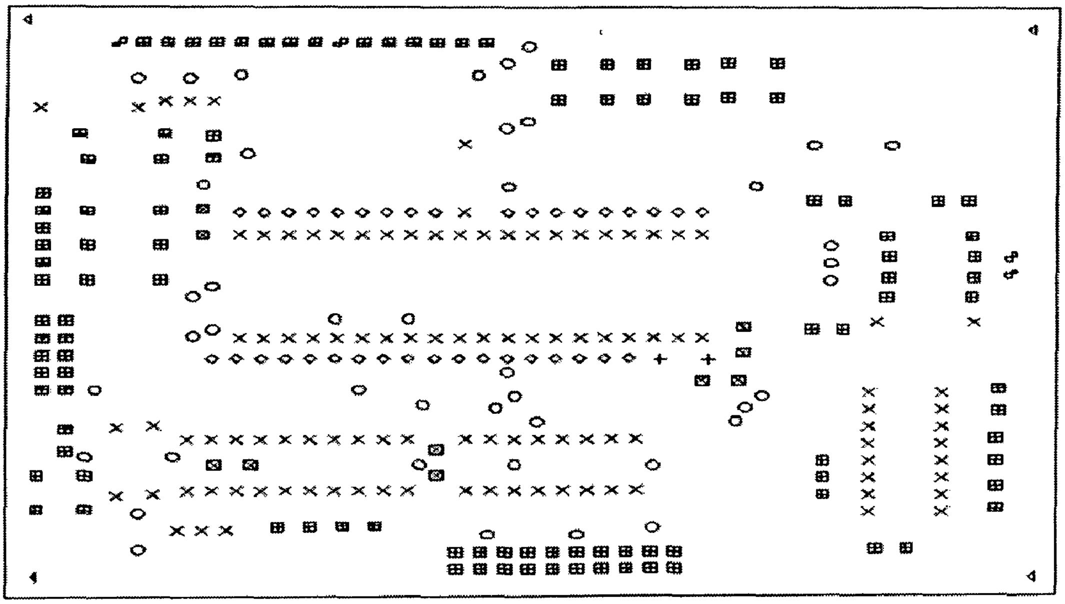


Fig 4.13 Diagram showing the drill chart of the PCB

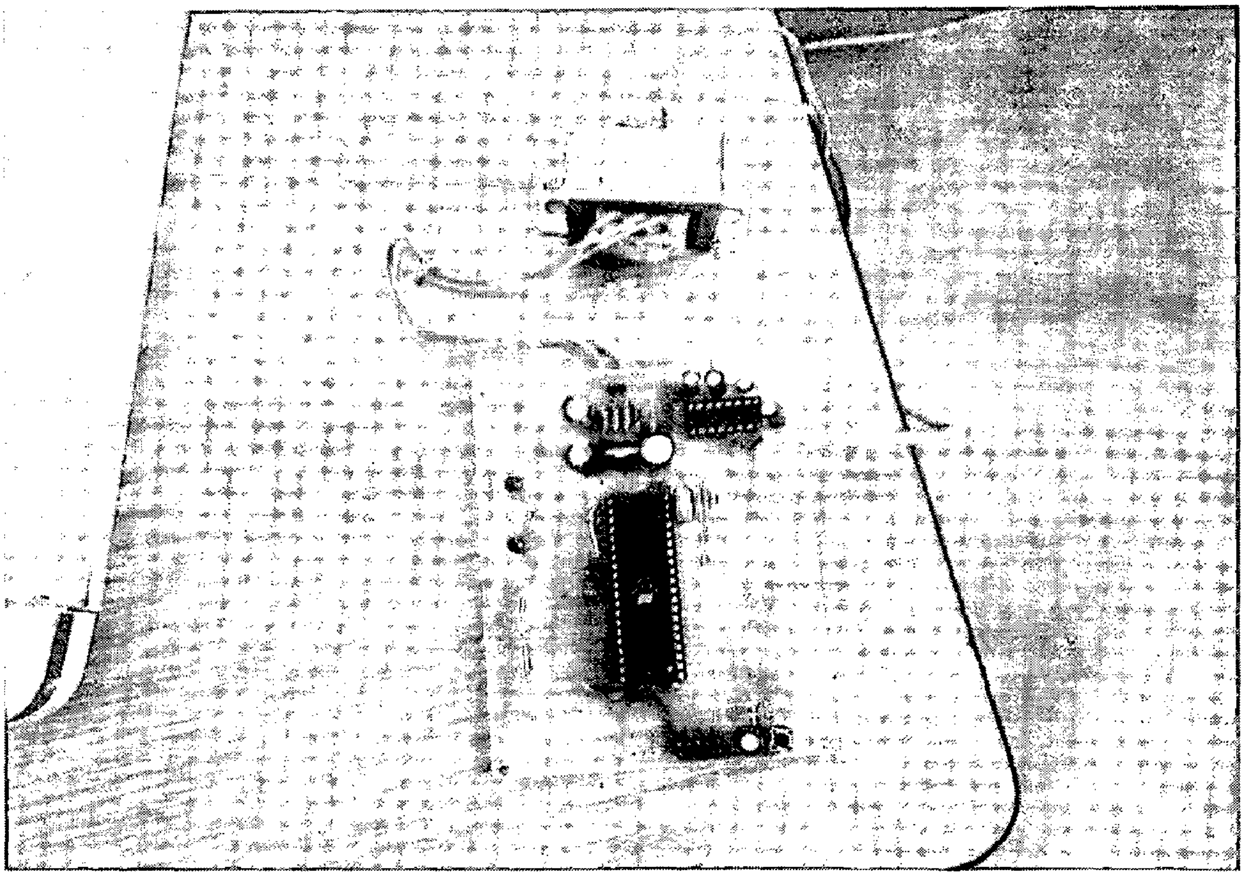


Fig 4.14 Hardware Unit

The Microcontroller is programmed using the following program .

```
#include<at89x51.h>
#include"srl_tmr.h"
void Delay(unsigned int cntr);
void main(void)
{
Delay(10000);
P2=0;
Init_SPT();     //serial port 9600bps
en_spt_int();
while(1){}
}
void Delay(unsigned int u)
{
while(u!=0)
        {u--;}
}
void Serial_Int() interrupt 4 using 1
{
unsigned char a;
RI=0;
a=SBUF;
switch(a)
{
case 'O':
        {P2_0=1;P2_1=0;P2_2=0;Delay(15000);P2=0;}
break;

case 'C':
        {P2_0=0;P2_1=1;P2_2=0;Delay(15000);P2=0;}
break;

case 'B':
        {P2_0=0;P2_1=0;P2_2=1;Delay(15000);P2=0;}
break;
default:
break;

}
}
```

This program is then burnt in the microcontroller memory using SDCC compiler.

