INSTRUMENTATION & TECHNIQUES

An on-line integrator for alpha quantification

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A system for the on-line graphic quantification of alpha frequencies (or other frequency bands extracted from EEG signals) is described. Alpha-frequency components (8 to 13 Hz) are actively filtered from complex EEG waveforms and presented to a laboratory-developed solid state integrator. The high-level output of the integrator, which is compatible with all popular EEG and polygraph recorders, is in the form of an ascending analog voltage ramp, reset at a predetermined level, to provide a rapid quantitative determination of alpha activity and variability. The design of the integrator permits an alternate mode of operation where time-synchronized resets, in lieu of voltage-dependent resets, produce variable height voltage ramps, whose amplitude is a direct function of the accumulated alpha activity per unit time. This method of preprocessing and signal conditioning the alpha components of the EEG waveform provides a simple analog registry of on-line real-time correlation of alpha activity with various physiological and behavioral activity.

Current techniques for quantifying alpha or other components of EEG employ methods ranging from simple visual examination of the polygraph tracing (Hockman, Perring & Kalant, 1971) to complex and extensive spectral analysis by means of a digital computer (Barnett, Johnson, Hicks, & Nute, 1971). A popular intermediate method of quantifying selected EEG frequency bands consists of measuring the percent time the selected band (for example, the alpha frequency band) exceeds a preselected level. This percentage is the basis for the measure of "alpha abundance" and is often used in research related to EEG feedback (Nowlis & Kamiya, 1970). Another intermediate method employs the Drohocki integrator (Goldstein & Beck, 1965). The output of this integrator is in the form of pulses, whose rate is proportional to the integrated energy.

Although these methods are standard and accepted techniques for the analysis of complex EEG frequency components, they have inherent shortcomings. Visual examination of raw EEG or selected frequency bands is qualitative and produces dichotomous, rather than interval, data. Measurement of alpha abundance disregards both wave amplitude and shape. The pulse output of the Drohocki type integrator produces quantifiable pulses on an interval scale, but the method of meaned electrical integration prevents the

transformation of the interval units to scaled units of absolute energy content in microvolt seconds. Spectral analysis by a digital computer assumes stationarity of the signal during the analysis period, an assumption rarely met in EEG monitoring.

This paper reports a technique, using a laboratory-developed solid state integrator, coupled with an active filter and conventional recorder, to provide an on-line quantitative determination of alpha activity.

SYSTEM OPERATION

The basic operation of the on-line system for alpha quantification is illustrated in the block diagram of Fig. 1. Although raw EEG can be quantified by the system, only evaluations of the alpha frequency band (8 to 13 Hz) will be illustrated. EEG signals derived from standard electrode placement are connected to an appropriate EEG channel of a Grass, Beckman, or similar type polygraph recorder. The amplified EEG signal is taken from the dc output of galvanometer driver amplifier to the polygraph recorder for direct insertion into an EEG frequency analyzer. The frequency analyzer is a solid state active filter device, which permits concurrent analysis of five EEG frequency bands. Although the system uses a commercially available Nihon-Kohden MAF-5 frequency analyzer, any active bandpass filter capable of frequency discrimination of 24 dB per octave within a bandwidth segment of 8 to 13 Hz may be substituted. The output signal of the

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Fig. 1. Block diagram of on-line system for EEG quantification.

frequency analyzer, which is an analog of the alpha frequencies extracted from the EEG waveforms, is presented to an appropriate channel of the polygraph where the alpha component of the waveform is graphically illustrated. The high-level dc output signal from this alpha channel is inserted into the lab-built solid state integrator which electronically computes the time integral of the filtered alpha frequencies. The high-level output of the integrator is presented to another dc channel of the polygraph where the on-line area summation of the filtered alpha is graphically ascertained and recorded.

DETAILED CIRCUIT DESCRIPTION

Circuit operation of the solid state integrator unit shown schematically in Fig. 2 is as follows: The input signal to the integrator is half-wave rectified to provide only the negative portion of the alpha signal. The "integrator gain" potentiometer adjusts the input sensitivity and the "X1-X10" switch selects the RC integrator constant of the circuit. Operational amplifier (op-amp) A1 is a high-impedance FET device connected in an integrating mode configuration (Philbrick, 1966). The rectified current flowing through the input resistor (R must also flow through the feedback or integrating capacitor (C). Hence:

$$-C \frac{de}{dt} \cdot \frac{e_{\text{input}}}{R}$$

and thus:

$$e_{\text{out}} = \frac{-1}{RC} \int_0^t e_{\text{input}} dt.$$

The integration capacitor, C1, is a hermetically sealed low-leakage capacitor to insure a minimum of long-term amplitude attenuation due to component leakage. The high-level analog output signal with a range from 0 to +9 V is taken directly from the integrating op-amp A2 and is adjusted via the "output gain" potentiometer.

