United States Patent [19]

Hartzell et al.

[11] **3,821,949**

[45] **July 2, 1974**

[54] **BIO-FEEDBACK APPARATUS**

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[73] Assignee: **The Menninger Foundation,** Topeka, Kans.

[22] Filed: **Apr. 10, 1972**

[21] Appl. No.: **242,567**

[52] **U.S. Cl.** ..... **128/2.1 B**

[51] **Int. Cl.** **A61b 5/04**

[58] **Field of Search** ..... 128/2.06, 2.1 B, 2.1 R, 128/419–424; 340/407

[56] **References Cited**

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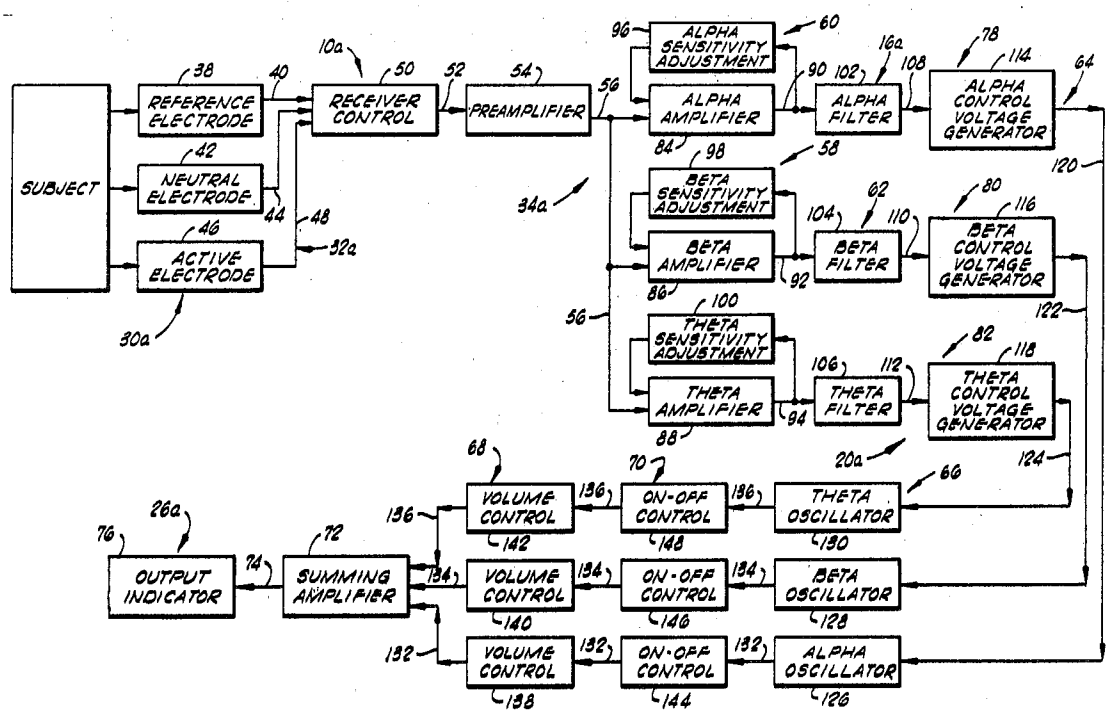
Primary Examiner—William E. Kamm

Attorney, Agent, or Firm—Dunlap, Laney, Hessin, Dougherty & Codding

[57] **ABSTRACT**

An improved bio-feedback apparatus for sensing the brain-wave potentials produced by a subject wherein the sensed brain-wave potentials are processed through separate parallel processing channels of a controlling channel, each processing channel processing a preselected frequency range of the sensed brain-wave potential to provide subject-preceivable feedback signals indicative of signal presence within the preselected frequency of each processing channel. Each processing channel is constructed to provide predetermined signal amplitude and duration criteria for determining signal presence prior to initiating and terminating the feedback signals and, in one form, each processing channel is constructed to provide feedback signals indicative of the percentage of time during a subsequent predetermined epoch of time wherein a signal presence existed in the sensed brain-wave potential. In one form, the bio-feedback apparatus simultaneously produces audible feedback signals, each audible feedback signal having a separately identifiable tone indicative of signal presence within the preselected frequency range of the processing channels.