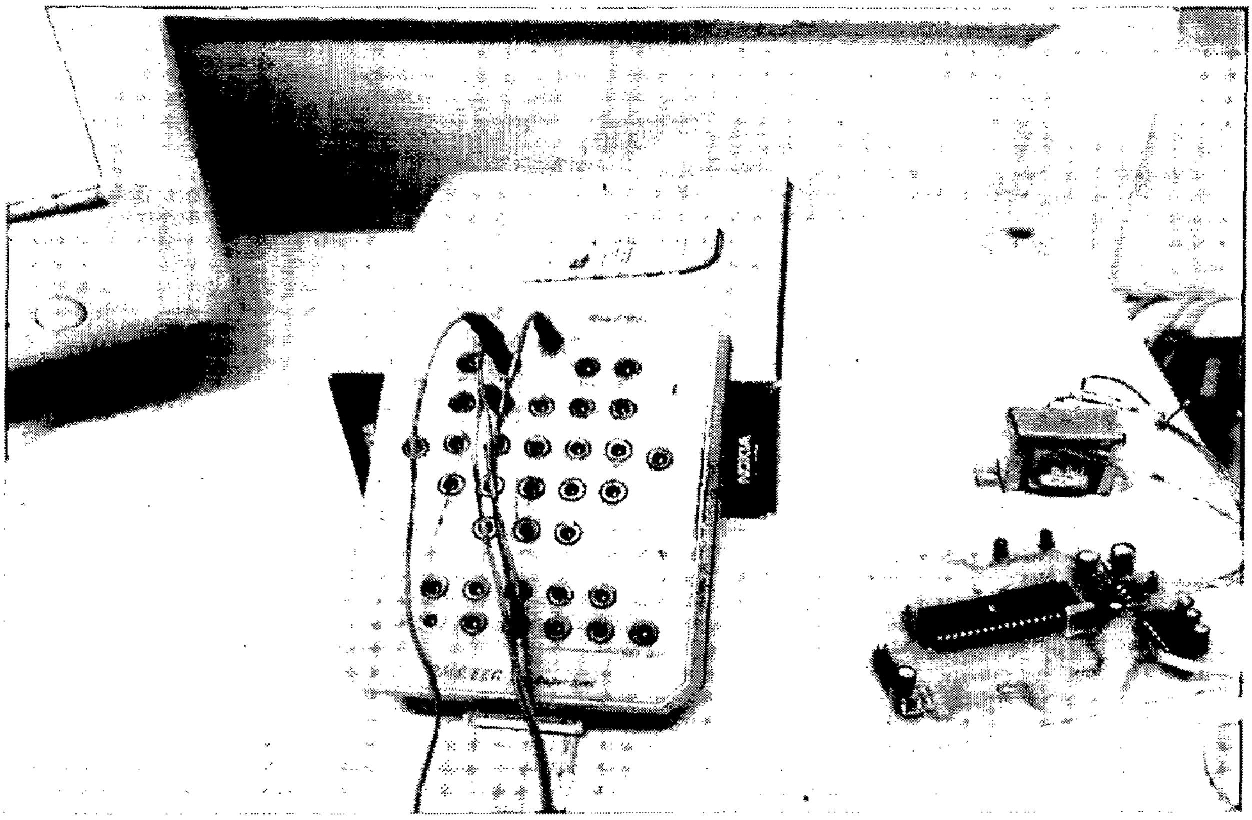


Fig 4.15 Photographs of the complete Experimental setup

4.7 On Line Analysis

The on line analysis means that as soon there is a change in the EEG rhythms, they are detected and control action is generated. Initially the subject is prepared for the EEG recording. The scalp is first cleaned with the spirit so that the contact impedance is lowered and then electrodes are place on the head with the help of the paste. The patient is subjected to various stimuli and the recording of the events is done. Software is developed to detect theses events on line and it indicates the type of event that has occurred. Hardware is attached to the PC, which is then driven via interrupt-generated form the software. The hardware then generates and executes the control action in the form of LEDs. The sample text file generated by the EEG hardware is as shown:

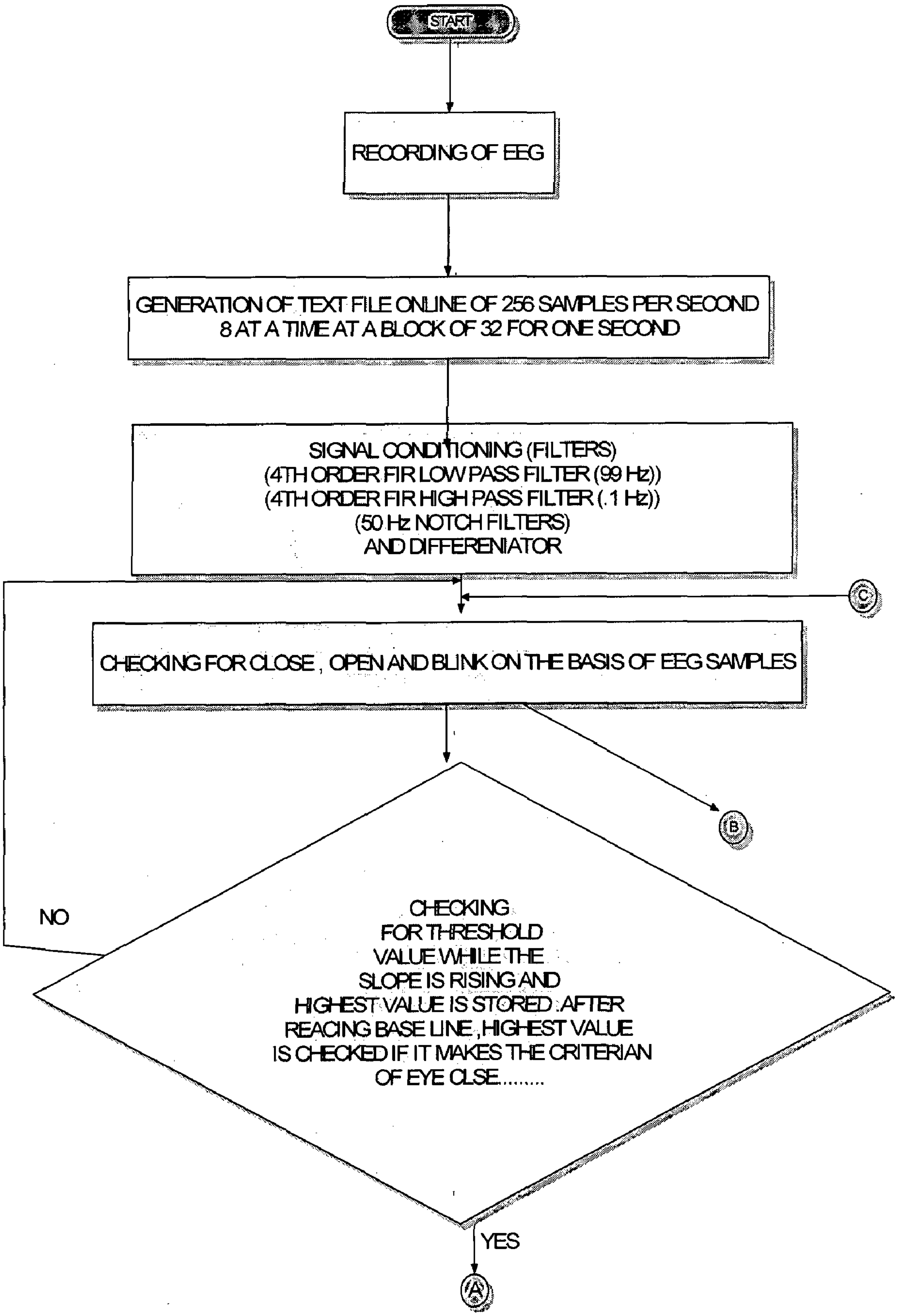
Test -17 -15 -11 -6 0 5 8 10 Test 9 6 1 -4 -8 -12 -14 -14 Test -15 -13 -9 -3 1 7 10 8 Test 4 1 0 1 4 9 12 15 Test 16 18 20 21 22 20 17 12 Test 8 5 2 1 1 -1 -4 -8 Test -11 -14 -13 -10 -5 2 9 14 Test 18 20 21 22 22 23 24 24 Test 21 17 11 5 0 -4 -6 -8 Test -10 -13 -16 -17 -17 -15 -9 -2 Test 6 13 16 15 9 0 -8 -13 Test -14 -11 -3 5 12 16 16 13 Test 9 6 2 -1 -3 -1 2 8 Test 16 24 28 30 33 36 40 44 Test 46 47 45 41 37 33 31 29 Test 30 32 33 31 27 20 13 9 Test 9 11 14 17 19 19 17 13 Test 10 6 4 4 6 9 13 16 Test 19 21 21 18 12 4 -4 -10 Test -15 -17 -19 -19 -19 -19 -19 -18 Test -17 -14 -11 -8 -6 -5 -6 -9 Test -12 -15 -18 -21 -23 -25 -26 -26 Test -24 -20 -15 -11 -9 -13 -20 -24 Test -26 -24 -19 -13 -13 -19 -29 -37 Test -43 -47 -50 -49 -45 -40 -35 -30 Test -26 -24 -24 -23 -21 -19 -18 -17 Test -16 -14 -14 -16 -20 -25 -29 -33 Test -36 -38 -39 -41 -40 -37 -33 -28 Test -22 -19 -18 -19 -21 -22 -22 -23 Test -25 -26 -25 -22 -16 -8 0 5 Test 6 6 5 3 2 2 5 8 Test 12 15 17 17 15 12 10 8 Test 5 2 1 3 6 9 13 15 Test 14 12 10 10 9 8 5 1 Test -3 -7 -10 -12 -11 -8 -5 -3 Test 1 4 8 13 18 22 23 23 Test 22 23 27 31 36 38 37 32 Test 26 20 13 8 5 2 -1 -3 Test -6 -9 -12 -13 -13 -12 -11 -11 Test -12 -13 -14 -13 -10 -7 -5 -3 Test -2 -2 -2 -3 -5 -6 -7 -7 Test -6 -7 -7 -8 -7 -3 2 8 Test 14 18 19 17 14 11 8 8 Test 10 13 15 17 18 19 18 15 Test 12 10 10 12 15 18 19 17 Test 14 10 8 7 5 2 -3 -7 Test -12 -16 -19 -21 -23 -24 -24 -24 Test -25 -25 -23 -18 -10 3 17 30 Test 40 46 49 48 45 41 38 35 Test 34 33 31 28 25 22 18 15 Test 11 7 1 -4 -8 -9 -9 -7 Test -4 -3 -2 -2 -1 1 3 6 Test 7 6 3 -1 -6 -11 -16 -

