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The impetus for this paper comes from three sources: first, a concern for the role of the "theorist" as a planner of possible and advantageous musical techniques. Second, the possibility of electronic and automatic sound generation and the need for knowledgeable research, which requires simultaneous concern with the musical as well as the electronic aspects. Third, certain problems which are inherent in improvised music, specifically in contemporary Jazz. These three general areas contribute to the character and outlook of the present paper. It is presented with the fond hope that the possibilities of bio-music will resurrect the spontaneous in music and with the ardent belief that spontaneous music represents the highest peak of the musical art.

The idea of employing bio-potentials as a source of musical material occurred to me during August of 1961. At the time I thought that the idea was completely novel. My interest in the possibility was aroused by two specific problems; first was the fact that in Jazz improvisation the musicians are quite limited by the necessity for predetermined material. Second, the improviser, even when improvising alone, is severely limited and guided by the physical restrictions imposed by his body and by the mechanical nature of all conventional instruments.

By 1963 my conception of the use of bio-potentials had developed from one of direct conversion of signals into sound to a more sophisticated approach. I began to think in terms of data acquisition and manipulation to derive signals suitable for driving electronic sound generation equipment. In these systems the feedback loop consists of bio-sensors which, after signal processing, generate an audio output that is fed back through the brain and body to the bio-sensors. This basic feedback loop is the starting point for a large number of bio-music systems. The primary differences between systems are in

the nature of the data processing which occurs between the bio-sensors and the audio output, and the type or types of bio-potentials employed. These decisions concerning type of data processing and bio-potential sources involve several difficult philosophical questions.

The idea of employing bio-potentials for musical purposes is not as new as might be supposed. Around the turn of the century the U.S. Patent Office received an application concerning a proposed device which would allow the musician to manipulate the keys of a player piano by attaching wires to his head. This was before the discovery of "brain waves" and at the time constituted a rather far-fetched scheme. The applicant did not specify in any detail just what method was to be used to obtain signals which would be useful for the purpose of generating player piano music. The application was rejected...

The idea of converting bio-potentials into sound is not a completely new idea either. Several researchers have developed devices during the last 25 years for converting brain waves into sound, especially J. A. Bates; C. A. Beevers and R. Furth; and Bozenikov and Soroko. However, none of these have been for musical purposes but rather for electroencephalographic (EEG) analysis purposes. The sounds produced by these devices is singularly uninteresting, at least from a musical point of view. Nevertheless these devices do constitute the first practical circuits for converting this bio-potential into sound.

There are many bio-potentials which can be used for musical purposes. Some of them generate enough information to be used with only a small amount of processing. Some are of a more auxilliary character. The electrical signals generated by the heart are, for example, quite easily detected over the entire body and can be used as a source of information. Heart rate and waveform are affected enough by auditory experiences to make this source usuable. Generally, however, these changes are not great enough to allow the EKG to serve as the sole source of information.

The psycho-galvanic skin reflex, due primarily to changes in skin resistance during emotional stress can also serve as an auxilliary source. However, since these signals vary quite slowly and predictably they must be used in conjunction with other bio-potential sources. The signals generated by involuntary muscular contraction can also be used. The areas around the face are particularly subject to this type of activity. The signals generated by musicular activity are quite large compared to certain other bio-potentials and are for this reason quite easy to employ. The placements of the sensors is of course a determining factor in the nature of the signals which can be detected.

One of the easiest sources to employ and one which is more indicative of mental activity concerning shape and form is the movement of the eyes within their orbits. When the eyes are stationary a steady potential is generated between a pair of electrodes attached equidistant from them. However, eye movement produces a change in the ionic concentration of the eye fluids thus generating a changing electrical potential. The use of eyemovement potentials is quite simple since normal eyemovement generates signals in excess of 100mv. Certain eye rhythms are, however, sometimes confused with bio-potentials from other sources.

The source of bio-potentials which holds the greatest interest and the greatest challenge, however, is the cerebral cortex. It is primarily to this source that the present author has directed his attention. The discovery in 1929 by Hans Berger of the alpha rhythm produced a renewed interest in the dream of "think-work"; of mental mechanical control. However, the problem of correlating electroencephalographic (EEG) data with observable behavior has proved to be extremely slow and frustrating over the past forty years. Many postulates and thousands of experiments have failed to produce any widely accepted central theory of correlative interpretation.

There are, though, two important advances in cerebral research which have occurred during this century that have given researchers cause for some optimism.