32 Claims, 31 Drawing Figures



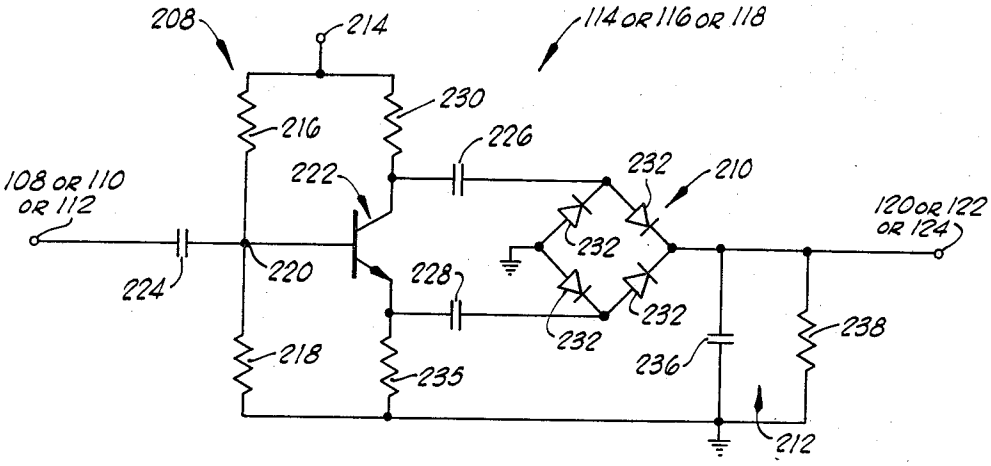


FIG. 5

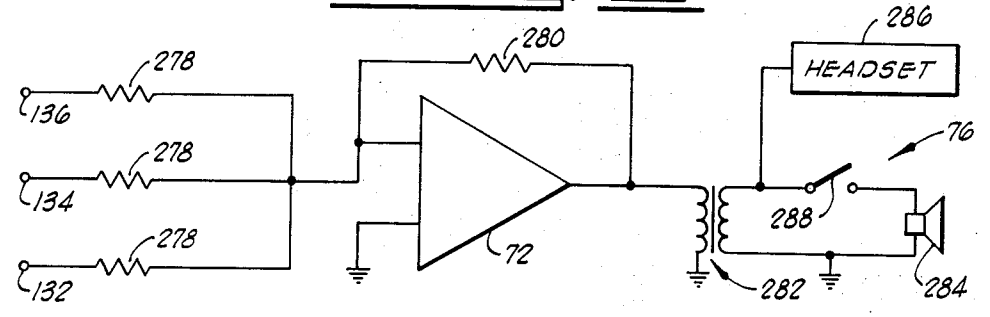


FIG. 6

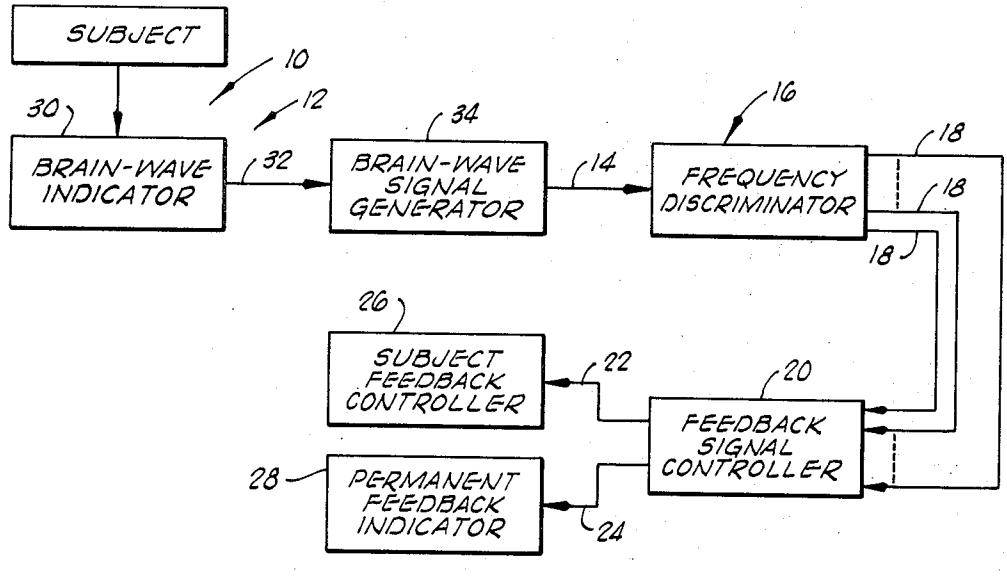


FIG. 1

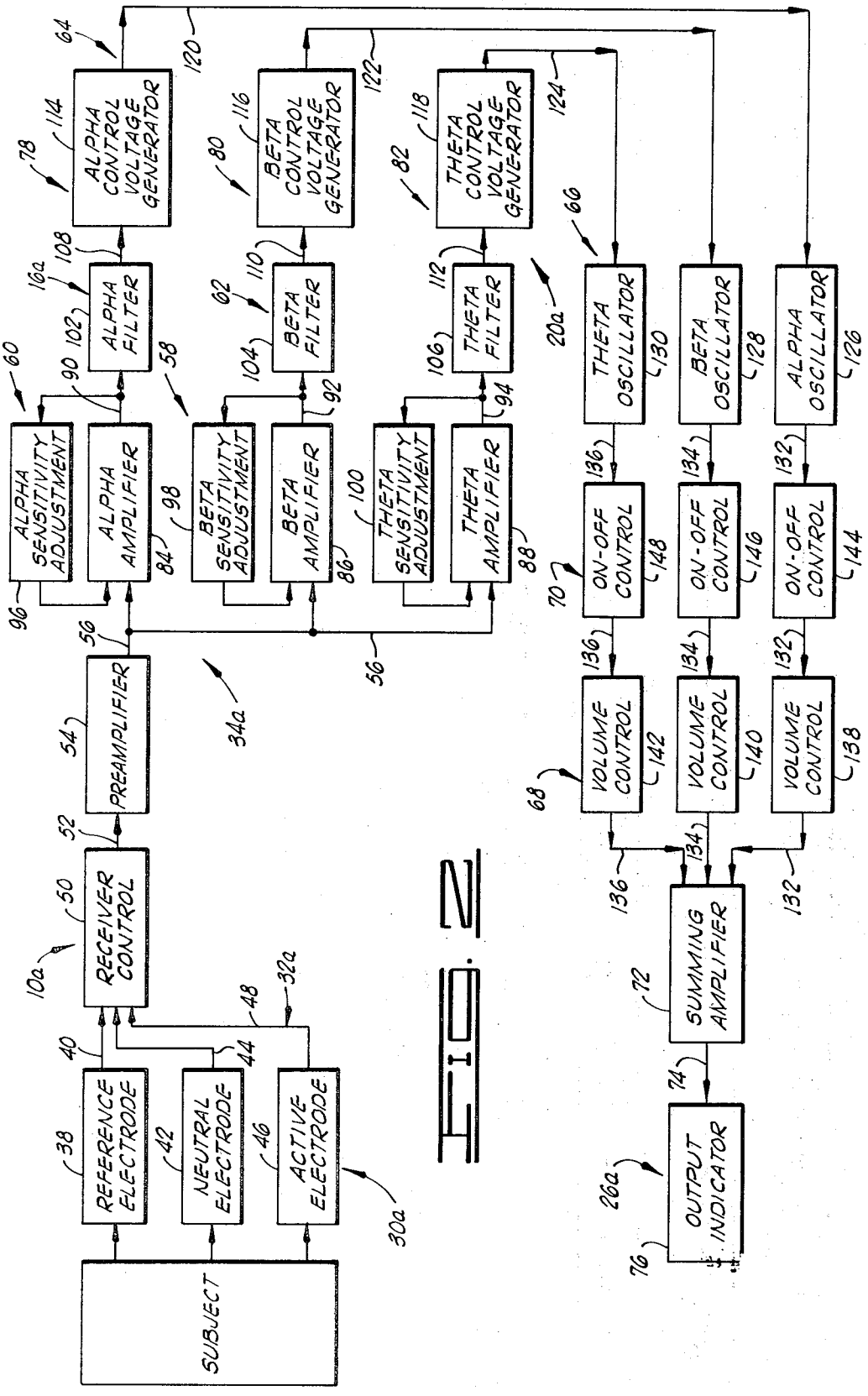

SUBJECT
REFERENCE ELECTRODE
NEUTRAL ELECTRODE
ACTIVE ELECTRODE
RECEIVER CONTROL
PREAMPLIFIER
ALPHA SENSITIVITY ADJUSTMENT
ALPHA AMPLIFIER
BETA SENSITIVITY ADJUSTMENT
BETA AMPLIFIER
THETA SENSITIVITY ADJUSTMENT
THETA AMPLIFIER
ALPHA FILTER
BETA FILTER
THETA FILTER
ALPHA CONTROL VOLTAGE GENERATOR
BETA CONTROL VOLTAGE GENERATOR
THETA CONTROL VOLTAGE GENERATOR
THETA OSCILLATOR
BETA OSCILLATOR
ALPHA OSCILLATOR
ON-OFF CONTROL
ON-OFF CONTROL
ON-OFF CONTROL
VOLUME CONTROL
VOLUME CONTROL
VOLUME CONTROL
SUMMING AMPLIFIER
OUTPUT INDICATOR

FIG. 2

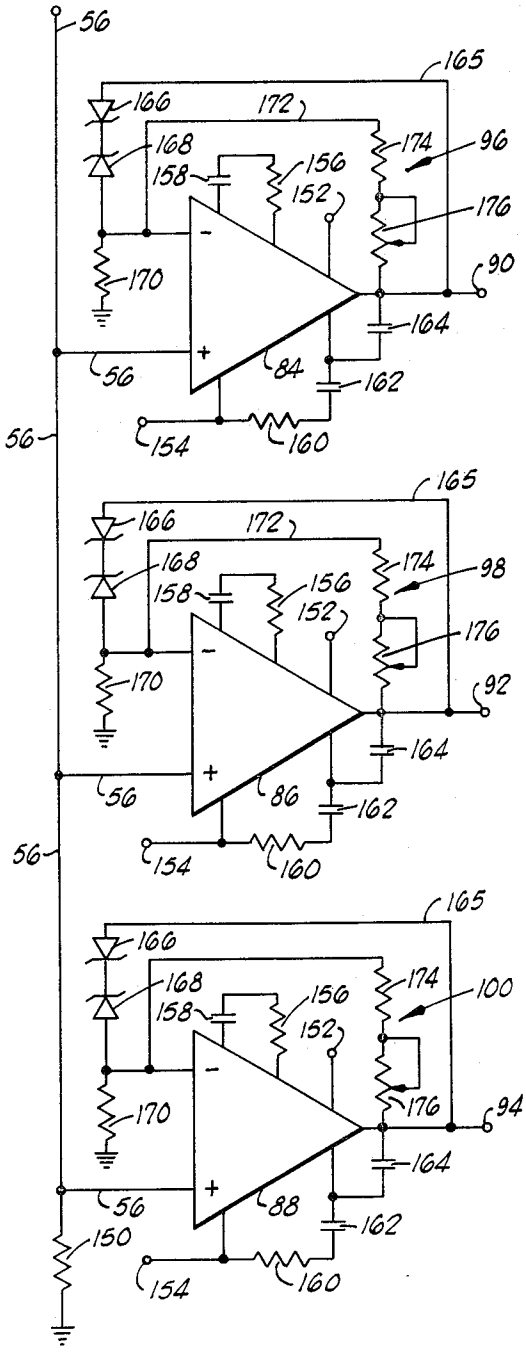

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FIG. 3

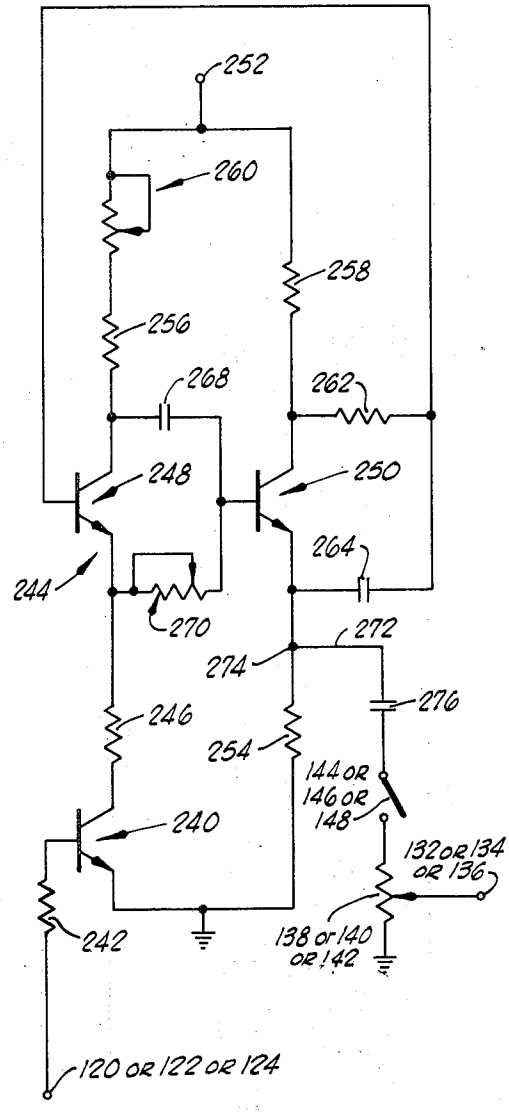

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OR 136
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OR 142
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FIG. 4