Resetting of the integrator circuit may be accomplished in either an amplitude or time mode of operation. In the amplitude mode, the "reset" potentiometer is adjusted to a predetermined voltage setting which produces a reference level to the op-amp A2 connected in a Schmitt trigger configuration. When the output signal voltage of the integrator exceeds this setting, the relay one-shot multivibrator K1 produces a 15-msec reset contact closure across the integrating capacitor C1. Transistor Q1 is an input amplifier circuit used to initiate the one-shot action of the reset relay, K1.

Fig. 2. Schematic diagram of lab-built solid state integrator. The integrator operates as a half-wave area summator.

Fig. 3. Polygraph tracings of the basic EEG signal, the filtered alpha signal, and the integrated alpha signal. The integrator is amplitude reset and requires reset to reset time interval measurement for a quantitative determination of alpha activity.

In the time reset mode, an external time-dependent contact closure bypasses the Schmitt trigger circuit to directly drive Transistor Q1. In this mode, the "reset" potentiometer should be adjusted to a full +15 V to render the amplitude reset circuit inoperative. A parallel pushbutton switch provides a manual reset.

CALIBRATION PROCEDURE

The "gain" and "output" controls of the integrator are adjusted so that the output can be read directly in terms of the parameter represented by the input signal. In most physiological applications, the voltage value applied to the input is not a significant number, but it should be a predictable value. For example, if a voltage at the integrator input represents 3.0 microV sec, the actual absolute value of the voltage is not important as long as 3.0 microV sec is always represented by the same voltage.

Actual calibration of the integrator circuit is accomplished by applying a known sinusoidal signal from a low-frequency waveform generator to the input jackbox of the raw EEG channel. A sine-wave frequency within the bandpass of the frequencies to be analyzed should be used even though the output of the integrator is proportional to the average value of the input signal and is independent of frequency.

The amplitude of the calibrating sine wave should be adjusted to register a full-scale deflection on the filtered EEG channel. The full-scale amplitude of the integrator should be scaled to correspond to 0.318 times the full-scale value of the filtered EEG channel. As an example, if the full-scale value of the filtered EEG channel is 10 microV peak, and a full-scale calibrating

sine-wave signal is applied, the full scale value of the integrator is 3.18 microV sec.

The scaling factor of 0.318 represents one half the average instantaneous value of a sine-wave value which is equal to 0.636 times the peak sinusoidal amplitude. Since the integrator is operated in a half wave summation mode, and only one half the sine wave is integrated, the scaling factor of 0.318 is appropriate.

Output scaling of the integrator from 0 to +9 V is accomplished via the "output" potentiometer. The "gain" potentiometer should be adjusted to insure a linear summation of the input amplitudes from -6 V to -10.0 V. The RC integrator constants of "X1" and "X10" effectively provide an internal gain control, since the integrator amplifier gain is 10 times higher in the "X10" position than in the "X1."

It should be noted that the integrator blocks positive signals and will accept only the negative portion of the sine wave. This procedure corresponds to the standard Grass and Beckman polygraph convention where the dc output signal to servo signal produces a 0-V output for center pen deflection, a negative voltage output for an upward pen deflection, and a positive voltage output for a downward pen deflection.

DISCUSSION

Figure 3 illustrates the integrator used in an amplitude reset mode at a predetermined or preset level of 3 microV sec. Quantitative measurement is obtained by measuring the intervals between resets or the number of resets per given epoch.

The time reset mode is shown in Fig. 4. Quantitative determination of alpha activity is achieved by measuring the amplitude reached by the ramp at time of reset, as references to a full scale value of 3 microV sec. Since in this sample the time

Fig. 4. Polygraph tracings of the basic EEG signal, the filtered alpha signal, and the integrated alpha signal. The integrator is time reset at 1-sec intervals. Quantitative determination of alpha activity is achieved by measuring the height of each ramp as referenced to a full-scale value for 3 microV sec. Output is in absolute units of microvolt seconds per second for the preceding epoch.

resets occur once a second, the output determination is in absolute units of microvolt seconds per second. EEG voltage determination in units of microvolt seconds provides a very convenient and pertinent measure for correlation between experimental studies of this nature.

Summary

The output of the integrator, which is compatible with most popular EEG and polygraph recorders, provides a rapid quantitative determination of the mean energy content in microvolt seconds. The design of the integrator also permits a time based mode of operation where amplitude is a direct function of the accumulated energy per unit time. This method of preprocessing and signal conditioning raw EEG or specific frequency components of the EEG waveform not only expedites real-time correlation of the EEG activity with other physiological and behavioral activities, but can also provide a convenient method for transmitting biofeedback information to a S in contingency mode procedures.

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