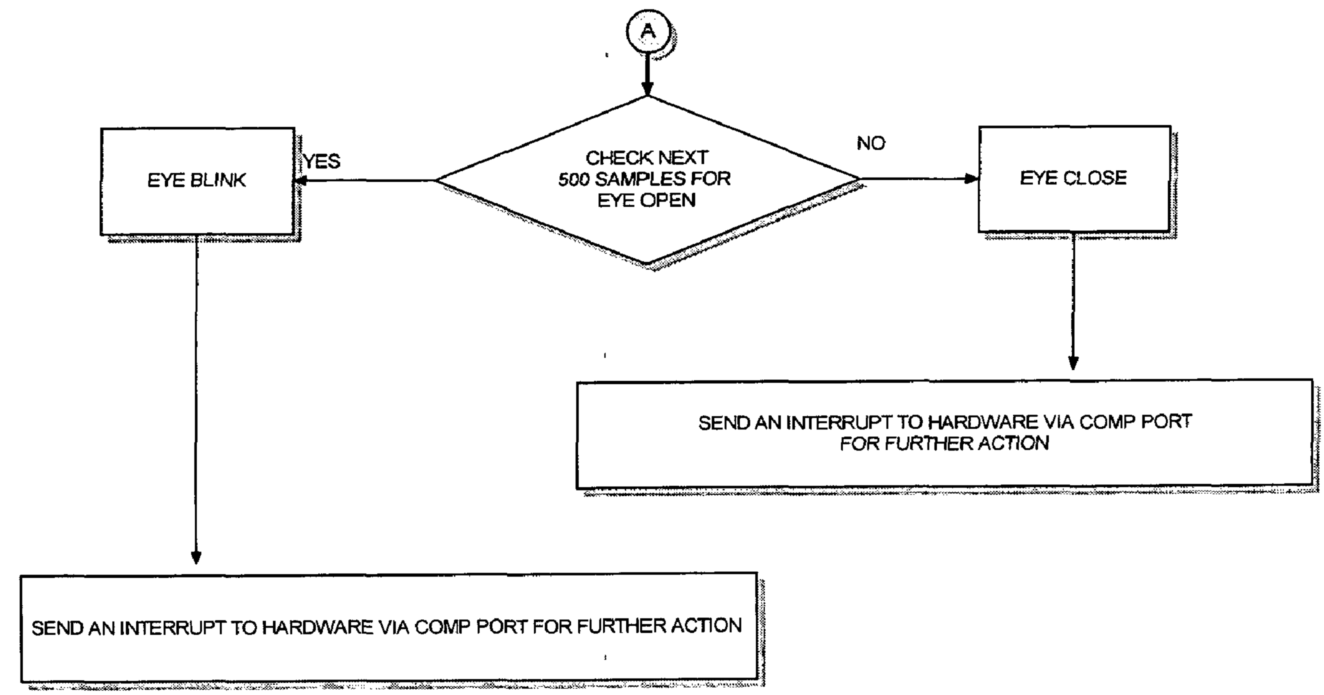
20 Test -23 -25 -25 -23 -21 -18 -15 -13 Test -12 -11 -10 -10 -10 -9 -6 -3 Test 0 2 3 2 0 -3 -6 -8 Test -10 -12 -12 -12 -13 -16 -19 -24 Test -30 -35 -37 -36 -33 -27 -20 -13 Test -5 2 9 14 16 16 14 10 Test 6 2 -1 -1 0 3 8 11 Test 12 9 3 -1 -4 -5 -5 -5 Test -6 -13 -20 -24 -25 -25 -23 -18 Test -13 -8 -2 5 11 16 18 16 Test 11 4 -4 -12 -18 -19 -16 -9 Test -1 6 11 13 11 4 -5 -16 Test -25 -32 -35 -34 -32 -29 -27 -25 Test -22 -19 -18 -18 -20 -23 -25 -25 Test -22 -17 -12 -6 -2 3 7 11 Test 13 14 14 12 9 7 7 8 Test 9 9 9 7 3