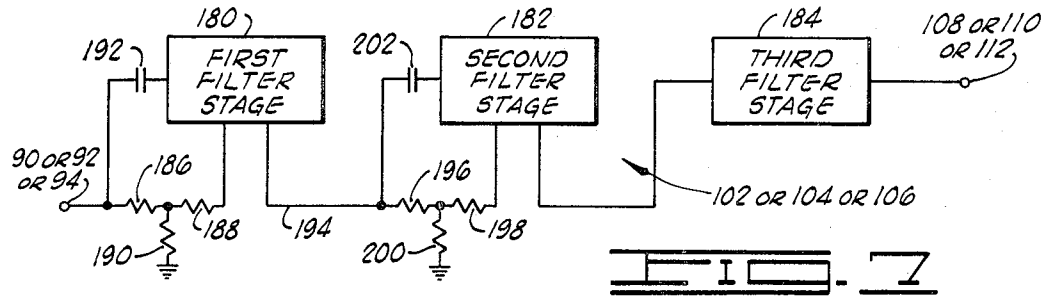


FIG. 7

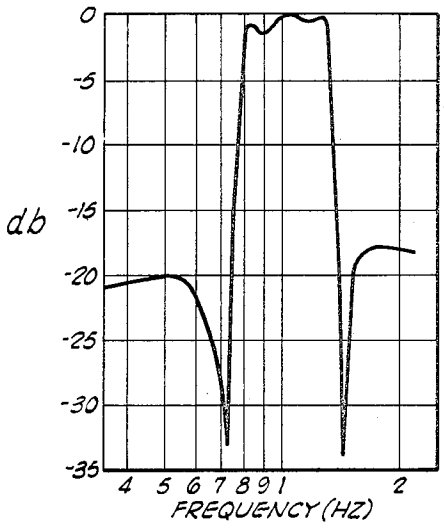


FIG. 8

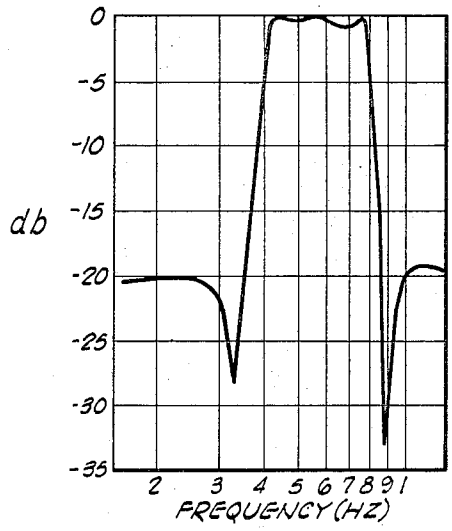


FIG. 9

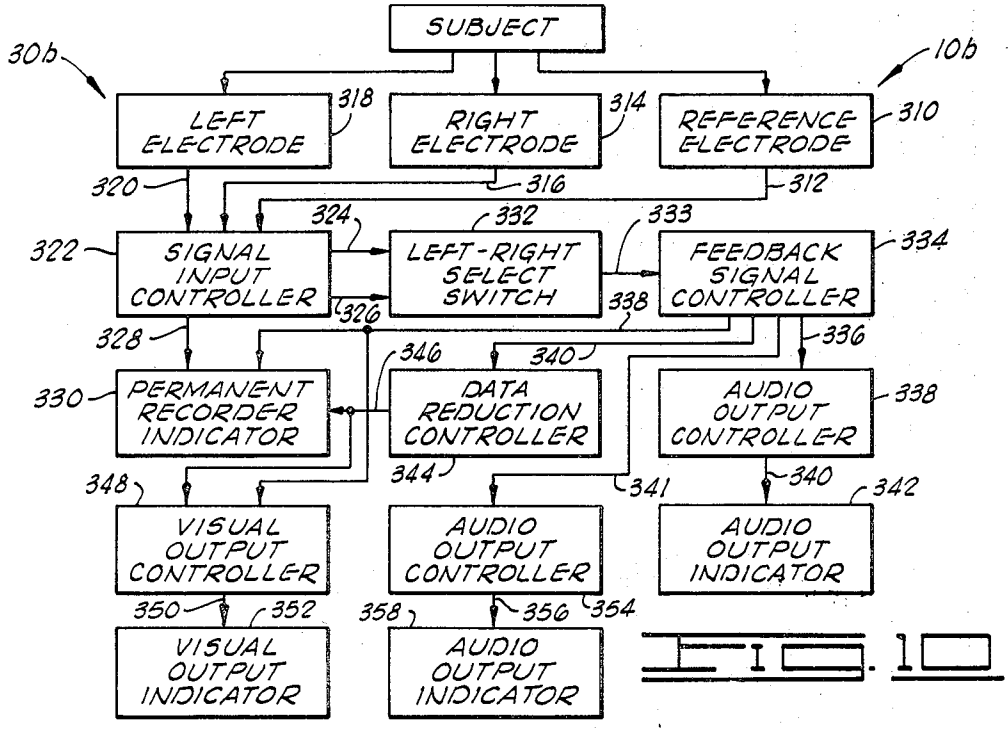


FIG. 10

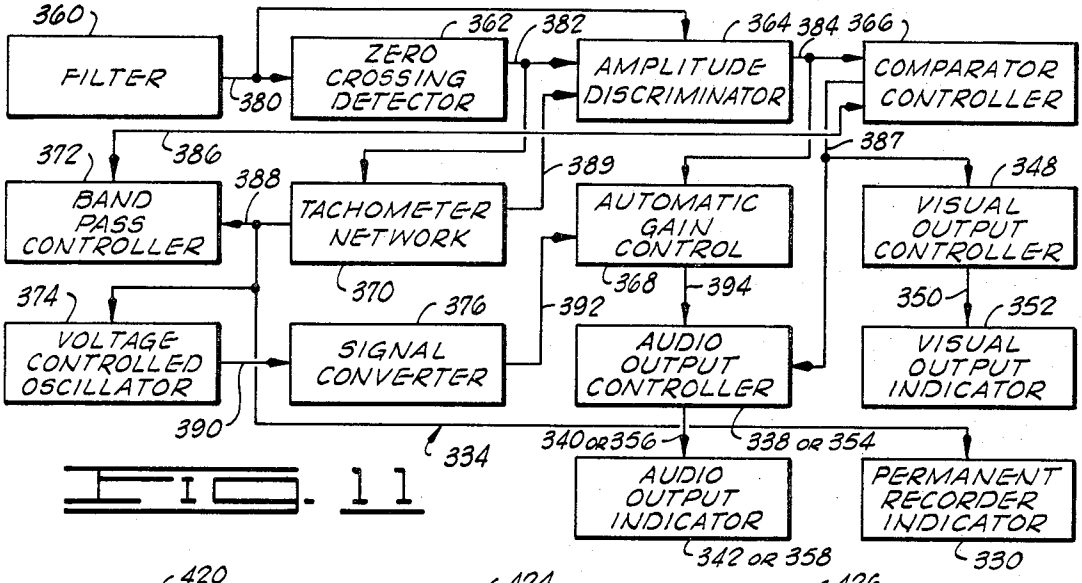


FIG. 11

