AN ANALOG PROGRAM FOR ELECTROENCEPHALOGRAPHIC DATA ANALYSIS

INTRODUCTION

This Study describes the application of the EAI TR-48® General Purpose Analog Computer to the analysis of electroencephalogram (EEG) data. In addition, it represents in the type of analysis employed, the wide range of data reduction techniques which can be implemented effectively on properly-complemented general purpose analog computers.

The method used measures the amplitude spectrum of the EEG record at a given number of frequencies and then correlates this spectrum measurement against given standards to determine which standard is significant.

The method is useful in deriving *on-line* results rather than waiting for the output from an exhaustive digital technique. The analog data obtained, while less comprehensive than that received from a digital machine, has been shown to be more informative and reliable than that gained by an experienced experimenter observing the same results. As such, this analog method provides an experimenter with a valuable aid in deciding how to proceed with his program rather than relying on his own observations of the bulk of the results taken or only being able to take a sample of these results for digital processing and examination.

MATHEMATICAL ANALYSIS

In presenting this program it will be shown how the analog computer can be used to measure the amplitude spectra of an EEG record for the purpose of detecting changes in the record. The typical EEG record of a cat shown in Figure 1 is made up of signals whose frequency content is in the range of 0.50 cycles per second.

Figure 2 shows a typical amplitude spectrum analysis of an EEG record of a cat.
An approximation of this amplitude spectrum can be found by passing the signal through a set of bandpass filters of the form

$$\frac{Y_i(s)}{X_i(s)} = \frac{asw_{oi}}{s^2 + bsw_{oi} + w_{oi}^2} \qquad (1)$$

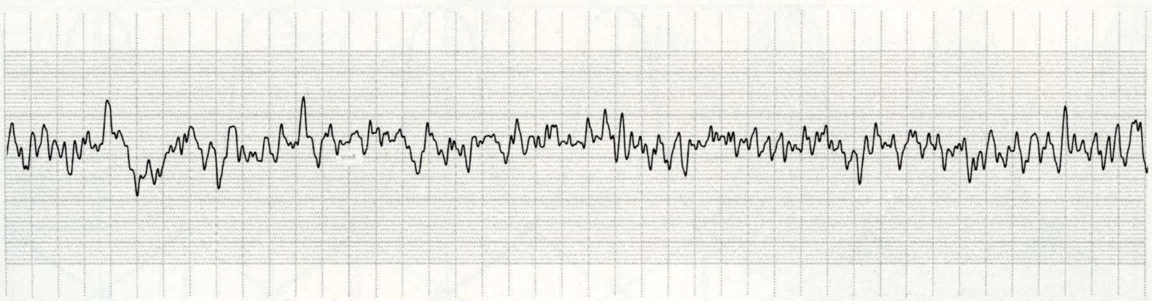
Start  Finish

Figure 1. Typical EEG Record

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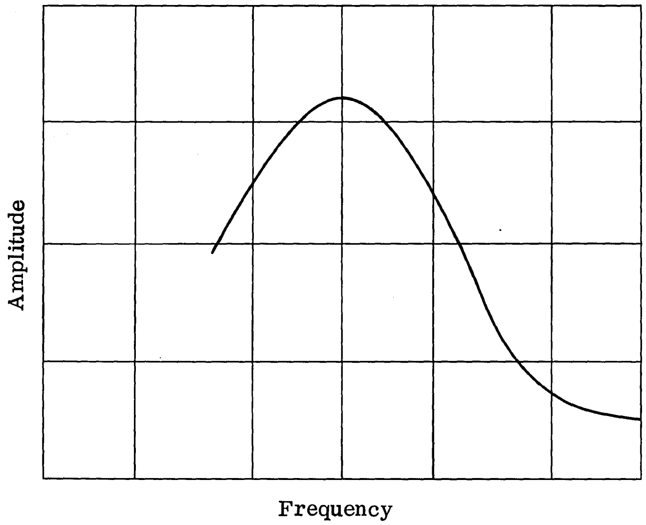

Figure 2. Typical Amplitude Spectrum Analysis of EEG Record of a Cat

in which *a*, *b* and w_{oi} are chosen to cover the frequency domain required. The resultant amplitude plot of all the filters is shown in Figure 3.

Now w_{oi} is chosen as the center frequency of the i th filter. If n filters are to be used, then w_{oi} is given by

$$w_{oi} = w_{min}\left(\frac{w_{max}}{w_{min}}\right)^{i/n-1} \qquad (2)$$

where $0 \leq i \leq n-1$ and w is in the range $w_{min} \leq w \leq w_{max}$

Also, it is usual to choose *b* (Eq. 1) such that the crossover amplitude between the filters is (1/n) of the peak amplitude of the filters ($A_1/A_2 = n$).

