CHAPTER 1

INTRODUCTION

The research work reported in this thesis is on the study of the bio-feedback of electroencephalogram (EEG) on humans. Earlier reports by many research workers have shown therapeutic effect of such feedback. They have used the alpha signal for treatment of depression related clinical disorders. In doing so, the effect of the full band of alpha signal and also the effect of spot frequencies of alpha signal have been investigated. As a new approach this thesis deals with a different kind of alpha bio-feedback namely split band alpha bio-feedback. In this, experimental studies have been conducted on human subjects using the various spilt bands of the alpha signal to study the feedback effect on the EEG, which is an index of the therapeutic value of the feedback. Comparative studies and measurement have been made to quantify the relative merits of split band alpha bio-feedback with those of the full band and spot frequency bio-feedback. It turns out that the effect of split band bio-feedback is more pronounced than the others, although the research was aimed only to study the split band alpha bio-feedback as yet another type of alpha bio-feedback.

This thesis is organized in the following manner. The first chapter deals with certain introductory topics on bio-feedback. The second chapter deals with the optimization of scalp electrode position for strong EEG signal pickup based on experimental studies conducted by this author. The next chapter three reports the results of bio-feedback studies with split band alpha signal and the inference there on. Chapter four explores the effect of phase shift in such bio-feedback experiments. This is followed by chapter 5 wherein an attempt is made to formulate a control system approach based
model for bio-feedback system. The concluding chapter six reviews the results of experimental studies and suggests future areas for further research.

1.1 PHYSIOLOGICAL SIGNALS

Human physiological signals play a significant role both in diagnostic and therapeutic procedures adopted in human health care. The field of medical electronics deals with biomedical instruments and equipment capable of monitoring and processing such human physiological signals, also known as biomedical signals.

The following is a list of such biomedical signals, with their frequency range and major diagnostic range shown in bracket.

**Electroencephalogram (EEG)**

- Frequency range: dc-100 Hz (0.5 - 60 Hz)
- Signal range: 15 - 100 μV.

**Electromyogram (EMG)**

- Frequency range: 10 - 200 Hz
- Signal range: function of muscle activity and electrode placement.

**Electrocardiogram (ECG)**

- Frequency range: 0.05 - 100 Hz
- Signal range: 10 μV (fetal), 5 mv (adult)
Heart rate

Frequency range : 45 - 200 beats/min

Blood pressure

Frequency range : dc - 200 Hz (dc-60 Hz)
Signal range : 40-300 mm Hg (arterial), 0-15 mm Hg (Venous)

Breathing rate

Frequency range : 12-40 breaths/min.

1.2 EEG AND ITS ELECTRODES

The brain is a major center for measuring physiological signal stimuli, for recording physical disorders and for observing a wide range of physical events. The brain function could be controlled by using bio-feedback signals also. The Electroencephalogram (EEG) is a record of the summated neuronal electrical activity of the brain. It is a collaborative tool in diagnosing brain function and diseases. With suitable bio-feedback it could also modify the brain activity. The EEG signals are a measure of the brain potentials which can be recorded by electrodes placed on the scalp. Only the following four major types of electrical waves produced by the brain and recorded by EEG are considered significant.

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency in Hz</th>
<th>Amplitude in µV</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta (Δ)</td>
<td>1 - 4</td>
<td>10</td>
<td>Sleep, Brain disease</td>
</tr>
<tr>
<td>Theta (θ)</td>
<td>4 - 8</td>
<td>20-40</td>
<td>Stress/Frustration</td>
</tr>
<tr>
<td>Alpha (α)</td>
<td>8 - 12</td>
<td>30 - 50</td>
<td>Awake, Resting</td>
</tr>
<tr>
<td>Beta (β)</td>
<td>12 - 50</td>
<td>5</td>
<td>Stress/Tension</td>
</tr>
</tbody>
</table>
The alpha (α) waves vary considerably from eyes open to eyes closed condition of the subject. This makes the alpha waves ideal for biofeedback signals application on the subject for the treatment of stress related illness. The bio-feedback method emphasizes the patient’s ability to guide the course of his/her own treatment. Successful bio-feedback training teaches the patient to recognize and control variety of physiological indices.