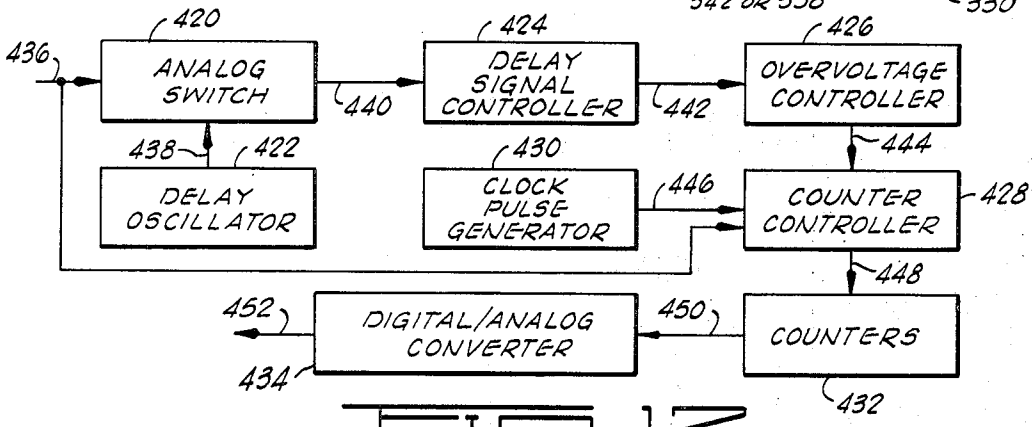


FIG. 12

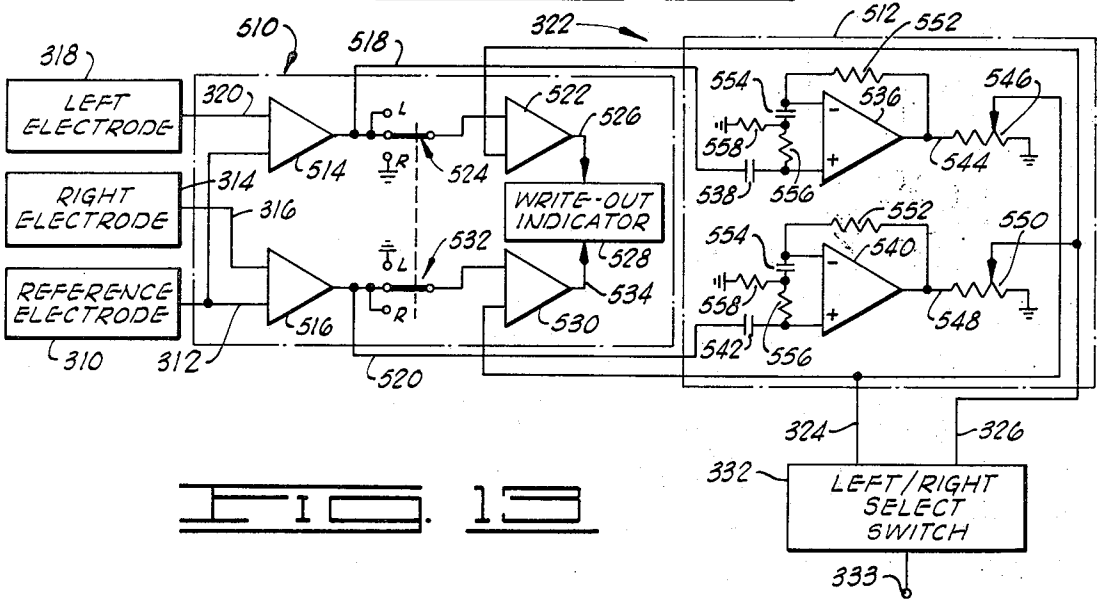


FIG. 13

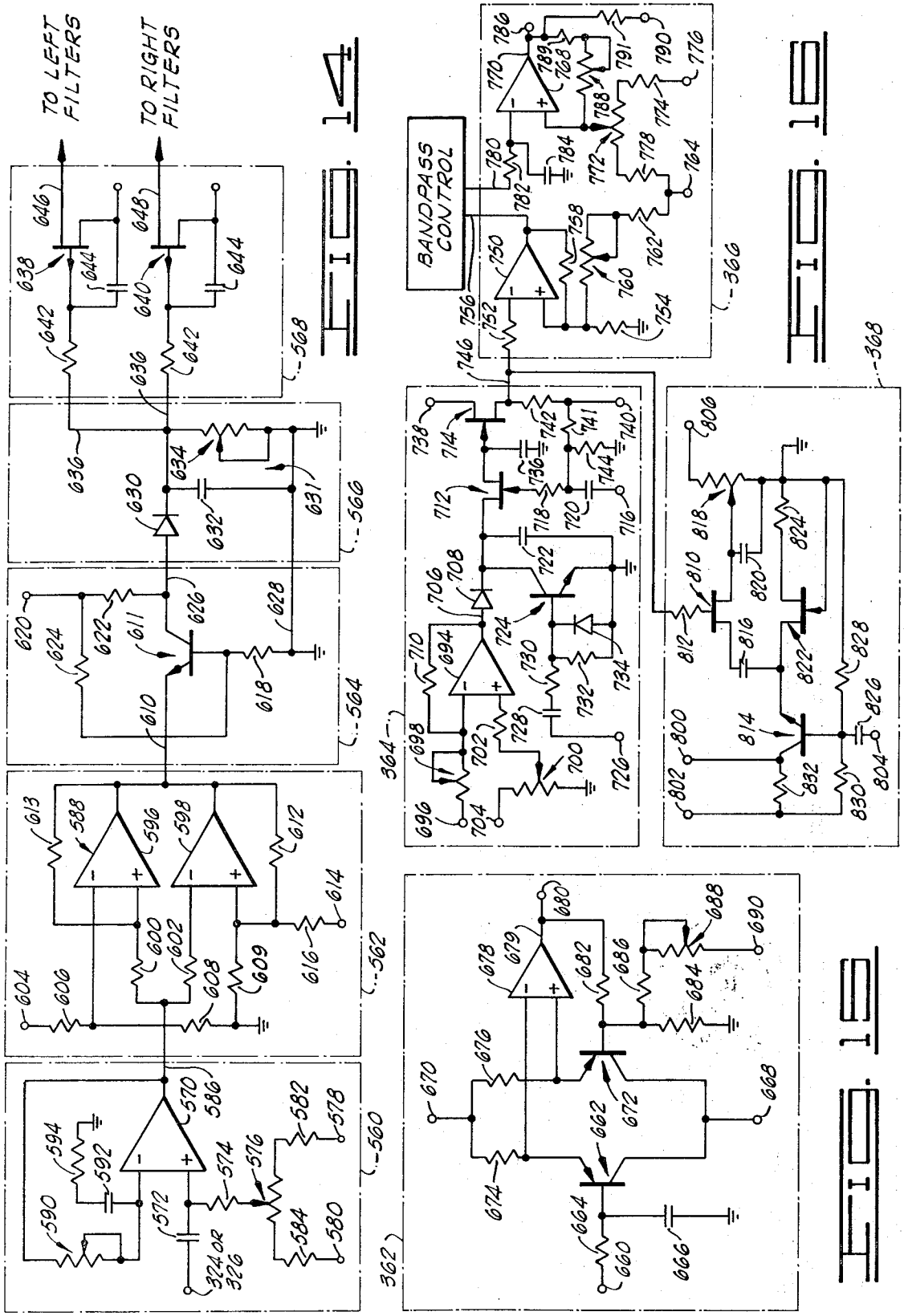


FIG. 14

FIG. 15

FIG. 16

FIG. 15

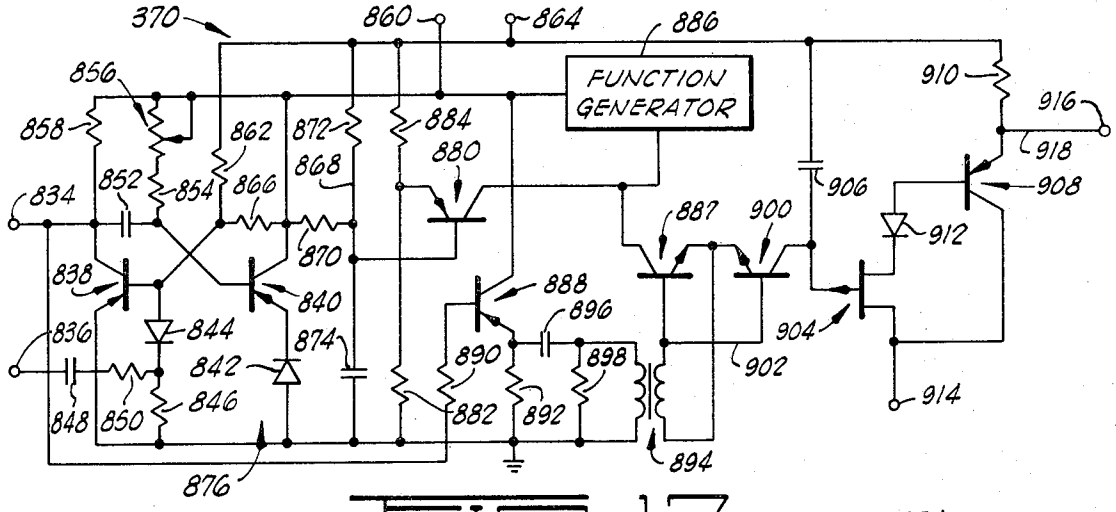
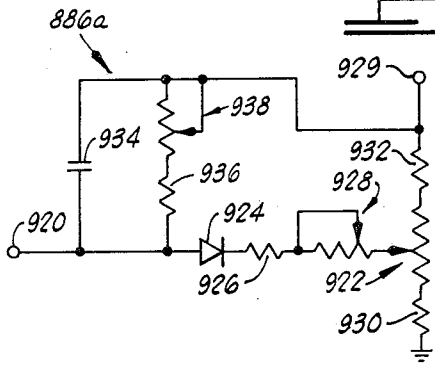