The first of these is the determination of functional cortical areas of the brain. It is now quite clear that certain areas of the brain control specific types of behavior. For exa , the parietal area controls fine hand and finger movements; the temporal lobes being associated with memory functions. The contributions of Bremer, Von Bonin, McCulloch and especially of Penfield and Rasmussen of the Montreal Neurological Clinic are quite important. These researches stand as important sources of information on cortical function as well as guide-posts in EEG research.

The second important advance is the discovery of spontaneous electrical rhythms of cortical origin. The first of these (the alpha rhythm) has proved to be extremely important in electroencephalographic research. A large portion of the EEG literature is on this rhythm since it is the most cominant cortical signal. It can be detected over a large portion of the skull, is relatively easy to identify and maintains certain stable characteristics during the entire adult life of an individual. It is generally agreed that the alpha rhythm becomes the dominant brain rhythm by the age of five; has a frequency of 10-12Hz dependant on mental activity; that its amplitude and harmonic content often vary greatly with mental activity and that the rhythm has the greatest amplitude in the vicinity of the occipital lobe. The following quotation from Electroencephalography by Hill and Parr (page 220) indicates the importance of this rhythm:

> "The slight changes in frequency which do seem to occur are usually closely related to the degree of alertness of the subject; mental activity with the eyes shut may produce a transient acceleration by 0.5Hz or so, and in subjects in whom the rhythm persists with the eyes open visual scanning of a significant pattern has the same effect. The form of the individual waves, and accordingly their harmonic content as displayed in the analysis, also show fluctuations with attentiveness; a rhythm which has been diminished by attention usually has a more spikey or monophasic

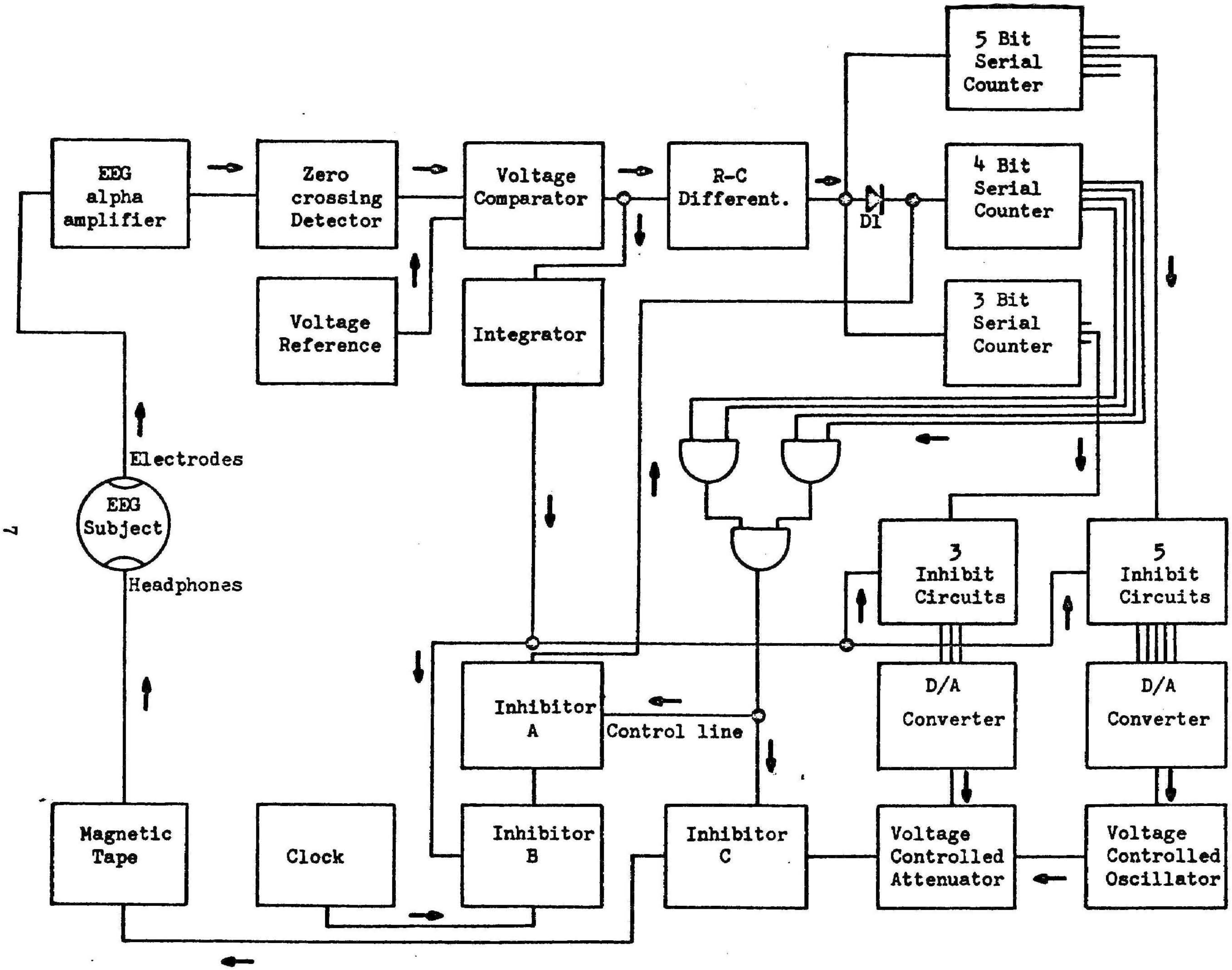
appearance and the second harmonic content is proportionately higher."...