Among the alpha, beta, theta and delta waves, the alpha waves are more important indicating relaxation, rest and alertness, whereas a theta wave indicates tension, frustration and stress. Emphasis is usually placed on increasing the amplitude of alpha wave to theta wave. EEG recordings are usually taken from several sites on cortex. Fig. 1.1 shows some typical sites for making such records. Multichannel records are used so that events in several locations can be studied simultaneously. A typical recording of normal EEG with filtered voltages is shown in Fig. 1.2.

Before seeing more details of the EEG signal and its components, we shall now have a look at the EEG electrodes and the formation of EEG channel inputs.

1.2.1 EEG Electrodes

EEG electrodes transform ionic currents from cerebral tissues into electrical currents used in EEG preamplifiers. The electrical characteristics are primarily determined by the type of metal used to form electrodes. In electrode disc silver-silver chloride is commonly used.

Typically there are five types of electrodes used to pick up EEG signal.
Figure 1.1 Some Typical EEG Recording Sites
1. Frontal - parietal
2. Parietal - occipital
3. Left occipital - Right occipital
4. Result from eye movement
5. Filtered theta wave
6. Filtered alpha wave
7. Filtered beta wave

Figure 1.2 Typical Record of EEG and its Components
1. Scalp electrodes - silver pads/discs/cups, stainless steel rods and chlorided silver wires.

2. Sphenoidal electrodes - alternating insulated silver and bare wire and chlorided tip inserted through muscle tissue by a needle.

3. Nasopharyngeal electrodes - silver rod with silver ball at the tip inserted through the nostrils.

4. Electrocorticographic electrodes - cotton wicks soaked with saline solution that rest on the brain surface (removes artifacts generated in the cerebrum by each heart beat).

5. Intracerebral electrodes - sheaves of Teflon coated gold or platinum wires cut at various distance from the sheaf tip used to electrically stimulate brain.

In most clinics, reusable scalp discs or cup electrodes are placed on the head using a conductive cream (similar consistency to body fluids/electrolytes). Before EEG electrodes are placed, the area is first cleaned with alcohol or acetone to remove skin oils. Using conductive paste the contact resistance is lowered below 10 KΩ. This ensures good recording of EEG. To be sure that the contact resistance is less than 10 KΩ, the resistance is measured between electrodes using an ac ohmmeter, since ac signal between electrodes avoids polarization.

The amplitude, phase and frequency of EEG signal depends on the electrode placement. The placement of electrode is based on the frontal (F), parietal (P), temporal (T) and occipital cranial areas as already shown in Fig.1.1.
Fig. 1.3a EEG Recording Mode - Unipolar

*only four channel of a multichannel recording system shown
Chart paper movement

Fig. 1.3.b EEG Recording Mode - Average

* Only four channels of a multi channel recording system shown
Chart paper movement

* Only four channels of a multi channel recording system shown

Fig.1.3.c EEG Recording Mode - Bipolar
1.2.2 Electrode Arrangement

One of the most popular schemes is the 10-20 EEG electrode placement system established by the International Federation of EEG Societies. In this setup, the head is mapped by four standard points: The nasion (nose), the inion (external occipital protuberance or projections) and the left and right preauricular points (ears). 19 electrodes are used on the scalp and an additional electrode is used for grounding the subject.

Electrode arrangement may be either unipolar or bipolar. An unipolar arrangement is shown in Fig.1.3.a. It is composed of a number of scalp electrodes and a reference electrode connected to a common indifference point such as an ear lobe. This reference electrode is common to all channels and is also the ground electrode. A variation of the unipolar mode uses a summing resister circuit as shown in Fig.1.3.b. In bipolar arrangement as shown in Fig.1.3.c any 2 electrodes form a channel input and the ear lobe electrode is used as ground.