FIG. 17



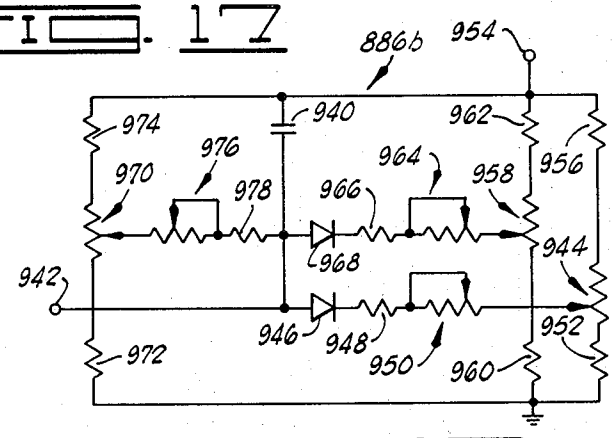


FIG. 18

FIG. 19

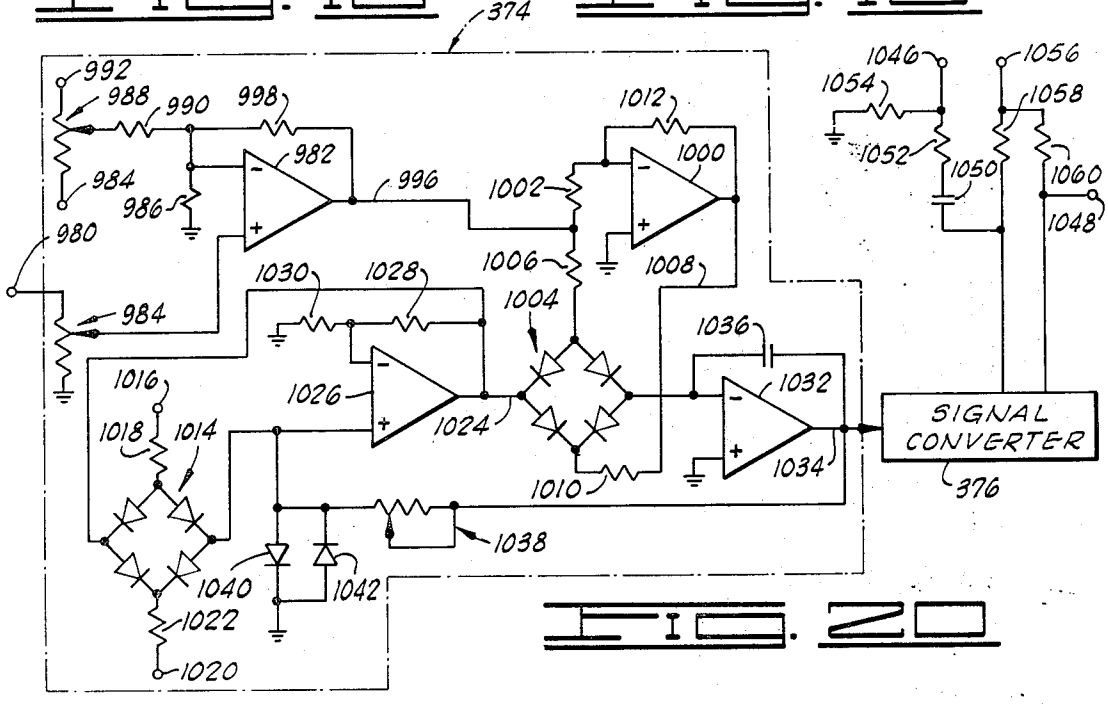


FIG. 20

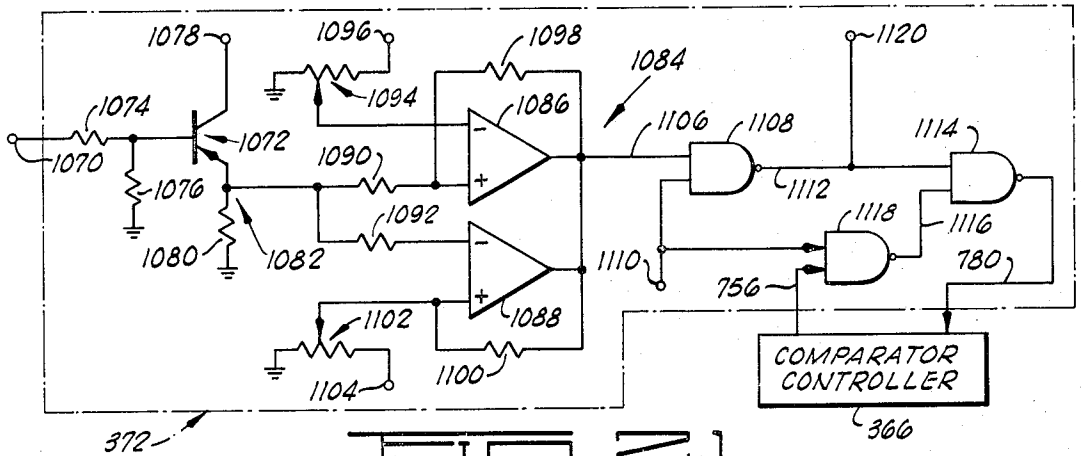


FIG. 21

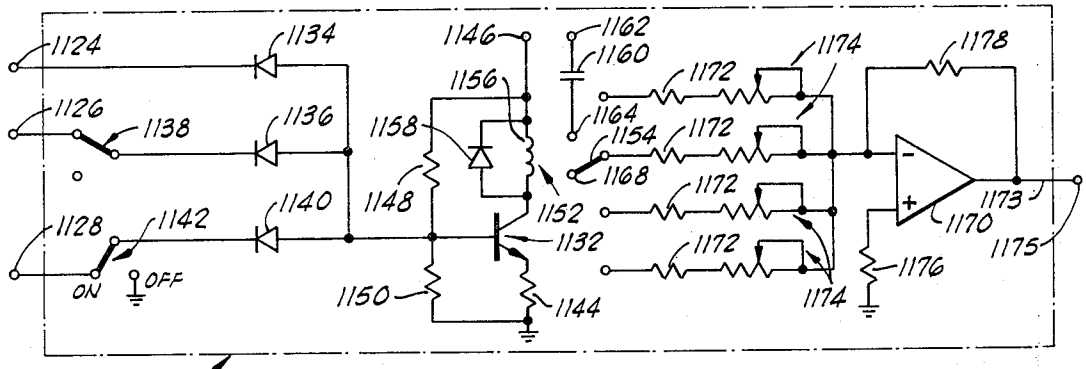


FIG. 22

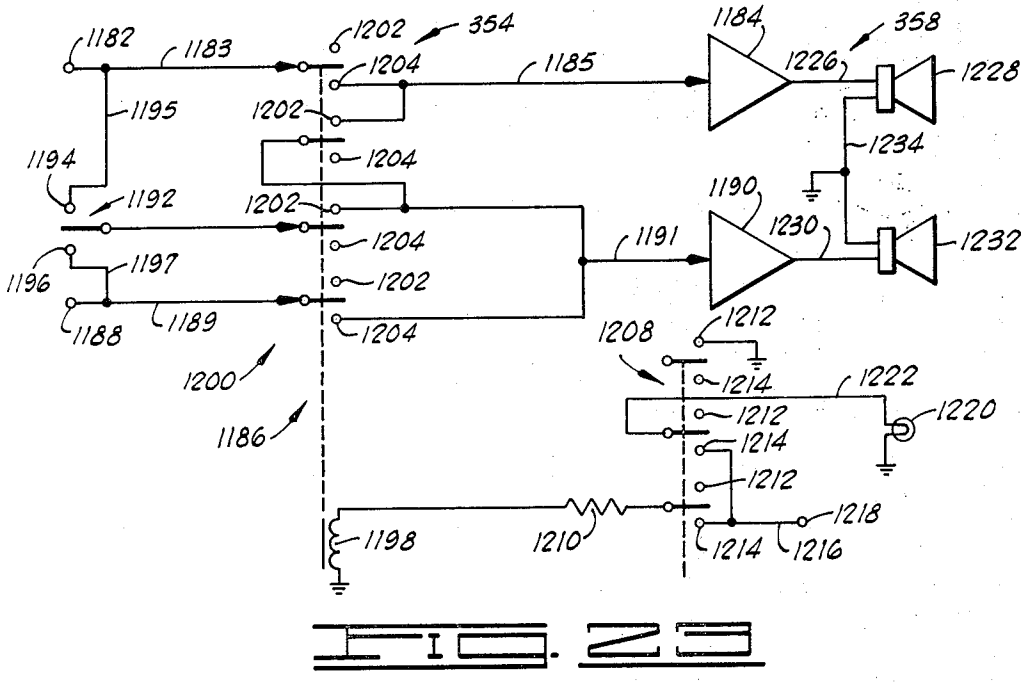


FIG. 23

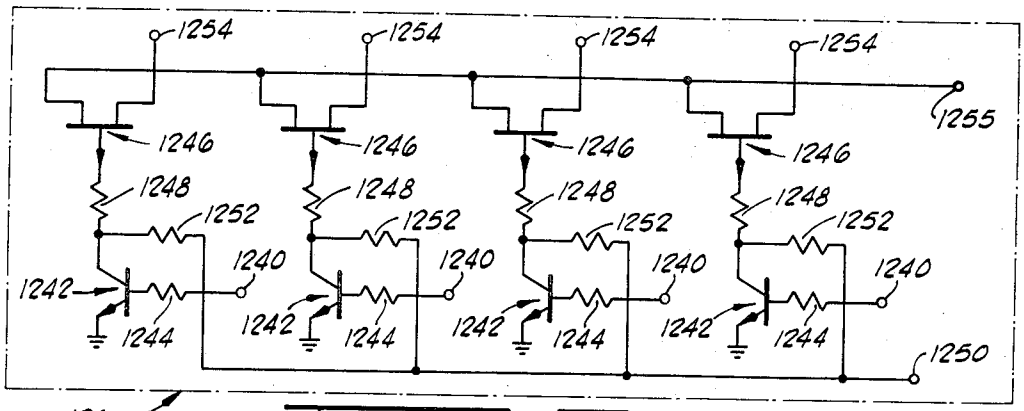


FIG. 24

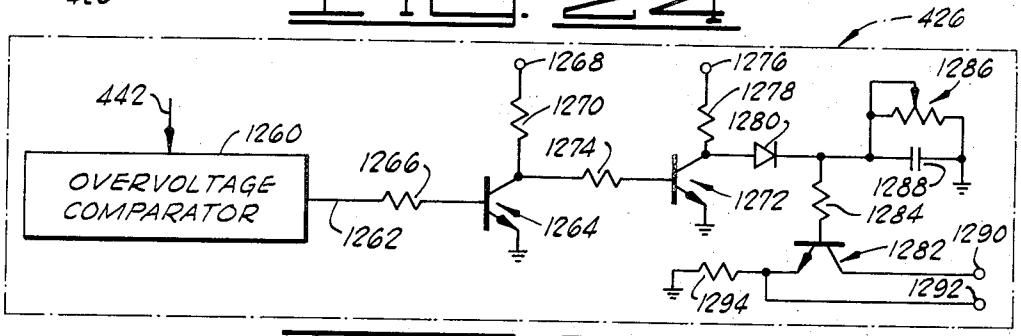


FIG. 25

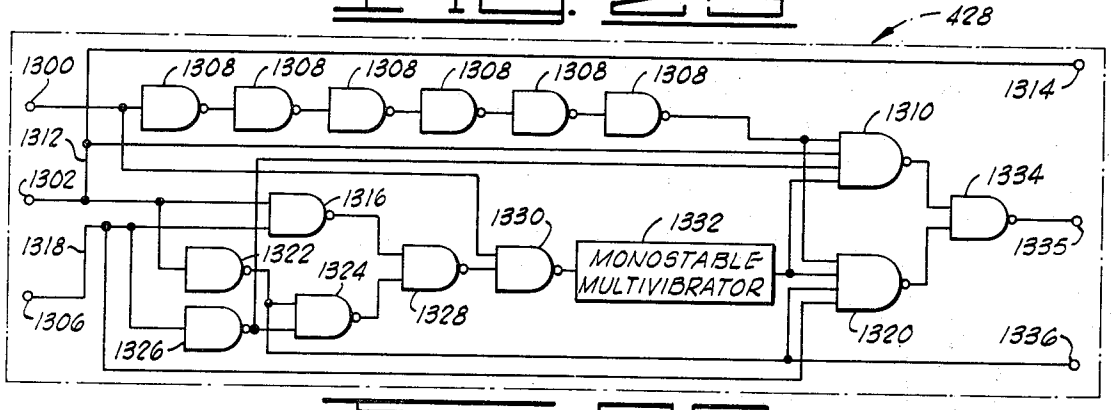


FIG. 26

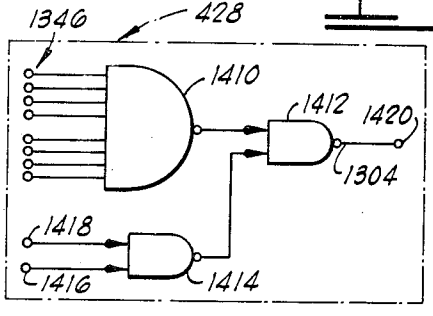


FIG. 27

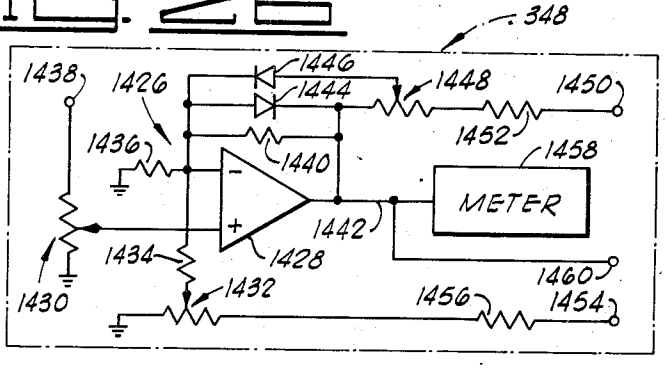


FIG. 28

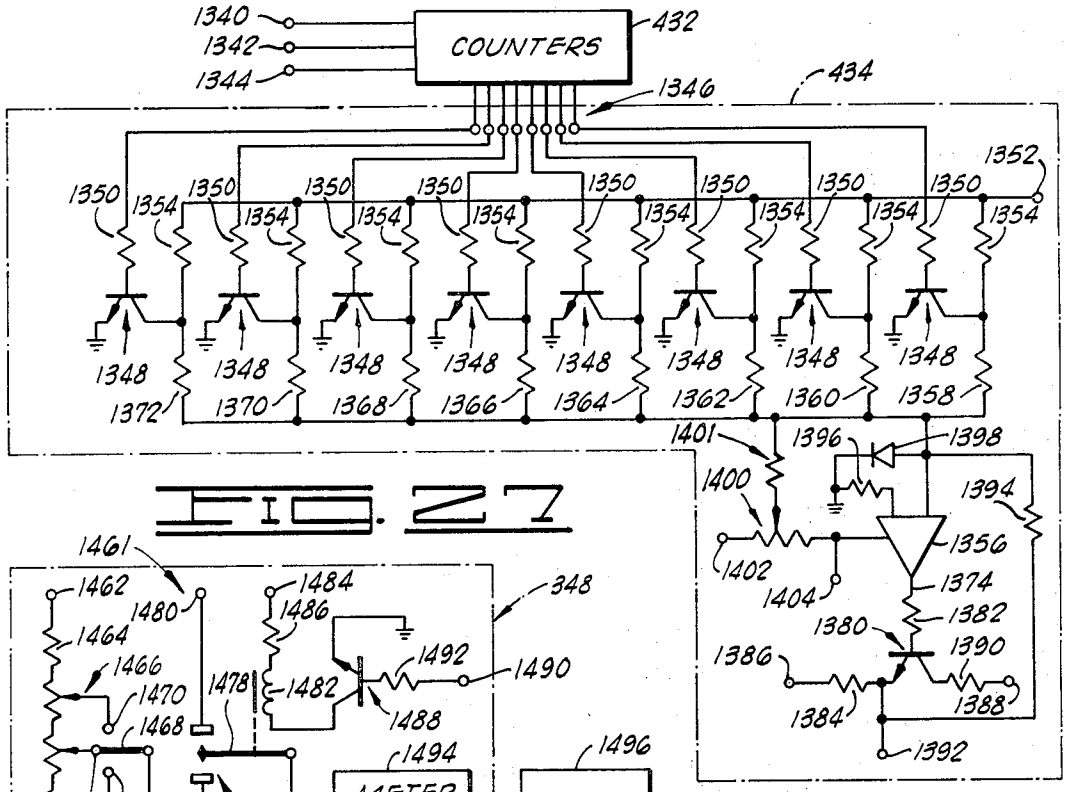


FIG. 27

FIG. 30

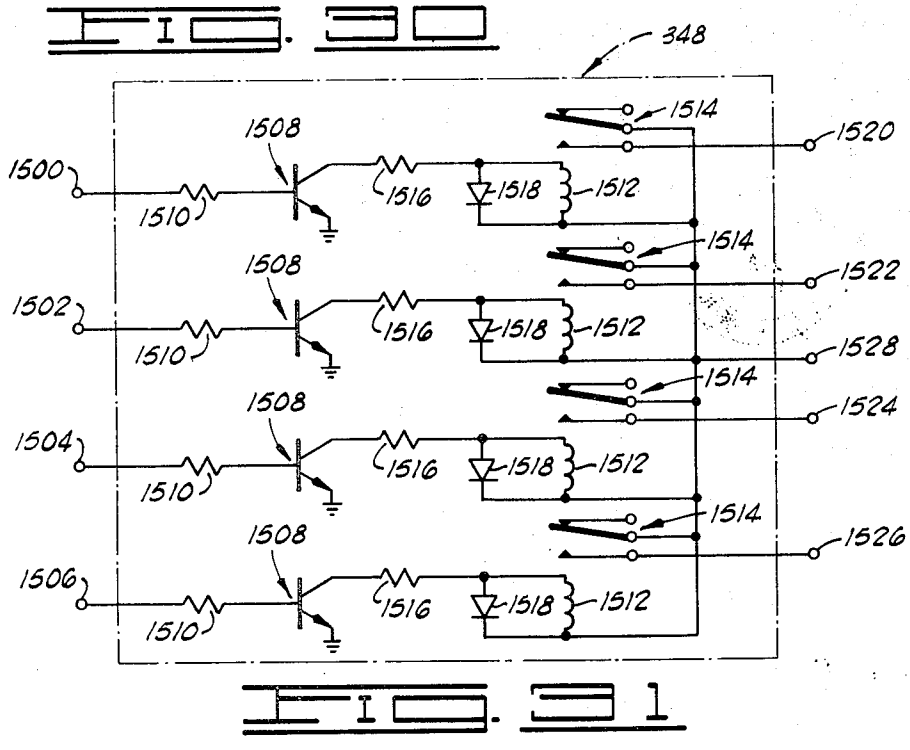


FIG. 31

BIO-FEEDBACK APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates in general to improvements in bio-feedback apparatus and, more particularly, but not by way of limitation, to a bio-feedback apparatus for providing subject-perceivable feedback signals indicative of a controlled signal presence within preselected frequency ranges of a sensed brain-wave potential via separate parallel processing channels.

2. Description of the Prior Art

In the past there. have been various devices constructed to sense brain-wave potentials, such devices being commonly referred to as electroencephalographic equipment, and the sensed brain-wave potentials being commonly referred to simply as "EEG" signals. In the simplest form, the brain-wave potentials are detected and the sensed potentials are plotted on a graph-type, read-out. Other devices have been constructed to sense the brain-wave potentials, and to utilize the sensed potentials or portions thereof for providing certain feedback indications.

voluntary device disclosed in the past was described in the U.S. Pat. No. 3,548,812, issued to Paine. This patent disclosed an electroencephalographic apparatus for quantitatively measuring brain activity and utilizing the measured brain-wave activity for indicating a level of consciousness. The sensed brain-wave activity was amplified and passed through a bandpass filter having a passband generally between 0.7 Hz and 13.0 Hz, the filtered signal being subsequently fed through the three adjustable amplitude comparators having adjustable gain controls. Each of the amplitude comparators produced an output signal when the input signal was within the threshold setting of the amplitude comparator, the three output signals being utilized to generate signals indicative of various stages of sleep or consciousness and subsequently being fed through an analog adder.