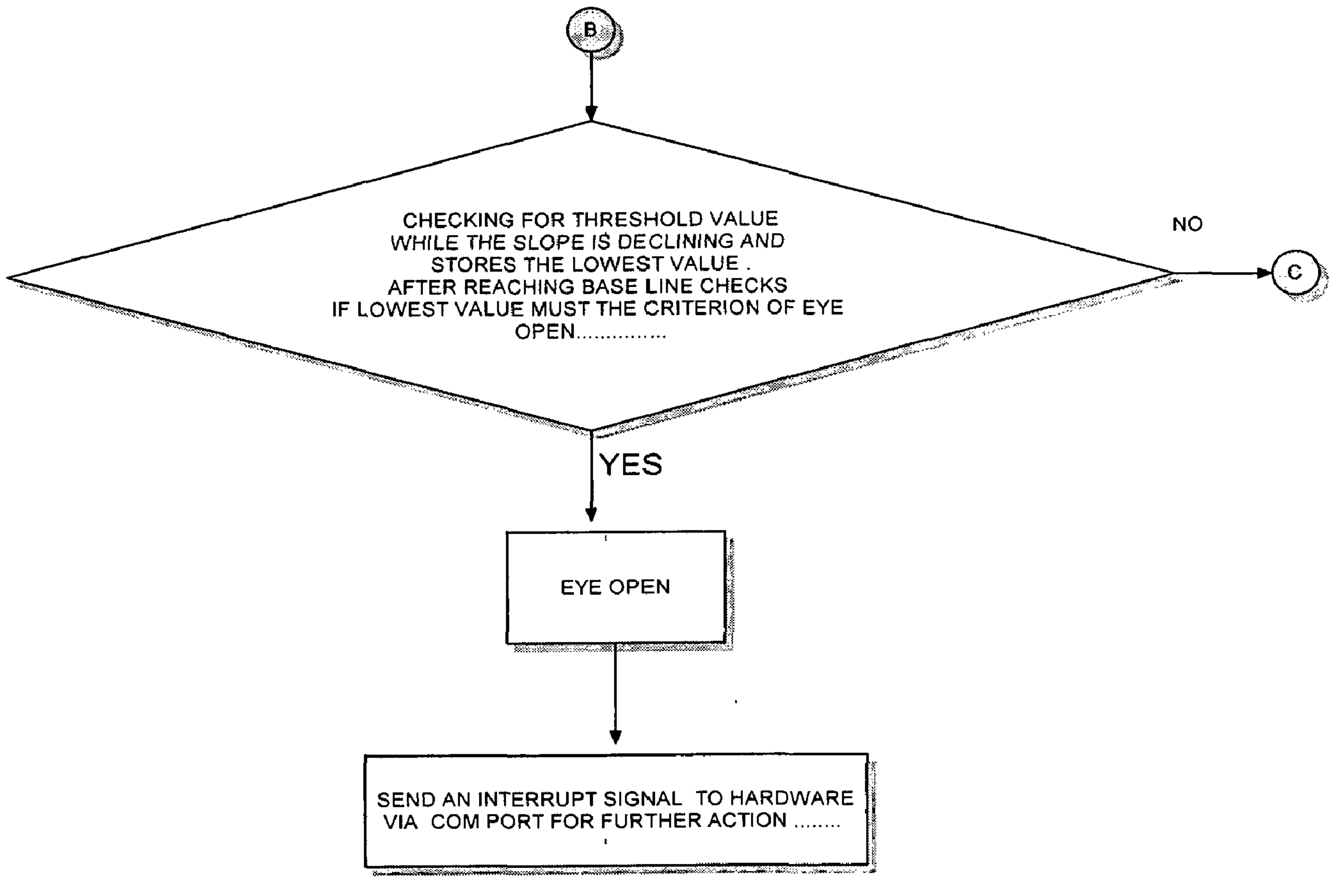
We can do a number of analyses with this data. For instance, we can do the frequency analysis of the EEG wave by taking FFT, which converts the entire wave into a simplified spectrum. It is separated into frequency bands of alpha, beta, delta and theta waves. The redistribution of electrical activity in the brain among certain frequency bands or the predominance of one band over the others correlates with specific physiological and pathological conditions. The total power of the EEG spectrum can be determined and the power of the individual frequency bands is normally expressed as percentage of the total power. The correlation among data of 2 channels can be done to find out interactive state of mind. As EEG spectrum shows the frequencies present in the segment of EEG, we can determine Peak power frequency, Mean dominant frequency and spectral edge frequency. We can do time domain analysis for the extraction of instantaneous envelope and phase of EEG signal. The instantaneous envelope is proportional to the instantaneous root mean square value of the signal, and therefore the energy of a certain frequency band could be traced in time.

This file is processed further to extract features and to generate an intelligent control action. We in our work have used hardware for the control action but we can also generate software controls. We can mark the various events by numbers or alphabets. These markings can be used for generation of control action like the motion of the line etc.

The flowchart for the software developed for the feature extraction and generation of control action is as follows


START
RECORDING OF EEG
GENERATION OF TEXT FILE ONLINE OF 256 SAMPLES PER SECOND 8 AT A TIME AT A BLOCK OF 32 FOR ONE SECOND
SIGNAL CONDITIONING (FILTERS)
(4TH ORDER FIR LOW PASS FILTER (99 Hz))
(4TH ORDER FIR HIGH PASS FILTER (.1 Hz))
(50 Hz NOTCH FILTERS)
AND DIFFERENIATOR
C
CHECKING FOR CLOSE , OPEN AND BLINK ON THE BASIS OF EEG SAMPLES
B
NO
CHECKING FOR THRESHOLD VALUE WHILE THE SLOPE IS RISING AND HIGHEST VALUE IS STORED .AFTER REACING BASE LINE ,HIGHEST VALUE IS CHECKED IF IT MAKES THE CRITERIAN OF EYE CLSE........
YES
A


A
CHECK NEXT
500 SAMPLES FOR
EYE OPEN
YES
EYE BLINK
NO
EYE CLOSE
SEND AN INTERRUPT TO HARDWARE VIA COMP PORT
FOR FURTHER ACTION
SEND AN INTERRUPT TO HARDWARE VIA COMP PORT FOR FURTHER ACTION


B
CHECKING FOR THRESHOLD VALUE
WHILE THE SLOPE IS DECLINING AND
STORES THE LOWEST VALUE .
AFTER REACHING BASE LINE CHECKS
IF LOWEST VALUE MUST THE CRITERION OF EYE
OPEN..............
NO
C
YES
EYE OPEN
SEND AN INTERRUPT SIGNAL TO HARDWARE
VIA COM PORT FOR FURTHER ACTION ....

The source code for the on line analysis is as follows:

```
Private Type Valuetype
    a As String * 5
End Type

Dim buffer As Valuetype

Dim str As String

Dim CurrentNo As Integer

Dim HighestNo As Integer

Dim LowestNo As Integer

Dim TempCntr As Long

Dim Trend As String * 1

Dim cntr As Long

Dim fileNum As Integer

Dim SenstivityFactor As Long

Dim SenstivityFactorVaraition As Long

Dim EyeOpenAt As Long, EyeCloseAt As Long, EyeBlinkAt As Long


Private Sub cmbPort_Click()
On Error GoTo Err_handler

    If MSComm1.PortOpen = True Then MSComm1.PortOpen = False
        MSComm1.CommPort = cmbPort.ListIndex + 1
        MSComm1.PortOpen = True


'error handler
Exit Sub
Err_handler:
If Err.Number <> 0 Then
    'errLogger Err.Number, Err.Description, Me.Caption,
SubroutineName
    Err.Clear
    Resume Next
End If

End Sub

Private Sub Command1_Click()

    SenstivityFactorVaraition = SenstivityFactorVaraition + 100

End Sub

Private Sub Command2_Click()
```

```
    SenstivityFactorVaraition = SenstivityFactorVaraition - 100
End Sub
Private Sub Form_Load()
    fileNum = FreeFile
    HighestNo = 0
    LowestNo = 0
    cntr = 1
    SenstivityFactor = 350
    SenstivityFactorVaraition = 0
    Timer1.Enabled = True
End Sub
Private Sub Timer1_Timer()
On Error Resume Next
eyeopen.Visible = False
eyeclose.Visible = False
eyeblink.Visible = False
shapeeyeblink.Visible = False
shapeeyeopen.Visible = False
shapeeyeclose.Visible = False
Open "c:\testfile1.txt" For Binary As fileNum
    While (EOF(fileNum) = False)
        Get #fileNum, cntr, buffer.a
        cntr = cntr + Len(buffer.a)
        If cntr = EyeCloseAt + 500 Then ''''''''''''''''''
            MSComm1.Output = Chr(&H43)     'Hexadecimal Value for "C"
''''''''''''' 'value for eyeclose
            eyeclose.Visible = True
            eyeblink.Visible = False
            eyeopen.Visible = False
            shapeeyeblink.Visible = False
            shapeeyeopen.Visible = False
```

```
            shapeeyeclose.Visible = True

            form1.Caption = 0

        End If

        If cntr = EyeOpenAt Then     ''''''''''''''''''''

            MSComm1.Output = Chr(&H4F)      'Hexadecimal Value for "B"
''''''''''''' 'value for eyeopen

            eyeopen.Visible = True

            eyeclose.Visible = False

            eyeblink.Visible = False

            shapeeyeblink.Visible = False

            shapeeyeopen.Visible = True

            shapeeyeclose.Visible = False

            form1.Caption = 0
        End If

        If cntr = EyeBlinkAt Then
            MSComm1.Output = Chr(&H42)      'Hexadecimal Value for "B"
''''''''''''' 'value for eyeblink

            eyeblink.Visible = True

            eyeclose.Visible = False

            eyeopen.Visible = False

            shapeeyeblink.Visible = True

            shapeeyeopen.Visible = False

            shapeeyeclose.Visible = False

        End If

        If Trim(buffer.a) = "Test" Then

        Else

            CurrentNo = CInt(buffer.a)    'gets current number

            If CurrentNo > -100 Then     '0

                If Trend = "D" Then UpTrendStartedAt = cntr 'to get
Starting counter of uptrend

                Trend = "U"

                 ' range of eye movement
                If LowestNo < ((150 * -1) -
SenstivityFactorVaraition) Then
                        EyeOpenAt = cntr + 500 '''''''''''''''
```

```
                    form1.Caption = EyeOpenAt - EyeCloseAt

                    If (EyeOpenAt - EyeCloseAt > 100) And
(EyeOpenAt - EyeCloseAt < 800) Then

                        EyeBlinkAt = cntr + 500

                        EyeOpenAt = 0

                        EyeCloseAt = 0

                    End If

                    LowestNo = 0

                End If

                ' to store the highest value in uptrend
                If CurrentNo > HighestNo Then HighestNo = CurrentNo

            ElseIf CurrentNo < 0 Then

                ' to get starting counter of downtrend

                If Trend = "U" Then DownTrendStartedAt = cntr

                Trend = "D"

                If HighestNo > (250 + SenstivityFactorVaraition) Then
'range of eye movement   '350

                    EyeCloseAt = cntr + 500 '''''''''''''''

                    If (EyeCloseAt - EyeOpenAt > 100) And
(EyeCloseAt - EyeOpenAt < 800) Then

                        EyeBlinkAt = cntr + 500

                        EyeOpenAt = 0

                        EyeCloseAt = 0

                    End If

                    HighestNo = 0

                End If

                ' to store the lowest value in downtrend

                If CurrentNo < LowestNo Then LowestNo = CurrentNo

            End If

        End If
        Wend
       Close fileNum

End Sub
```