"Summarising this selection of data, we have a complex rhythmic activity, closely associated functionally and anatomically with visual perception and integration, and particularly with the appreciation and imagination of form and pattern.

It remains to speculate on the possible functional properties of alpha activity as a type of the spontaneous resting rhythms. It should be recalled that the alpha rhythm is only one of a number, perhaps a very large number, of similar phenomena."

The alpha rhythm is by no means the only rhythm of the brain nor are all cortical potentials rhythmic. The work of Lion, Winter, Levin and of Jan Trabka listed in the bibliography are especially important in this connection. Research into the nature of non-rhythmic cortical activity has increased considerably in the past ten years. The parameters of amplitude, frequency and harmonic content are of more difficult to study with transient signals of course.

These parameters of amplitude, frequency and harmonic content can be used as basic information which after processing can be used to drive any desired type of sound generating equipment. Let us consider a quite simple EEG music system. This circuitry, although not sophisticated enough for serious music composition, will serve to illustrate all of the important principles of EEG music systems.



A BASIC ELECTROENCEPHALOGRAPHIC COMPOSITION SYSTEM

NOTES:

1. Diode D1 prevents positive pulses from the clock from feeding back to the 3 Bit and 5 Bit counter inputs.

2. All Logic gates shown are "AND" gates.

3. All Inhibition Circuits are of the "Reverse Bias" type. That is, they pass signals present at their inputs only when the control line signal is zero.

4. The Voltage Controlled Oscillator has a one octave range within the audio spectrum. The five bit counter has 32 possible output combinations, each of which generates a unique analog output signal value from the associated D/A Converter. Thus there are 32 distinct sine wave frequencies which can be generated over the one octave range of the oscillator.

5. There are 16 possible output combinations from the 4 Bit Counter which controls the duration of the audio signal. Thus there are 16 possible durations; the range of these durations, however, is a function of the clock speed. Each clock pulse represents 1/16 of the maximum possible duration time.

6. The EEG amplifier amplifies the Alpha Rhythm of the brain which is approximately 10Hz to 12Hz dependant upon mental activity and whose amplitude ranges from less than 1uv to approximately 50uv, the amplitude also being dependant upon mental activity. The "mental activity" which varies the parameters of the Alpha rhythm is primarily "concentration" or "attention" to external stimuli or to mental effort of an abstract nature. In most subjects, concentration brings about an increase in Alpha frequency and a decrease in alpha amplitude.

7. The Zero Crossing Detector operates as follows:
The output changes state each time the input waveform passes through zero. These are rectangular pulses of positive or negative polarity and their amplitude is directly proportional to input amplitude up to a certain level and are of constant amplitude for input amplitudes greater than this level.

8. The Voltage Comparator operates as below:
For voltage amplitudes greater than the amplitude of the Voltage Reference a positive output voltage step is generated; for input amplitudes less than the Voltage Reference no output occurs. The circuit does not respond to

negative inputs. The amplitude of the output is constant for all inputs greater that the Voltage Reference. In the system shown the Voltage Reference amplitude is less than the constant amplitude level of the Zero Crossing Detector.

9.. The R-C Differentator serves to provide pulse waveforms for the counter inputs.

10. The purpose of the "Integrator" is to obtain a positive DC voltage from the voltage comparator output for Inhibition circuits B, 3, and 5 during EEG pulse trains.

OPERATION:

Suppose that due to the EEG Source (the composer) being in a quiescent state, the Alpha rhythm amplitude increases. These will be squared by the Zero Crossing Detector and fed to the input of the Voltage Comparator. If the amplitude of these signals from the Zero Detector is greater than the amplitude of the Voltage Reference, a positive pulse will occur at the output of the Voltage Comparator for each positive pulse present at its input.

Due to the action of the Integrator, these positive rectangular pulses will be an essentially direct positive voltage as described above. This positive direct voltage will prevent Inhibit Circuit B from passing the clock pulses at its input and will prevent the 3 Inhibit Circuits and the 5 Inhibit Circuits from passing signals present at their inputs.

