A SYSTEM OF EEG TELEMETRY

ELDON A. BYRD
U.S. Naval Ordnance Laboratory
White Oak, Maryland

Summary  A theoretical system for telemetry of the EEG is described, followed by a practical experiment to demonstrate feasibility of brain wave telemetry in the electrically noisy environment of a large university hospital. Equipment designed for the telemetry of the ECG was modified for the purpose. Good signal quality was obtained over a distance of forty feet through two intervening concrete and steel walls. This first step in demonstrating the feasibility of single channel EEG telemetry in a hospital environment is envisioned and described as part of a future total patient monitoring system or as an on-line diagnostic aid for surgery.

Introduction  Several operational and successful automatic ECG analysis systems are in operation throughout the world. An analogous system could be configured for automatic analysis of the EEG, providing the clinician with valuable information concerning patient status.

A review of the current literature in EEG telemetry revealed that most work was concerned with laboratory or field telemetry, but nothing was noted dealing with the practical aspects of EEG telemetry in a hospital environment.

The experimental part of the project consisted of demonstrating the feasibility of EEG telemetry in an electrically noisy environment of a large university hospital intensive care unit.

This was followed by the description of a theoretical overall system for the transmission, reception, automatic analysis, and display of the EEG, on line, in the intensive care unit and Operating Room.

Clinical Usefulness of the EEG  Although there are several definitive brain problems that appear on EEG’s, a shortage of qualified electroencephalographers cause backlogs of recordings. A few of the clinically useful diagnoses from brain wave analysis are listed below:
1. Seizures - The EEG is used to determine the presence of epilepsy and to characterize it in terms of definable patterns.

2. Lesions - Ninety percent of all brain tumors, abcesses, and subdural hematomas make the EEG abnormal. Discrete localization is possible in seventy percent of the cases.


4. Blunt Injury - EEG’s provide a basis for suspecting concussion, contusion, or internal hemorrhage.

5. Coma - The EEG can differentiate unconsciousness due to an organic disease from that due to psychological causes.

6. Blindness - The visual evoked response as displayed on the EEG will distinguish between true blindness and pseudo-blindness.

7. Deafness - The auditory evoked response establishes the true ability to hear.

**Characteristics of the EEG** Variability in EEG signals due to age, bloodchemistry, sex, etc. make them so difficult to analyze that most doctors are reluctant to attempt further definition. A routine EEG of ten minutes duration produces a graphical record 30 feet long and can have a dozen or so channels of information.

Cybernetic systems involving the EEG have been designed and are generally well known, such as those for alpha rhythm feedback conditioning. There is still controversy, however, over the source of alpha rhythms. One school claims they may be involved with occular muscle output, another says they are not. Cohen (1) found that subjects blind since birth have no alpha rhythms.

**EEG Waveform Analysis** EEG waveforms have been analyzed in at least the following ways:

- Time Series (including auto-correlation)
- Auto Spectra
- Cross Correlation
- Auto Covariance
- Cross Covariance
- Power Spectra
- Evoked Responses
Pattern Recognition
Amplitude
Frequency or period

Time Series (auto-correlation) - is used primarily to identify frequency changes of the alpha, theta, delta, etc. rhythms. Campbell (2) claimed that EEG waves were non-gaussian in amplitude using auto-correlation techniques.

Auto Spectra - can be used to identify states of wakefulness and sleep. Tends to separate signal from noise.

Cross Correlation - is useful for analyzing evoked responses. The technique relates outputs to inputs.

Power Spectra - is used to identify the various EEG waveforms (alpha, delta, etc.).

Amplitude - is useful for data compression.

Frequency and Period - is useful for identifying levels of consciousness and drug effects.

Evoked Responses - is used for determining conversion hysteria from functional disorders of the ocular and auditory systems.

Pattern Recognition - is useful for breaking waveforms into groups of frequencies, amplitudes, phases, etc.

Others - such as Fourier Transforms and data compression by integration, have specific uses in special instances.

Criticisms of Techniques: Spectral techniques neglect amplitude information while frequency analyses may destroy phase relationships. Auto correlation and Fourier transforms cannot be used for small samples and non-stationary data.

Computer Program The particular program available for the automatic analysis of the EEG was written for a CDC-160A.