The U.S. Pat. No. 3,032,029, issued to Cunningham, disclosed an apparatus for indicating the alertness of an individual and providing a means for stimulating the individual in response to a preset alertness level. The Cunningham apparatus utilized the alpha and the theta EEG signals which were passed through separate bandpass filters, threshold amplifiers, and diode rectifiers to the input of a coincidence circuit constructed to produce an output signal when the alpha and the theta signals were simultaneously applied thereto. The output of the coincidence circuit activated a remote warning and a random sequencer for enabling and disenabling a plurality of gates for activating various other warning devices such as a light stimulator, a sound stimulator and an electrical stimulator.

The U.S. Pat. No. 3,195,533, issued to Fischer, disclosed an apparatus for detecting physiological conditions wherein sensed electrical signals from spaced locations on an individual's body were fed through a filter for passing only certain frequency components and subsequently passed through a control circuit for providing an output signal having an average voltage responsive to the frequency of the sensed electrical signals. The control circuit of the Fischer apparatus generally included: a limiter means for controlling peak amplitude; a discriminator for providing a pulse for each reversal in polarity of the limiter output signal;

and an integrator providing an output signal having an amplitude proportional to the average DC component of the pulses from the discriminator, the integrator output signal being utilized to control the output signal from the Fischer apparatus.

Various other devices for recording and analyzing EEG responses or the like are typlified in the U.S. Pat.: No. 2,860,627, issued to Harden; No. 2,848,992, issued to Pigeon; and No. 3,513,834, issued to Suzuki, for example.

SUMMARY OF THE INVENTION

An object of the invention is to provide a bio-feedback apparatus having an improved, more efficient and more accurate apparatus for developing feedback signals indicative of signal presence within preselected frequency ranges of a sensed brain-wave potential.

Another object of the invention is to provide an improved bio-feedback apparatus for simultaneously providing subject-perceivable and distinguishable audible feedback signals indicative of signal presence within preselected frequency ranges.

One other object of the invention is to provide a bio-feedback apparatus for simultaneously processing brain-wave potentials of a controlling channel through parallel processing channels for developing feedback signals indicative of signal presence in the processing channels.

Yet another object of the invention is to provide an improved bio-feedback apparatus for providing feedback signals indicative of the percentage of time during a predetermined epoch period of time wherein signal presence existed in the sensed brain-wave potential.

An additional object of the invention is to provide a bio-feedback apparatus having an improved apparatus for assuring signal presence within predetermined criteria prior to initiating feedback signals.