The positive pulses at the output of the Voltage Comparator are fed for storage into the 3 Bit and 4 Bit and 5 Bit counters.

When the output of the Voltage Comparator falls to zero due to increased mental activity and its resultant decrease in Alpha amplitude long enough for the output of the Low Pass Filter to fall to zero, the events described below occur:

(A) Inhibit Circuit B begins to pass the clock pulses present at its input. Since, there is no signal present on the control line of Inhibit Circuit A it also passes the clock pulses which begin changing the state of the 4 Bit counter, from the state that it is in. (This state was inserted into the counter by the prior pulses from the Voltage Comparator output.) The situation where the control line to Inhibit Circuit A is not zero will be discusses below.

(B) The 3 Inhibit Circuits and the 5 Inhibit Circuits pass their counter states to their respective D/A Converters.

(C) Since the output of the "AND" circuits is assumed to be zero, there is no signal present on Inhibit C control line and it passes the audio signal which is present at its input. The amplitude and frequency of this signal is controlled by the analog signal present at the Voltage Controlled Attenuator and the Voltage Controlled Oscillator.

(D) The clock changes the state of the 4 Bit counter until all flip-flop outputs are in the logical "1" state. Under this condition the three "AND" gates produce an output which inhibits the oscillator signal present at the input of Inhibit Circuit C and which also prevents further clock pulses from reaching the 4 Bit counter since Inhibit circuit A will no longer pass the signals.

(E) The system remains quiescient until the EEG signal becomes large enough to initiate another series of rectangular pulses from the Voltage Comparator.

In the event that a series of pulses should begin at the Voltage Comparator output before the oscillator sound ends due to an output from the three "AND" circuits, the oscillator will be prevented from reaching the Magnetic Tape Input as soon as the Voltage Comparator output becomes positive, since the 3 Inhibit Circuits and the 5 Inhibit Circuits will be prevented from passing their input signals.

Above, it was assumed that the 4 Bit counter was not in the 1111 state when the series of rectangular pulses at the Voltage Comparator output ended. In the event that the counter is in the 1111 state, initially, no audio sound will reach the Magnetic Tape Input since Inhibit Circuit C will not pass the Oscillator signal. The system will remain quiesceht until the 4 Bit Counter contains another state due to new pulses arrivigg from the Voltage Comparator.

Due to the arithmetical ratio of the number of flip-flops in the 3, 4, and 5 Bit counters, the situation where a given duration, amplitude, or frequency would always result in the same value each time for the other two parameters is avoided.

The system described is based on the ability of the composer to direct, or to avoid directing his attention to the sound being generated. The sounds generated are found "interesting" or "not interesting" to the composer and partial control over their reaching their full duration remains with the composer. Obviously the composer does not wield full objective control over the system by specifying, consciously or willfully, the frequency, amplitude and duration of the desired audio signal. This is not the point of the system; it is rather to provide the composer with a direct and "semi-automatie" method of composition which is intimately related to his mental activity in both an objective and subjective sense while allowing him to retain some measure of "real-time" control over the course of the composition.

Through the use of a digital memory, the present system can be extended to profice sucessions of sounds based upon the digital analysis of prior counter states. This will provide longer intervals for the composer to "consider" the course of the composition.

The basic elements of any EEG music system are: (1) The signals generated by the cerebral cortex and the rest of the brain. (2) Circuitry to process and convert this raw data into appropriate digital information. (3) Memory circuitry and decision circuitry to store and direct this data. (4) Sound generation equipment. (5) The human ear and brain which complete the feedback loop. It is evident that a large number of systems is possible. It is also quite evident that a plethora of difficult philosophical problems arise in determining the nature of the feedback loop elements. Many of the same philosophical problems found in conventional electronic music confront the theorist in electroencephalomusic; there are in addition to these several new difficulties. New questions also arise concerning the nature of "spontaneous music". As an approach to these problems, then let us first consider the following:

The developments of any given age are a function of the relationship between the creative thought of the artist and the technical means which are available to him. These two facets of artistic production are intimately linked together. Only rarely does the artist find the technical capabilities of his age adequate for the expression of his artistic intentions. This problem is generally ignored by musicologists and by theorists; it is generally accepted that the limits imposed by given instrumentation correspond to the limitations that the composer would place upon himself from aesthetic-philosophical considerations. However, as we consider the development of instrumentation and of musical practice it would seem that we are viewing the development of an incresingly large field of possible events which can grow in only one direction. The development appears as a series of dilemmas.