We have also developed a code for offline analysis:

```
Private Type Valuetype
    a As String * 5
End Type

Dim buffer As Valuetype
Dim str As String, CurrentNo As Integer, HighestNo As Integer,
LowestNo As Integer
Dim UpTrendStartedAt As Long, UpTrendEndedAt As Long,
DownTrendStartedAt As Long, DownTrendEndedAt As Long
Dim TempUpTrendStartedAt As Long, TempCntr As Long, Trend As String *
1, RevCntr As Long, RevCntrflag As Boolean
Dim cntr As Long, Filecntr As Long
Dim fileNum As Integer

Private Sub Form_Load()
fileNum = FreeFile
RevCntr = 600: HighestNo = 0: LowestNo = 0: cntr = 1
End Sub

Private Sub Command1_Click()
On Error Resume Next
eyeopen.Visible = False
eyeclose.Visible = False
eyeblink.Visible = False

Open "c:\testfile1.txt" For Input As fileNum
    While (EOF(fileNum) = False)
        Line Input #fileNum, str
        cntr = cntr + 1
        If RevCntrflag = True Then RevCntr = RevCntr - 1      ' to
check if after eye close eye blink is there or not
        If str = "This is a test. " Then
        Else

            CurrentNo = CInt(str)    'gets current number
            If CurrentNo > 0 Then
                If Trend = "D" Then UpTrendStartedAt = cntr 'to get
Starting counter of uptrend
                Trend = "U"
                If LowestNo < -350 Then ' range of eye movement '-
350
                    If RevCntrflag = True And (cntr - TempCntr) < 500
Then    'check if eye open is there or eye blink is there
                        MsgBox "Eye Blink started at " &
TempUpTrendStartedAt & " till " & cntr & " diff " & cntr -
TempUpTrendStartedAt
                        'eyeblink.Visible = True
                        RevCntrflag = False ' to reset this flag so
that we have taken eye closed movement into eye blink movement
                    Else
                        MsgBox "Eye Open started at " &
DownTrendStartedAt & " till " & cntr & " diff " & cntr -
DownTrendStartedAt ' eye open message
                        'eyeopen.Visible = True
                    End If
                    LowestNo = 0
                End If
```

```
                If CurrentNo > HighestNo Then HighestNo = CurrentNo '
to store the highest value in uptrend
            ElseIf CurrentNo < 0 Then
                If Trend = "U" Then DownTrendStartedAt = cntr   ' to
get starting counter of downtrend
                Trend = "D"
                If HighestNo > 350 Then 'range of eye movement   '350
                    'MsgBox    "Eye    Close    started    at    "    &
UpTrendStartedAt  &  "  till  "  &  cntr  &  "  diff  "  &  cntr  -
UpTrendStartedAt
                    TempUpTrendStartedAt  =  UpTrendStartedAt  '  save
the value of eye close to check that immidiately _
                                                              after
this eye open is there or not. if yes then count _
                                                              this  as
eye blink else eye closed after 600 sample
                    TempCntr = cntr
                    RevCntr = 600
                    RevCntrflag = True
                    HighestNo = 0
                End If
                If CurrentNo < LowestNo Then LowestNo = CurrentNo
            End If
            If RevCntr = 0 And RevCntrflag = True Then
                    MsgBox    "Eye    Close    started    at    "    &
TempUpTrendStartedAt & " till " & TempCntr & " diff " & TempCntr -
TempUpTrendStartedAt
                    'eyeclose.Visible = True
                    RevCntrflag = False
            End If

        End If
    Wend
    Close fileNum
End Sub
```

CHAPTER 5
RESULTS AND DISCUSSIONS

Many factors determine the performance of a BCI system. These factors include the brain signals measured, the signal processing methods that extract signal features, the algorithms that translate these features into device commands, the output devices that execute these commands, the feedback provided to the user and the characteristics of the user. The parameters of the features extracted vary from individual to individual so it is important to develop the generalized BCI.

While studying the variations in the EEG patterns due to various stimuli, it is found that there is variation in waveforms of the electrodes Cz-A1, Cz-A2 due to the changes in the intensity, frequency and location of the click i.e. auditory stimuli. The frequency of clicks is varied from 1click per second to 10, 20 clicks per second and responses are noted. The intensity is varied from 30 to 90 dB nHL (Normal Hearing Level) and responses are recorded. Also the location is changed from left ear to right ear and the response is recorded. These changes are far more difficult to be used for the development of BCI as the sampling frequency of our EEG machine is 256. For AEPs to be reconstructed we need a much higher sampling frequency.

The changes in the EEG due to eye motion are detected from the waveforms originating at FP2-F4, FP1-F3. The amount of change in the amplitude during eye open, eye close vary from subject to subject, location of electrodes on the forehead, intensity of light in the room where EEG is being is performed, physiological state of the patient and contact impedance of the electrodes on the scalp. The wave can be reconstructed and hence can be used for further control action in the development of BCI. For observing the changes in the EEG due to eye, we took around thirty cases and saw the results.

The first problem is to correctly place electrodes on the scalp. As the diameter and area of the scalp varies from subject to subject, it is very difficult to place the electrodes in the correct position for every individual. Also sometime problem of electrode popping comes, which leads to an error. Sometimes, an error comes due to sweating and that also increases the contact impedance between the electrode and skin. For a correct recording of EEG, the impedance of the contact should be less than 5K.

We found that, the production of changes due to eye events is not same for all the cases. For some person the amplitude change, for some latency is more. To remove this problem we used an sensitivity factor .The function of the sensitivity factor is to vary the threshold values for the eye events. Normally, it is observed if we keep the factor at 250 on positive side and –125 on negative side the detection is almost clear. In some cases we have to increase sensitivity. A factor of 100 is provided. If we increase the sensitivity the factor on positive side now goes to 250 and on negative side it goes to –225. Similarly we can further increase or decrease the sensitivity factor depending on the patient's context.