Another object of the invention is to provide a bio-feedback apparatus having an improved apparatus for assuring an absence of signal presence for a predetermined period of time prior to terminating feedback signals.

One additional object of the invention is to provide an improved bio-feedback apparatus for selectively providing feedback signals indicative of signal presence within controlled combinations of frequency ranges.

Another object of the invention is to provide an improved apparatus for selectively passing a signal component of a predetermined frequency range through separate processing channels.

A further object of the invention is to provide an improved bio-feedback apparatus which is more efficient and more economical in the construction and operation thereof.

Other objects and advantages of the invention will be evident from the following detailed description when read in conjunction with the accompanying drawings which illustrate various embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatical view of a bio-feedback apparatus for producing feedback signals constructed in accordance with the present invention.

FIG. 2 is a diagrammatical view of another bio-feedback apparatus constructed to produce feedback

signals, similar to the bio-feedback apparatus of FIG. 1.

FIG. 3 is a schematic, diagrammatical drawing showing the amplifier assembly and the sensitivity adjustment assembly of the bio-feedback apparatus of FIG. 2.

FIG. 4 is a schematic view showing a typical oscillator, one such oscillator being utilized in each of the processing channels of the bio-feedback apparatus of FIG. 2.

FIG. 5 is a schematic view of a typical control voltage generator, one such voltage control generator being utilized in each of the processing channels of the bio-feedback apparatus of FIG. 2.

FIG. 6 is a schematic view of the summing amplifier and the output indicator of the bio-feedback apparatus of FIG. 2.

FIG. 7 is a typical filter construction, one such filter being utilized in each of the processing channels of the bio-feedback apparatus of FIG. 2.

FIG. 8 is a diagrammatical view showing a filter response curve for a filter utilized in one of the processing channels constructed in accordance with the filter construction of FIG. 7.

FIG. 9 is a diagrammatical view showing a filter response curve for another filter utilized in one of the processing channels constructed in accordance with the filter construction of FIG. 7.

FIG. 10 is a diagrammatical view, similar to FIGS. 1 and 2, but showing yet another bio-feedback apparatus constructed to produce feedback signals.

FIG. 11 is a diagrammatical view of a portion of the feedback signal controller of the bio-feedback apparatus of FIG. 10.

FIG. 12 is a diagrammatical view of a portion of the data reduction controller of the bio-feedback apparatus of FIGS. 10 and 11.