The parameter *a* controls the overall amplitude of the signal received from the set of filters.

These filters then have an output signal composed of frequencies about the center frequency of the filter. Each filter output then is rectified and smoothed to give an amplitude spectrum measurement around the given frequency. These averaged values can be plotted to give immediately *n* points on the amplitude spectrum graph

$$Z_i(s) = \text{mod}\left\{x(s)\,\frac{a s w_{oi}}{s^2 + b s w_{oi} + w_{oi}^2}\right\}\frac{1}{(1 + \tau_i\, s)} \qquad (3)$$

These *n* points can be used to show an abbreviated amplitude spectrum of the EEG or can be used to detect changes in the EEG from one condition to another where the spectrum is expected to change.

Such a testing procedure can be carried out by taking the abbreviated amplitude spectrum signals and correlating them with known amplitude spectra of the form

$$C' = Z_o Z_o' + Z_1 Z_1' + Z_2 Z_2' + \ldots Z_{n-1} Z_{n-1}'$$

$$C'' = Z_o Z_o'' + Z_1 Z_1'' + Z_2 Z_2'' + \ldots Z_{n-1} Z_{n-1}''$$

where $Z_0' \cdots Z_{n-1}'$ and $Z_0'' \cdots Z_{n-1}''$ are components of the known standard spectra to which comparison is being made.

The values C', C", etc. represent the degree of correlation that the measured spectrum has with the standard spectra. A selection is then made among the C', C", etc to find C^j such that

$$C^j = \max \langle C', C'' \ldots \rangle$$

Immediate visual indication of the selection informs the operator which case is most significant.

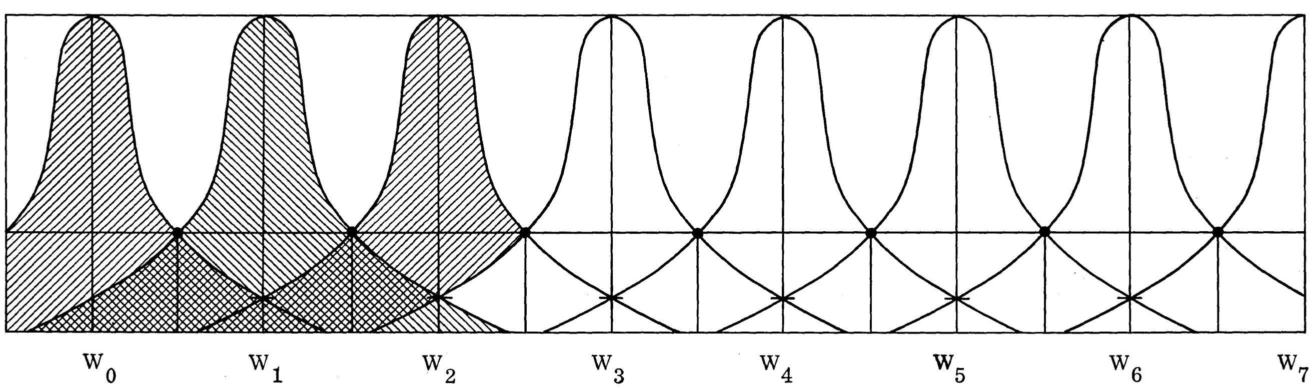

Figure 3. Resultant Amplitude Plot, All Filters

ILLUSTRATIVE PROGRAM

In order to illustrate the effectiveness of this analog data reduction technique for electro-encephalographic analysis, tests were made on the EEG's of a cat before and after the injection of the animal with a drug.

The frequencies of interest were in the range of 0-20 cycles per second, and particular filters (n = 5) were located at 0.25, 0.53, 1.11, 2.36 and 5.00 cycles per second. The parameters a and b were chosen such that a = 1.000 and b = 0.333; $\tau_0 = \tau_1 = \tau_4 = 40$ seconds were used as smoothing time constants.

The analog computer diagram for the program is shown in Figure 4.

RESULTS

The curves shown in Figures 5 and 6 are the results of the analog analysis. Figure 5 shows, at top, the actual EEG of the cat over a short duration of time (approximately 2 seconds), and emphasizes the changes occurring in the averaged amplitude spectrum measurements at each filter during that period. It should be noted that the cat was artifically aroused (salt water sprinkling, etc.) before this test. Please note that each spectrum measurement is immediately available as the output of an amplifier.

Figure 6 shows a five minute EEG record and the results (at each filter) of four tests of 5 minutes duration each in which the amplitude spectra are measured under four different conditions, viz:

a) 5 minutes before drug injection
b) 5 minutes after drug injection
c) 30 minutes after drug injection
d) 60 minutes after drug injection

It can be seen from Figure 6 that the incidence of high frequency signals increases at each filter immediately after drug injection over and above those occurring as a result of pre-test stimulation, and that this high frequency "behavior" is still quite pronounced even as long as 60 minutes after injection.