The program was not operational for general use, but it had been used successfully by specialists. Basically, it was a pattern recognition program that had the capability to break waveforms into frequency and amplitude “bins.” Figure 1, below, illustrates the concept:
Values of the data are examined by the computer in order to determine the first encountered maximum value. The computer assumes this to be an “absolute” maximum, and then searches for the first minimum value. The process is repeated until 16 successive values are determined; then the “lowest midpoint” is determined and assumed to be the baseline. The value for the first “K” is established as the distance from the baseline to the first midpoint between the first maximum and first minimum. Provided K is at least 4 times larger than the difference between any successive maximum and minimum, the peaks are considered to be absolute maxima or minima. If the first maximum value is small compared with the following 16, it will be discarded until an “absolute” peak is obtained. Figure 1 shows that the first maximum is acceptable as an absolute maximum but the first minimum is not acceptable as an absolute minimum because the peak-to-peak distance between it and the previous absolute maximum is less than 1/4 K. The period of waves is defined as the time between absolute minimums.

Thirteen patterns are recognized by this program; spike and dome, Eta bursts, etc. These are determined from an array of data obtained by sorting the patterns of waves into frequency and amplitude bins. The computer then uses these patterns to arrive at one of the statements below:

- Normal
- Behavior Disorder
- Convulsive Disorder
- Abnormal (slow waves)

**Model System**  A total system was envisioned where the transmission, reception, analysis, and display of results would be analogous to existing ECG systems. Figure 2 displays the various blocks of the system:

**Experimental System**  Standard EEG scalp electrodes were used on a comatose patient in the intensive care unit of the George Washington University Hospital. These were input to a Hewlett Packard Standard EEG/ECG preamplifier. The output of the preamplifier was fed into the input of an ONYX FM integrated circuit transmitter operating at 86.5 MHz (the volume of the transmitter including batteries was only 1/3 of a cubic inch). The receiver/discriminator was also manufactured by ONYX. The transmitter antenna consisted of 34" of #18 wire; however, a 4" stub antenna was satisfactory. The receiver antenna was made by International Components Corporation and measured 24" x 1" x 4". This equipment was originally designed for use in infant crib death monitoring project; therefore, it was necessary to modify it. The transmitter needed a thousand-to-one increase in gain over what it was designed for (an ECG transmitter), because the EEG signal is about 1/1000 that of the ECG. Also the EEG/ECG preamp’s output was not a suitable impedance for directly inputing to the transmitter. Thus, a combination filter/impedance
matching voltage divider was constructed in order to attenuate 60 Hz interference and pick off a signal at the proper voltage level for transmitter input.

An undetermined amount of shielding was provided the transmitter by placing it in a #303 empty fruit can obtained at the grocery store. The output of the system was displayed on a Hewlett-Packard 780-6A “Viso-Scope”.

Figure 3 illustrates the experimental system as used in the intensive care unit of the hospital:

The purpose of the experiment was to demonstrate feasibility of a single channel EEG telemetry system in the electrically noisy environment of a hospital intensive care unit. Diathermy devices, electrically driven pumps, etc. filled the air with radiated signals which not only were continuous in nature, but transient as well, due to the cycling on and off of some of the equipment.

**Results**  Figure 4 is a portion of a standard EEG strip chart recording made at the patient’s bedside moments before the telemetry experiment. This strip represents about 6 seconds of real time recording, and the amplitude of the waves are about 50 micro amps peak-to-peak. Figures 5 and 6 show the relatively “clean” signals that were obtained from the system. The photographs were taken from the Viso-Scope with a Polaroid camera while triggering the Scope with a 5-second sweep. The top line in the figures shows the short circuit voltage input to the transmitter (thus, it indicates the amount of noise in most of the system). Amplitudes of the signals ran about 50 microamps peak-to-peak maximum even though it appears that the signals may be significantly different than those of Figure 4. Two walls of concrete and steel as well as 40 feet separated the transmitter and the receiver.

**Conclusions**  It is envisioned that a total system may be configured as shown Figure 7. This system would obviate the need for connecting equipment using voltages dangerous to life directly to the patient. Also, it would be used as an aid to on-line processing of EEG data to enable the physician in the Operating Room and/or nurse in the intensive care unit to diagnose changes in patient status. Computers could be used, for example, to analyze telemetered data and control drug infusion during surgery. An on-line display in an intensive care unit could monitor the EEG as part of an overall patient monitoring system.

(This work was part of an engineering Master’s Thesis for the George Washington University, Washington, D. C.)
References:


Fig. 1 - EEG Pattern Recognition Details

Fig. 2 - Ideal Hospital EEG Telemetry System

(DOTTED LINE INDICATES FEEDBACK TO ON-LINE DISPLAY IN THE HOSPITAL)

Fig. 3 - Experimental EEG Telemetry System
Fig. 4 - Actual Bedside EEG (non-telemetry)

Fig. 5 - Actual EEG Telemetry
Signal, Forty Feet,
Medium Sensitivity

Fig. 6 - Actual EEG Telemetry
Signal, Forty Feet,
Medium Sensitivity

Fig. 7 - Total EEG Telemetry System