1.3 EEG AMPLITUDE AND FREQUENCY BANDS

EEG signal voltage amplitudes range from about 1 μV to 100 μV peak to peak of low frequencies (0.5 Hz - 100 Hz) at the cranial surface. At the surface of cerebrum, signal may be 10 times larger. Since cranial surface signal is weak, it requires input preamplifier with high gain and internal/external noise rejection.

The rhythmic activity of the brain is characterized by its frequency. The harmonic composition of EEG is usually complex. As indicated earlier, the EEG has delta, theta, alpha and beta wave components.

The alpha frequency range is between 8 and 12 Hz. Brain activity that has this frequency is distributed over posterior regions of the head.
during wakefulness and is attenuated by visual and other sensory stimuli. Since this thesis mainly deals with alpha signal, more details will be found in the subsequent chapters. Alpha activity is around 50 µV peak to peak. This signal arises from the posterior brain in an alert person with eyes closed. Opening the eyes and focusing attention greatly reduces alpha waves.

Mu (µ) rhythm is a brain activity with a frequency at the upper end of the alpha range and found in the central regions of one or both sides of the brain. It is unresponsive to eye opening but is attenuated by contralateral movement or even the thought of movement.

Beta has a frequency above 12 Hz and amplitude less than 20 µV peak to peak. This signal arises over the entire brain but is most predominant over the central region, at rest. Beta is often divided in to $\beta_1$ (13-20 Hz) and $\beta_2$ (20-50 Hz) bands. Signal above 50 Hz, if any, is termed as Gamma (γ). Scalp recorded potentials above 20 Hz arise either from brain activity or from muscle action potentials. Their origin remains ambiguous. Beta signal can resemble an alpha or Mu rhythm in its distribution and responsiveness and hence it is regarded as a variant of these rhythms.

Theta (θ) signal has a frequency between 4 and 7 Hz, while delta signal (δ) has a frequency between 0.5 and 4 Hz. These signals are strongest over the central region and are indication of sleep. In healthy and alert young adult such slow activity is generally absent. These signals appear during certain stages of sleep or during hyperventilation. Diffuse theta and slower activities are however commonly encountered shortly after a generalized seizure, as well as in patients with metabolic disorders.

The EEG is composed of transient discharges as well as background rhythms. A spike discharge is arbitrarily defined as a potential with a sharpened outline and duration of less than 80 ms, while a sharp
wave has a duration of between 80 and 200 ms. Spike or sharp wave discharges are commonly found in the EEG's of patients with epilepsy, but not all sharp transients are pathologically relevant. Indications that may be significant include an asymmetrical configuration, associated slow wave, and duration that differs from ongoing background activity.

The normal EEG pattern is altered during natural sleep. With increasing drowsiness (stage 1 sleep), the alpha rhythm becomes attenuated so that low voltage-fast activity seems more conspicuous. During light sleep (stage 2) theta activity increases and vertex sharp waves occur either spontaneously or with sensory stimulations. High voltage biphasic slow waves (K complexes) may also occur spontaneously or after sensory stimulation at this stage and are often associated with centrally predominant 12 to 14 Hz spindles. Positive occipital sharp transients that occur either singly or repetitively are also sometimes found during light sleep. As the depth of sleep increases, the EEG slows until 60% (stage 3) or more (stage 4) of the record consists of irregular activity having a frequency of 2 Hz or less. This deep sleep alternates with periods of rapid eye movement (REM) sleep. In REM sleep the EEG resembles that of stage 1 sleep.

1.4 ARTIFACT

Both physiological and instrumental artifact can contaminate the scalp recorded EEG, including those originating from such diverse sources as the subject eye or head movement, heart beats or poor electrode contacts. Indication of such artifact in normal EEG polygraph tracings include fuzziness or thickness of trace, sudden change in voltage or repetitive sharp or sawtooth wave form. The different types of artifacts and their sources are listed below.
1. Artifact due to electrode problems may result from
   a. Improper positioning
   b. Poor contact
   c. Poor electrode in the cap holding them
   d. Dried out gel
   e. Oozing of tissue fluids in needle electrodes
   f. Frayed connections
   g. Sweating.