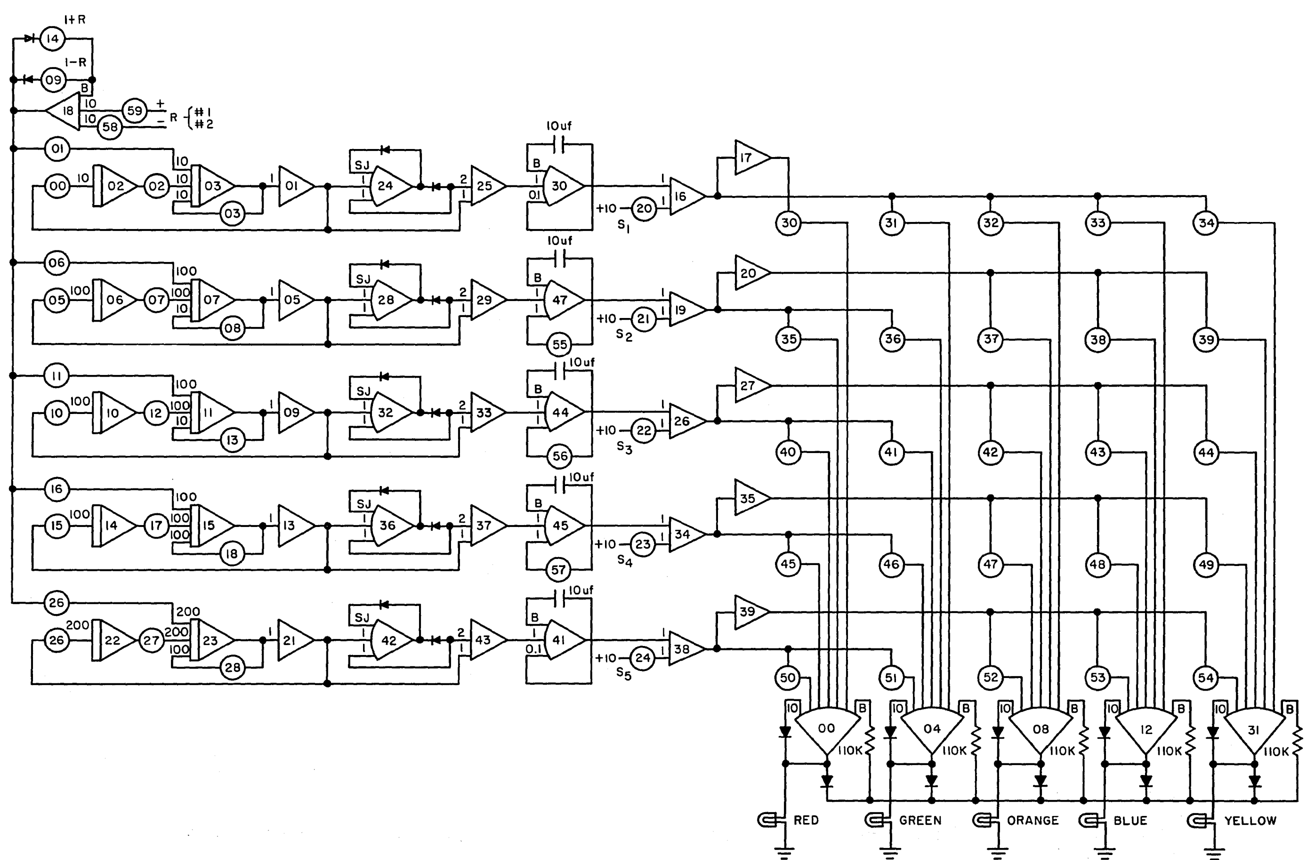

Figure 4. Analog Computer Diagram

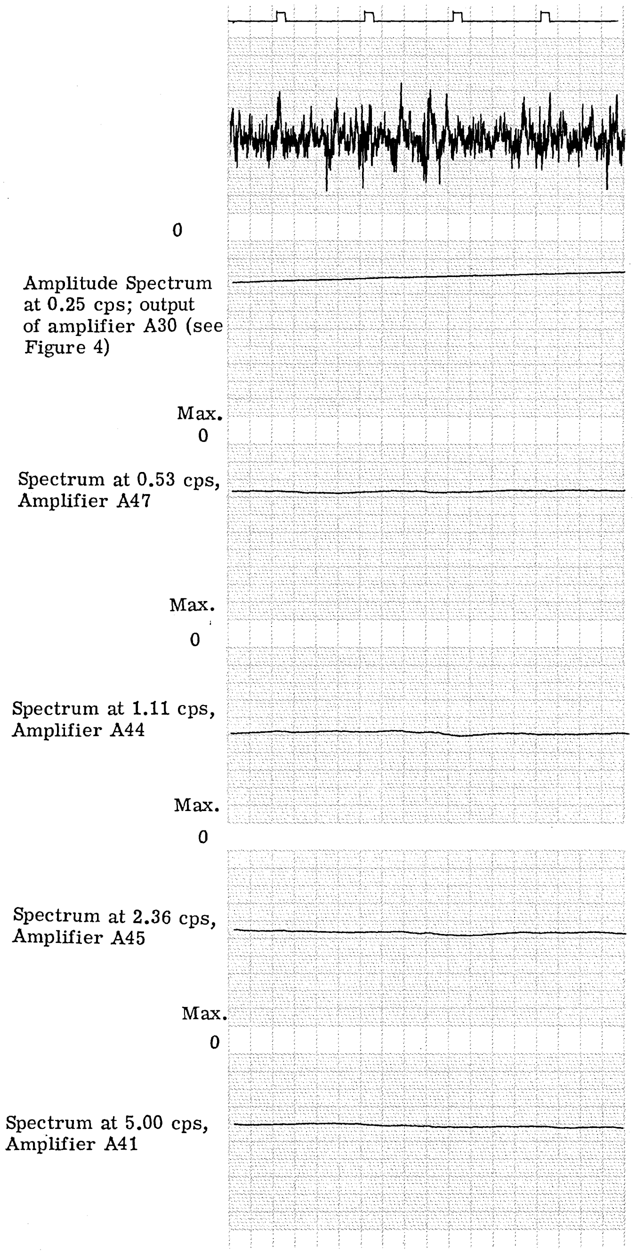

Figure 5. Short Term EEG Record of Cat Emphasizing Amplitude Spectra Changes

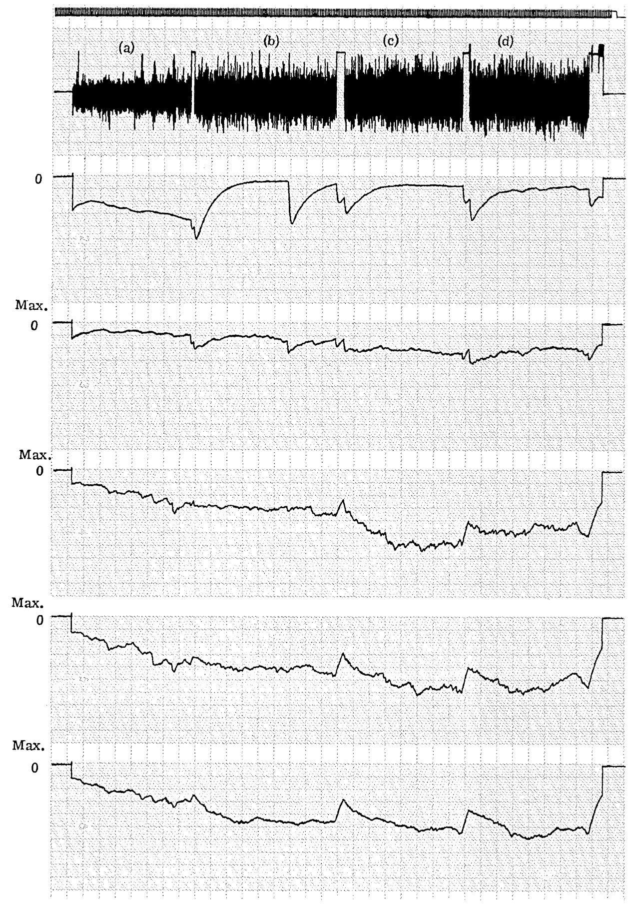

Figure 6. Timed Tests of Amplitude Spectrum Changes Occurring in EEG Record of Cat

This series of tests clearly shows the pronounced changes in amplitude spectra which can occur in specific tests over given periods of time. In practice, the analog computer can be used to detect these changes quickly and reliably by means of the correlation process described above.

CONCLUSION

The analog computer can be a great aid to the experimenter in analyzing EEG records. These records can be processed either on-line or can be recorded by FM technique on magnetic tape for later processing when required.

In addition, the analysis can be speeded up so that the EEG records can be processed in a few minutes even though they were taken over a period of hours, provided only that the highest frequency required on the computer does not exceed 100 cycles per second. In this way, those EEG's which indicate pronounced or otherwise significant variations from normal can be set aside for detailed analysis. This feature is particularly useful when the records to be analyzed are lengthy and/or in great number.

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