Another problem was the mental state of the subject. If the person is mentally disturbed we get some different amplitude changes in the rhythms. Also the changes depend on whether person is sitting or is lying on the bed. Normally the response for alpha wave is better if person is relaxed and is lying on the bed.

The response is also dependent on the conditions of the room. If a room is not having a dazzling light the EEG recording is more perfect.

There comes an error in the EEG recording if there is generation of spike due to switching ON and OFF of other devices present in the lab. For the removal of these artifacts we used a notch filter for removing the frequency interferences of 50 Hz.

Also the changes are detected inn the EEG records if a person is moving in the environment near to the place where EEG recording is taking place. To detect an event correctly, we should have clear environment near the place of EEG recording.

For detecting an event and generating a control action, we used a selector button for the COM port i.e. when event is to be send to the hardware unit for further control action we have an choice for the selection for the port.

If we wish to take EEG recordings for a longer time, the present hardware needs to be modified. We need to have electrode cap which can we worn on the head and the problem of electrode buckling is removed.

CHAPTER 6
CONCLUSIONS AND FUTURE SCOPE

The key is to take BCI technology beyond the demonstration stage to the real world applications, so that the quality of life for paralyzed patients is improved. We detected the changes in the EEG patterns due to Auditory and Visual Stimulus. To use these changes for the development of BCI, we need generalized software for parameter extraction, offline feature extraction, Pattern recognition & classification as well as generation of neuro feedback for a successful training of the user.

We also need an improvement in the hardware i.e. 32 channel machine is needed. Also the sampling frequency of the online text file generated should be much more than 256 so that waveform can be properly reconstructed that contains changes due to auditory and visual stimulus.

The following questions are to be answered before an effective real time generalized BCI can be developed:

- What existing Brain Computer interaction paradigms are most adaptable for brain computer interface? Are there more new paradigms that are even more effective?
- How can we compare the performances of different BCI systems for use with real world applications? Can we develop applications?
- How do we assess the usability of a BCI? What factors affect usability?

We need to do a significant progress on these questions in the coming years.

REFERENCES

1. Gerwin Schalk, Dennis j. Mcfarland, Thilo Hinterberger, Niels Birbaumer and Jonathan R. Wolpaw "BCI2000- A General purpose Brain Computer Interface(BCI) System" *IEEE transactions on Biomedical Engineering*, Vol.51,No.6 , June 2004.
2. Thilo Hinterberger, Gerold Brier,Jurgen Mellinger,Niels Birbaumar "Auditory feedback of human EEG for direct Brain-computer interface", *Proceedings of ICAD 04-tenth Meeting of the International Conference on Auditory Display, Sydney, Australia*, July 6-9, 2004.
3. Lucas c parra, Clay D. Spence, Adam D. Gerson and Paul Sadja- "Response Error correction-a Demonstration of improved Human Machine performance using Real time EEG monitoring", *IEEE transactions on neural systems and rehabilitation engineering,* Vol11, No.2, June 2003
4. Michael j. black, Mijail Serruya, Eleie Bienenstock, Yun Gao, Wei Wu and John P Donoghue-"Connecting brain with machines: The Neural Control of 2D movement", *IEEE transactions on neural systems and rehabilitation engineering,* Vol8, No.2, June 2000
5. M. Krauledat, G.Dornhege, B.Blankertz, G.Curio, KR Muller.- The Berlin Brain-Computer Interface for rapid response, *Science Direct*
6. Laucer.R, Peckham.P, Kilgore.K,-"Applications of cortical signals to Neuroprosthetic control: A Critical Review.", *IEEE transactions on neural systems and rehabilitation engineering,* Vol8, No.2, 205-208, June 2000.
7. Mason SG, Birch GE:-"A General Framework for Brain-computer Interface design.", *IEEE transactions on on neural systems and rehabilitation engineering,* Vol 11, No.1, March 2003.
8. Mason SG, Birch GE:-"A Brain controlled switch for asynchronous control applications", *IEEE transactions on on neural systems and rehabilitation engineering,* Vol 47, No.10, October 2000.
9. Moore Melody M: - "Real world applications for Brain interface Technology", *IEEE transactions on on neural systems and rehabilitation engineering,* Vol 11, No.2, June 2003.

10. Andera Kubler, Nicola Neumann, Jochen Kaiser, Thilo Hinterberger:- "Brain Computer Interaction-Self Regulation of slow Cortical potentials for Verbal Communication", *Arch Phys Med Rehabil,* Vol 82, November 2001.

11. Middendorf Matthew, McMillan grant, Jones Keith S:-"Brain Computer interface based on the Steady State Visual Evoked Response", *IEEE transactions on on neural systems and rehabilitation engineering,* Vol 8, No.2, June 2000.

12. "Special issues on Brain –Computer interfaces", *IEEE transactions on neural systems and rehabilitation engineering,* Vol 8, pp 1-270, June 2000.

13. ZA Keirn, JI Aunon :-" Anew mode of communications between man and its surroundings:, *IEEE Trans. Biomed. Engg.,* Vol 37, pp.1209-1214, Dec 1990.

14. JR Wolpaw, D. McFarland, GW Neat and CA Forneris," An EEG based Brain Computer Interface for cursor control," *Electroencephalogram Clin. Neurophysiol.* , Vol 70 , pp710-523, 1991.

15. EE Sutter," The Brain response interface: communication through visually induced electrical brain responses,",*J. Microcomputer App.,* Vol 15, pp 31-45,1992.

16. A. Kostov and M. Polak," Parallel man – machine training in development of EEG based cursor control," *IEEE transactions on neural systems and rehabilitation engineering,* Vol 8 , pp 203-205, June 2000.

17. JR Wolpaw, D. McFarland, TM Vauughan, "Brain computer interface research at wadsworth center ," *IEEE transactions on neural systems and rehabilitation engineering,* Vol 8 , pp 220-226, June 2000.

18. N. Birbaumer, A Kubler , N Ghanayim, Thilo Hinterberger "The thought translation device(TTD) for completely paralyzed patients", *IEEE transactions on neural systems and rehabilitation engineering,* Vol 8 , pp 190-193, June 2000.

19. Mason SG, Birch GE:-"Brain Computer interface research at the neil square foundation", *IEEE transactions on neural systems and rehabilitation engineering,* Vol 8, June 2000.

20. Vaughan T M, Wolpaw J R, Donchin E:-"EEG- based communication; Prospects and Problems," *IEEE transactions on neural systems and rehabilitation engineering,* Vol 4, pp.425-430,June 2000.

21. Brain View , EEG recording machine, Recorders & Medicare systems Ltd. , 181/5 Industrial area , Phase 1 , Chandigarh 160002

22. S. Makeig, "Event related dynamics of the EEG spectrum and effects of exposure to tones,"*Electroencephalogr. Clin. Neurophysiol.,*Vol 86, pp 283-293, 1993.