2. Artifact due to physiological interference may result from
   a. The heart ECG
   b. Tongue and facial movement
   c. Eye movement
   d. Skeletal muscle movement
   e. High scalp impedance
   f. Breathing

3. Artifacts due to electrical interference may result from
   a. 50 Hz common mode interference
   b. Radio frequency interference due to use of an electrical surgical unit
   c. Defibrillators
   d. Presence of pacemakers and neural stimulators.

1.5 BIO-FEEDBACK

Bio-feedback is a term associated with a new kind of therapeutic procedure wherein a patient's physiological parameters are utilized to control his/her physiological functions and hence certain pathologies. Bio-
feedback is one of the products of rapid development of medical instrumentation. Bio-feedback is equally the product of conceptual shift in understanding of what can be learnt, once the circumstance are provided for learning to occur. In this technique, variables like temperature, ECG, EEG, EMG are displayed to the subject through proper instrumentation and the subject is made to control these parameters through volitional (voluntary) or non-volitional (involuntary) process.

1.5.1 Volitional Bio-feedback

This type of feedback is one in which the subject is consciously trying to control his/her physiological parameters. These parameters, namely EMG and EEG are picked up and transduced into electrical variables and then displayed to the subject. He/She tries to alter it by his/her conscious will which in turn controls the physiological functions and hence certain pathologies.

The following biological variables have been the subjects for study of volitional bio-feedback therapy.

1. Electromyogram (EMG)
2. Electroencephalogram (EEG)
3. Electrocardiogram (ECG)
4. Skin temperature
5. Galvanic skin resistance (GSR)

Since this thesis is on EEG bio-feedback, some of the earlier work on this topic discussed will be reviewed in the following section.
Fig. 14. BIO- FEEDBACK INSTRUMENTATION SETUP
Electroencephalographic (EEG) Bio-feedback

The block schematic of EEG volitional bio-feedback system is shown in Fig. 1.4. This is used to enhance the alpha level of EEG, since the production of large amplitude of alpha wave is associated with relaxed mental state [Brown (1970), Green (1970), (1971)]. Here the alpha band of EEG is picked up from the scalp leads, processed and displayed to the subject as a feedback signal through proper instrumentation. The feedback signal is presented either as deflection on a meter or as an auditory tone through ear phones with loudness varying directly as a function of amplitude to the subject [Ronald (1975), William (1975) and Travis (1976)]. In a typical case, the subject concentrates on the display meter and tries to keep the deflection at maximum, so as to increase the amplitude of alpha band of EEG resulting in a therapy. This feedback method is powerful in training the autonomic nervous system, because seeing is believing. But this method is not applicable to those patients affected with psychosomatic disorders. They are not in a frame of mind to exercise conscious control to hold their required alpha level for therapy.

The term non-volitional implies that the conscious will of the subject is not utilized in controlling his/her EEG and pathologies during bio-feedback. A mentally depressed person whose mind is in a reduced threshold of awareness (who cannot be involved in volitional feedback) requires the assistance of a therapist in running feedback trials and tracking the response. The studies conducted over the years in EEG feedback on normal subjects and patients affected with epilepsy [Kamath (1975), (1980)] have yielded results and call for a better understanding of feedback procedure and responses for further studies in this field. Hence the present study is directed along these lines to identify the optimum electrode position and also the optimum type of alpha bio-feedback.
In both volitional and non-volitional types of feedback, the subject passes through a process of trial and error (consciously or otherwise) and evolves a complex strategy for augmenting the behaviour of the body. As the patient succeeds, he/she experiences proper receptive and interoceptive sensations and sometimes verbalizes them. These factors contribute in normalizing the patient's psychosomatic abnormalities and in rehabilitating the patient to his/her normal environment. Since this result work is on an experimental study on split band alpha bio-feedback the first step in EEG bio-feedback is the optimization of electrode location for maximum alpha signal pickup from the scalp. This will be dealt with in the next chapter, after the introduction of EEG recording system and a brief review on EEG signals.