The most significant and disastrous of these dilemmas was the choice of "pre-conceived" over "spontaneous music." The dilemma arose due to a severe disparity between creative thought and technical means. The choice was not at all difficult at the time however, since the technical capabilities of the age

provided the composer with various instruments but with no convenient method of combining the sounds in an organized fashion. Thus, the choice of pre-meditated and written over spontaneous music came about so simply and naturally that the dilemma went unnoticed. Spontaneous music became "improvised" music and evolved into present day folk music and into Jazz. F. Busoni in his prophetic book The Essence of Music and Other Writings states that "Improvisation would stand nearest the true essence of art if it lay within human capacities to master its promptings." (pp 100). The use of bio-potentials and electronic circuitry gives the composer the technical means to create a sophisticated spontaneous music; a music which will eclipse the premeditated music of past centuries.

Many problems in electroencephalomusic which appear to present difficulties are in fact quite illusory. The most important of these imaginary difficulties is the role of the "Will" of the composer in producing sounds. Jazz musicians are often asked how they can thing of the right notes so fast. Of course, any one who has ever improvised realizes the absurdity of the question. Furthermore, most will agree, that even in the construction of much written music the role of the "Will" is rather small. Nevertheless, the fact that it is often impossible for the composer of electroencephalomusic to will a specific sound is disconcerting to some. It is possible, incidently, to construct EEG music systems in which the composer can "Will" specific sounds. The success of any sophisticated EEG music system, though depends on the ability of the composer to guide the course of the composition by initiating, subconsciously, changes in the cortical signals which are producing the sounds. The degree of attention generally regulates the complexity of the flow of events. Of course, the type and complexity of decision and memory circuitry are also quite important in determining the final audio output.

The nature of the decision circuitry in the feedback loop can be such that it merely decideswhich information to present to the audio generation

equipment or it can assume the role of deciding which predetermined and stored sound sequences to present to the audio generators. In the first case extreme, any cortical signal containing sufficient information to initiate a sound would do so immediately. In the second case extreme, cortical signal data would be stored for a duration dependant upon some cortical signal parameter and would then produce its predetermined sound sequence. This sound sequence would constitute the composition. In practice the decision and memory circuitry never closely approach either of these extremes.

The next problem which confronts the theorist is the significance and nature of various cortical potentials. Within the confines of the present paper a complete survey of various theories of cortical function is, of course, impossible. However, the function of the various areas of the cerebral cortex as mentioned previously, is well established. It must be realized that detailed information on the exact site from which a signal emanates is difficult to determine even when the surfact of the cortex is exposed, and quite impossible under normal conditions. Furthermore, the determination of behavior correlation with recorded data remains in a relatively primitive state. In using cortical potentials for musical purposes, behavior correlates are of little concern. The The EEG signals can be treated as raw data which can be processed to produce any given system characteristics. The measure of the efficacy of the feedback loop is the effect of the audio output on the EEG signal compared statistically with the change in EEG parameters with no audio feedback. This is a somewhat idealistic goal presently. Nevertheless, it becomes apparent that behavior correlates are not of great importance in system design.

The last problem which I wish to mention is that of the role of the composer in employing electroencephalomusical systems. It is quickly realized that in EEG music systems the very mental activity of the composer is "automatically" becoming sound; and that the perception of this sound is "automatically" changing his mental activity. This represents an ideal situation from the point

of view of the creator of spontaneous music but it creates a problem rarely considered in pre-conceived music. This is the effect of cogitation upon the final musical product. In spontaneous music the mental effort is the composition. The process of exclusion becomes a portion of the composition. Thus the EEG composition unfolds in real time. The mental methods themselves become important in determining the aural output; and the composer soon discovers that the discipline involved in EEG music is a discipline of psychological states; which is the essence of creation.

The importance of mental states is shown quite simply by consideration of the elementary EEG music system described earlier which employed the alpha rhythm as the prime source of data. In this system a lack of attention to the audio output will completely attenuate the sound whereas intense concentration on the sound being produced will result in positive feedback producing an increase in duration, frequency and amplitude which becomes self-destructive.

The subject of the control of **psychological** states and of the immediacy of EEG composition raises important philosophical and religious questions which cannot be dealt with in this paper. I do, however, wish to mention that the inclusion of bibliographic references to research on mental states induced by drugs does not imply that this author supports these methods as techniques for achieving EEG compositions. The above material represents a minimal outline of the more important facets of Electroencephalomusic systems. Designs and experiments which are in progress now; present systems and the events of the next decade will, I think, indicate that bio-music represents a highly significant development. The centuries old dream of a musical system capable of intimate fufillment of the composers thought will be realized.

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