APPENDIX

APPENDIX A

DATA SHEETS OF AT89S52 (MICROCONTROLLER) AND MAX 232

AT89S52

Features

- **Compatible with MCS-51® Products**
- **8K Bytes of In-System Programmable (ISP) Flash Memory**

– Endurance: 1000 Write/Erase Cycles

- **4.0V to 5.5V Operating Range**
- **Fully Static Operation: 0 Hz to 33 MHz**
- **Three-level Program Memory Lock**
- **256 x 8-bit Internal RAM**
- **32 Programmable I/O Lines**
- **Three 16-bit Timer/Counters**
- **Eight Interrupt Sources**
- **Full Duplex UART Serial Channel**
- **Low-power Idle and Power-down Modes**
- **Interrupt Recovery from Power-down Mode**
- **Watchdog Timer**
- **Dual Data Pointer**
- **Power-off Flag**
- **Fast Programming Time**
- **Flexible ISP Programming (Byte and Page Mode)**

Description

The AT89S52 is a low-power, high-performance CMOS 8-bit microcontroller with 8K bytes of in-system programmable Flash memory. The device is manufactured using Atmel's high-density nonvolatile memory technology and is compatible with the industry- standard 80C51 instruction set and pinout. The on-chip Flash allows the program memory to be reprogrammed in-system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with in-system programmable Flash on a monolithic chip, the Atmel AT89S52 is a powerful microcontroller which provides ahighly-flexible and cost-effective solution to many embedded control applications. The AT89S52 provides the following standard features: 8K bytes of Flash, 256 bytes of RAM, 32 I/O lines, Watchdog timer, two data pointers, three 16-bit timer/counters, a six-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry. In addition, the AT89S52 is designed with static logic for operation down to zero frequency and supports two software selectable power saving modes. The Idle Mode stops the CPU while allowing the RAM, timer/counters, serial port, and interrupt system to continue functioning. The Power-down mode saves the RAM contents but freezes the oscillator, disabling all other chip functions until the next interrupt or hardware reset.

Pin Description

VCC

Supply voltage.

GND

Ground.

Port 0

Port 0 is an 8-bit open drain bidirectional I/O port. As an output port, each pin can sink eight TTL inputs. When 1s are written to port 0 pins, the pins can be used as high-impedance inputs.

Port 0 can also be configured to be the multiplexed low-order address/data bus during accesses to external program and data memory. In this mode, P0 has internal pull-ups.

Port 0 also receives the code bytes during Flash programming and outputs the code bytes during program verification. **External pull-ups are required during program verification.**

Port 1

Port 1 is an 8-bit bidirectional I/O port with internal pull-ups. The Port 1 output buffers can sink/source four TTL inputs. When 1s are written to Port 1 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 1 pins that are externally being pulled low will source current (I_{IL}) because of the internal pull-ups.

In addition, P1.0 and P1.1 can be configured to be the timer/counter 2 external count input (P1.0/T2) and the timer/counter 2 trigger input (P1.1/T2EX), respectively, as shown in the following table.

Port 1 also receives the low-order address bytes during Flash programming and verification.

Port Pin	Alternate Functions
P1.0	T2 (external count input to Timer/Counter 2), clock-out
P1.1	T2EX (Timer/Counter 2 capture/reload trigger and direction control)
P1.5	MOSI (used for In-System Programming)
P1.6	MISO (used for In-System Programming)
P1.7	SCK (used for In-System Programming)

Port 2

Port 2 is an 8-bit bidirectional I/O port with internal pull-ups. The Port 2 output buffers can sink/source four TTL inputs. When 1s are written to Port 2 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 2 pins that are externally being pulled low will source current (I_{IL}) because of the internal pull-ups.

Port 2 emits the high-order address byte during fetches from external program memory and during accesses to external data memory that use 16-bit addresses (MOVX @ DPTR). In this application, Port 2 uses strong internal pull-ups when emitting 1s. During accesses to external data memory that use 8-bit addresses (MOVX @ RI), Port 2 emits the contents of the P2 Special Function Register.

Port 2 also receives the high-order address bits and some control signals during Flash programming and verification.

Port 3

Port 3 is an 8-bit bidirectional I/O port with internal pull-ups. The Port 3 output buffers can sink/source four TTL inputs. When 1s are written to Port 3 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 3 pins that are externally being pulled low will source current (I_{IL}) because of the pull-ups.

Port 3 receives some control signals for Flash programming and verification.

Port 3 also serves the functions of various special features of the AT89S52, as shown in the following table.

Port Pin	Alternate Functions
P3.0	RXD (serial input port)
P3.1	TXD (serial output port)
P3.2	$\overline{INT0}$ (external interrupt 0)
P3.3	$\overline{INT1}$ (external interrupt 1)
P3.4	T0 (timer 0 external input)
P3.5	T1 (timer 1 external input)
P3.6	$\overline{WR}$ (external data memory write strobe)
P3.7	$\overline{RD}$ (external data memory read strobe)

RST

Reset input. A high on this pin for two machine cycles while the oscillator is running resets the device. This pin drives high for 98 oscillator periods after the Watchdog times out. The DISRTO bit in SFR AUXR (address 8EH) can be used to disable this feature. In the default state of bit DISRTO, the RESET HIGH out feature is enabled.

ALE/$\overline{PROG}$

Address Latch Enable (ALE) is an output pulse for latching the low byte of the address during accesses to external memory. This pin is also the program pulse input ($\overline{PROG}$) during Flash programming.

In normal operation, ALE is emitted at a constant rate of 1/6 the oscillator frequency and may be used for external timing or clocking purposes. Note, however, that one ALE pulse is skipped during each access to external data memory.

If desired, ALE operation can be disabled by setting bit 0 of SFR location 8EH. With the bit set, ALE is active only during a MOVX or MOVC instruction. Otherwise, the pin is weakly pulled high. Setting the ALE-disable bit has no effect if the microcontroller is in external execution mode.

$\overline{PSEN}$

Program Store Enable ($\overline{PSEN}$) is the read strobe to external program memory.

When the AT89S52 is executing code from external program memory, $\overline{PSEN}$ is activated twice each machine cycle, except that two $\overline{PSEN}$ activations are skipped during each access to external data memory.

$\overline{EA}$/VPP

External Access Enable. $\overline{EA}$ must be strapped to GND in order to enable the device to fetch code from external program memory locations starting at 0000H up to FFFFH. Note, however, that if lock bit 1 is programmed, $\overline{EA}$ will be internally latched on reset.

$\overline{EA}$ should be strapped to V_{CC} for internal program executions.

This pin also receives the 12-volt programming enable voltage (V_{PP}) during Flash programming.

XTAL1

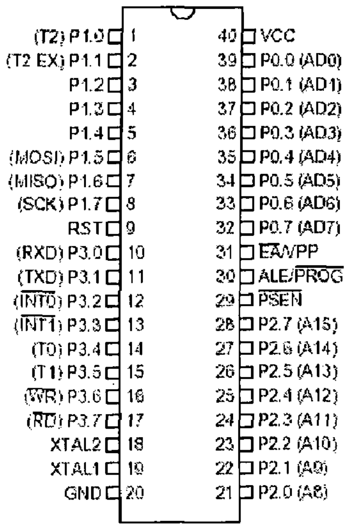
Input to the inverting oscillator amplifier and input to the internal clock operating circuit.

XTAL2

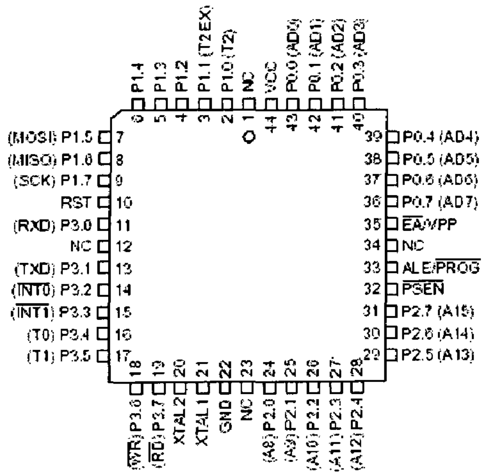
Output from the inverting oscillator amplifier.

Pin Configurations

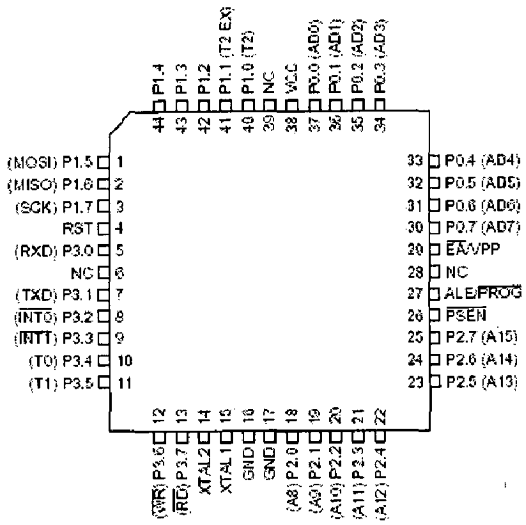
PDIP



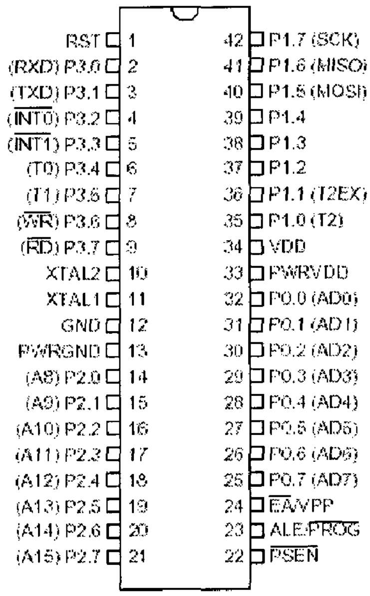
PLCC



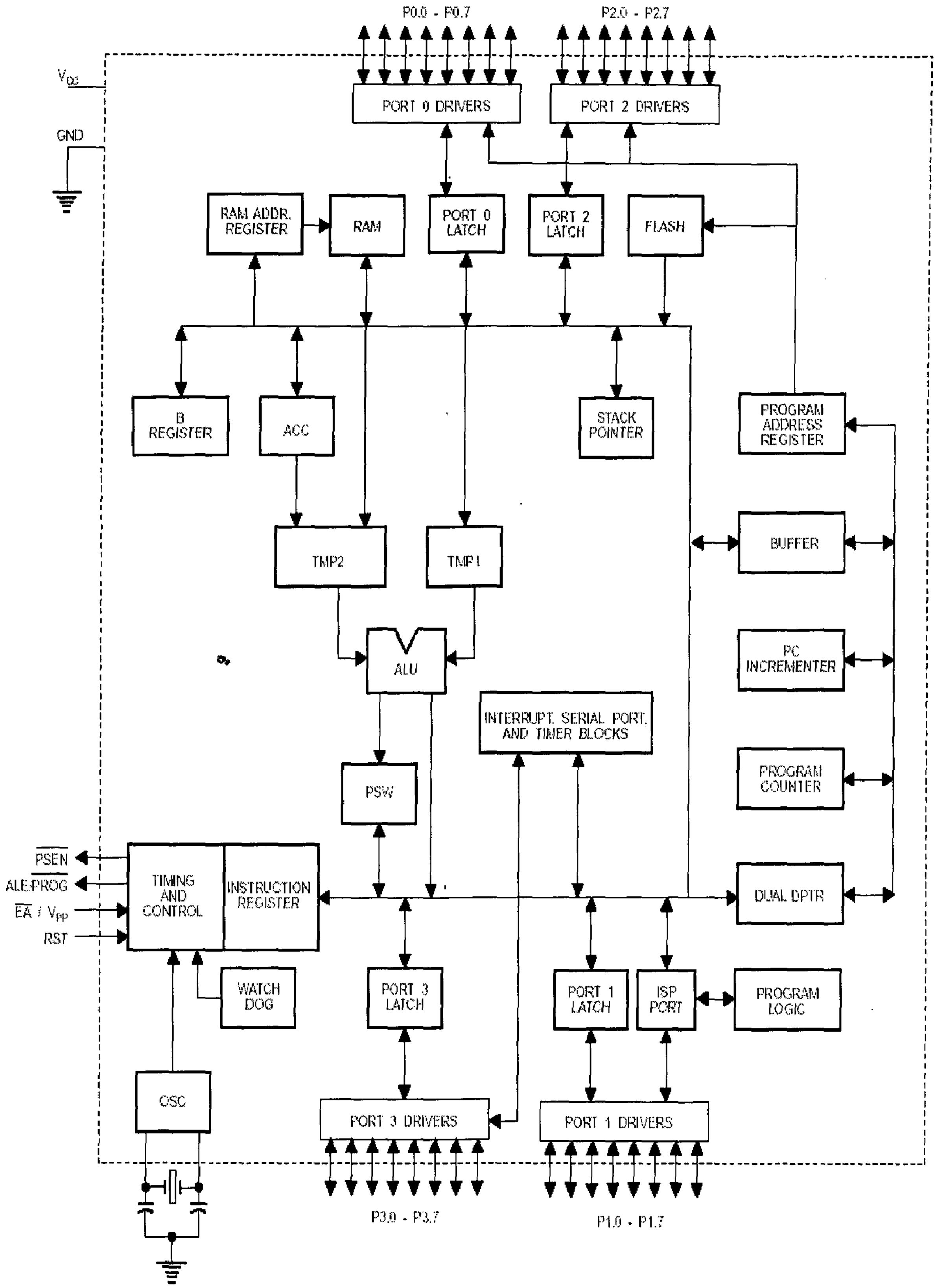
TQFP



PDIP



Block Diagram



ELECTRICAL CHARACTERISTICS—MAX220/222/232A/233A/242/243

(V_{CC} = +5V ±10%, C1–C4 = 0.1µF, MAX220, C1 = 0.047µF, C2–C4 = 0.33µF, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
RS-232 TRANSMITTERS					
Output Voltage Swing	*All transmitter outputs loaded with 3kΩ to GND*	±5	±9		V
Input Logic Threshold Low			1.4	0.8	V
Input Logic Threshold High	All devices except MAX220	2	1.4		V
	MAX220: V_{CC} = 5.0V	2.4			
Logic Pull-Up/Input Current	*All except MAX220, normal operation*		5	40	µA
	$\overline{SHDN}$ = 0V, MAX222/242, shutdown, MAX220		±0.01	±1	
Output Leakage Current	V_{CC} = 5.5V, $\overline{SHDN}$ = 0V, V_{OUT} = ±15V, MAX222/242		±0.01	±10	µA
	V_{CC} = $\overline{SHDN}$ = 0V, V_{OUT} = ±15V		±0.01	±10	
Data Rate			200	116	kb/s
Transmitter Output Resistance	V_{CC} = V+ = V- = 0V, V_{OUT} = ±2V	300	10M		Ω
Output Short-Circuit Current	V_{OUT} = 0V	±7	±22		mA
RS-232 RECEIVERS					
RS-232 Input Voltage Operating Range				±30	V
RS-232 Input Threshold Low	V_{CC} = 5V, All except MAX243 $R2_{IN}$	0.8	1.3		V
	V_{CC} = 5V, MAX243 $R2_{IN}$ (Note 2)	-3			
RS-232 Input Threshold High	V_{CC} = 5V, All except MAX243 $R2_{IN}$		1.8	2.4	V
	V_{CC} = 5V, MAX243 $R2_{IN}$ (Note 2)		-0.5	-0.1	
RS-232 Input Hysteresis	All except MAX243, V_{CC} = 5V, no hysteresis in shdn.	0.2	0.5	1	V
	MAX243		1		
RS-232 Input Resistance		3	5	7	kΩ
TTL/CMOS Output Voltage Low	I_{OUT} = 3.2mA		0.2	0.4	V
TTL/CMOS Output Voltage High	I_{OUT} = -1.0mA	3.5	V_{CC} - 0.2		V
TTL/CMOS Output Short-Circuit Current	Sourcing V_{OUT} = GND	-2	-10		mA
	Shrinking V_{OUT} = V_{CC}	10	30		