FIG. 13 is a schematic, diagrammatical view of one signal input controller of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 14 is a schematic view of a portion of the feedback signal controller of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 15 is a schematic view of one zero crossing detector of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 16 is a schematic view of one amplitude discriminator, one comparator controller, and one automatic gain control of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 17 is a schematic view of one tachometer network of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 18 is a schematic view of one function generator constructed for a predetermined frequency range for utilization with one tachometer network, constructed as typically shown in FIG. 17, in the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 19 is a schematic view, similar to FIG. 18, but showing one other function generator constructed for a predetermined frequency range for utilization with one tachometer network, constructed as typically shown in FIG. 17, in the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 20 is a schematic view of one voltage controlled oscillator, one signal converter, and a position of one interconnecting network between a signal converter and an automatic gain control of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 21 is a schematic view of one bandpass controller of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 22 is a schematic view of a portion of one audio output controller of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 23 is a schematic view of a portion of one audio output controller and a portion of one audio output indicator of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 24 is a schematic view of one analog switch of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 25 is a diagrammatical, schematic view of one overvoltage controller of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 26 is a diagrammatical, schematic view of one portion of a counter controller of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 27 is a schematic view of one digital/analog converter of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 28 is a diagrammatical, schematic view of one portion of a counter controller of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 29 is a diagrammatical, schematic view of one portion of one visual output controller and one associated visual output indicator of the bio-feedback apparatus of FIGS. 10, 11 and 12.

FIG. 29, is a diagrammatical, schematic view, similar to FIG. 29, but showing one other portion of one visual output controller and one associated visual output indicator of the bio-feedback apparatus of FIGS. 19, 11 and 12.

FIG. 31 is a schematic view of a portion of one visual output controller of the bio-feedback apparatus of FIGS. 10, 11 and 12.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings in general, and to FIG. 1 in particular, shown therein and designated by the general reference numeral 10, is a bio-feedback apparatus for sensing and detecting physiological and psychophysiological states and changes of a particular subject and providing subject-perceivable feedback indications of the sensed physiological and psychophysiological variables which is particularly useful in phychophysiological research and training. More particularly, the bio-feedback apparatus 10 is useful in inducing, promoting, sensing and detecting certain physiological and psychophysiological variables related to and indicative of various internal states and conditions such as, for example, "attention," "consciousness," "thought," "creativity" and levels of various emotions, and for teaching and enhancing voluntrary control of these various internal states and conditions in a manner which will be made more apparent below.

In general, the bio-feedback apparatus 10 includes: a sensing assembly 12 detecting and sensing various physiological and psychophysiological states and conditions of a subject and providing an output electrical signal 14 responsive thereto; a frequency discriminator 16 receiving the output signal 14 and providing a plurality of output signals 18, each frequency discriminator output signal 18 being indicative of the presence of

a signal within a preselected, discrete frequency band in the sensing assembly output signal **14**; a feedback signal controller **20** for receiving and processing the received frequency discriminator output signals **18**, each output signal **18** being processed in parallel through separate, distinct processing channels of the frequency discriminator **16** and the feedback signal controller **20** for selectively providing predetermined, selected output signals **22** and **24** from the feedback signal controller **20**; a subject feedback controller **26** receiving the feedback signal controller output signal **22** and providing a subject-perceivable output indication indicative of signal presence of the predetermined, preselected, sensed physiological and psychophysiological states and conditions; and a permanent feedback indicator **28** receiving the feedback signal controller output signal **24** and providing a permanent-type of output indication indicative of signal presence of the predetermined, preselected, sensed physiological and psychophysiological states and conditions. The bio-feedback apparatus **10** is constructed to provide a fast, convenient, efficient, positive, and selectively controlled apparatus providing various predetermined, controlled, immediate, subject-perceivable and permanent feedback indications of sensed physiological and psychophysiological states and conditions for subject training and conditioning in the general area of volitional control of various internal states and conditions and for evaluation and analysis to define more finite correlations between the various sensed physiological and psychophysiological states and conditions of one particular subject or particular groups of subjects.

The activity of various areas of an individual's brain has been associated with identifiable and definable conscious and unconscious states and conditions, and it has been determined that subjects can be trained to varying degrees to control both active and passive volitional aspects of the subject's nervous system, for example. It should also be noted that various physiological and psychophysiological internal states and conditions have been correlated and identified with particular frequency components of the sensed potentials produced by as individual's brain. For example, the four major frequency bands are generally referred to as: the "Delta" band having an approximate frequency band generally from 0.5 Hz. to 4.0 Hz.; the "Theta" band having an approximate frequency band generally from 4.0 Hz. to 8.0 Hz.; the "Alpha" band having an approximate frequency band generally from 8.0 Hz. to 13.0 Hz.; and the "Beta" band having an approximate frequency band generally from 13.0 Hz. to 26.0 Hz. Each of these frequency bands has been identified and associated with a particular physiological or psychophysiological state or condition and, in some instances, it has been determined that the presence of two or more of the frequency bands is also indicative of a predetermined or identifiable physiological or psychophysiological state or condition.

In the past, devices have been developed for measuring and recording the rhythmetically varying potential produced by an individual's brain, the potential being sensed or detected by electrodes applied to preselected portions of the individual's scalp and the devices were generally constructed to receive the sensed potential and provide a chart-type of output indicative thereof. Apparatus of the type referred to above is generally known as an electroencephalograph, and the brain-wave signals which were sensed and recorded by the electroencephalograph are commonly referred to by the letter designations "EEG."

In a preferred form, the bio-feedback apparatus **10**, shown in FIG. **1**, is constructed to sense the varying potential produced by the activity of an individual's brain, and to provide the various feedback indications indicative of or in response to the presence of predetermined portions of the sensed varying potential. The sensing apparatus **12**, more particularly, includes a brain-wave indicator **30** having a portion connected to sense and detect the varying potentials produced by the individual's brain and provide an output signal **32** responsive thereto and indicative thereof; and a brain-wave signal generator **34** receiving the brain-wave indicator output signal **32** and providing the amplified output signal **14** responsive thereto indicative of the sensed brain-wave potential, as mentioned before. In one form, the brain-wave indicator **30** includes a number of electrodes which are attached to the individual's scalp, the electrodes being constructed, attached and positioned to sense the brain-wave potential produced by the subject and provide the output signal **32**. Since the sensed potentials produced by an individual's brain are of a small amplitude, the brain-wave signal generator, more particularly, receives the electrodes' output signal **32** and provides an amplified output signal **14**.

In one form, the brain-wave indicator **30** is attached to the subject to sense brain-wave potentials from two or more preselected portions of the individual's scalp, thereby providing two or more distinct brain-wave potentials to the input of the brain-wave signal generator **34**. In this form, the brain-wave signal generator **34** is constructed such that one of the sensed brain-wave potentials is selectively provided at the brain-wave signal generator output signal **14**; the distinct, sensed brain-wave potentials each being referred to below as "channels" and the brain-wave potential selected via the brain-wave signal generator **34** for controlling the feedback indications being referred to below as the "controlling channel."

The controlling channel signal **14** is connected to the frequency discriminator **16**, the frequency discriminator **16** selectively detecting predetermined frequency components of the controlling channel signal **14** for processing through separate, parallel "processing channels" of the bio-feedback apparatus **10**. Thus, each processing channel of the bio-feedback apparatus **10** processes one frequency component, defined by the predetermined passbands of the frequency discriminator **16**, and each processing channel is processed via the feedback signal controller **20** to develop and generate the feedback signals **22** and **24**. The processing of the preselected frequency components of the detected, received brain-wave potential via parallel processing channels of the feedback signal controller **20** allows the various components and assemblies of the bio-feedback apparatus **10** to be sized and constructed for processing a single preselected signal having a predetermined frequency band, thereby facilitating the construction and design of a more efficient, more accurate signal processing assembly for indicating signal presence of a particular frequency component in the detected brain-wave potential. The utilization of separate signal processing channels for the various predetermined, preselected frequency components also provides a bio-feedback apparatus **10** which has a substan-

tially higher stability and, in general, a more selective type circuitry for providing preselected, controlled feedback signals, yet eliminating undesirable artifacts such as those commonly referred to in the art as "EEG spike discharges," eye blinks, muscle artifacts, twitches, and the like, for example.

In one preferred embodiment, brain-wave potentials are detected and sensed at two, preselected scalp sites, and the two sensed, brain-wave potentials are processed in parallel through the bio-feedback apparatus via separate channels, each channel including a plurality of parallel processing channels. In this embodiment, the two channels are each utilized to provide subject-perceivable audio feedback in a monaural or stereo form, and one channel is utilized for control of the artifacts generated in the sensed brain-wave potentials and for control of subject-perceivable feedback presented in a visual and permanent form, as will be made more apparent below.

Electrodes are attached to the subject for detecting and sensing the brain-wave potentials and, initially, two scalp sites on the individual's head are selected (preferably on opposite sides of the subject's head and generally in the occipital areas) and the electrodes are attached at these preselected scalp sites. In general, the preselected scalp sites are cleaned with an alcohol, electrode paste which is rubbed into the skin to remove the horny layer and permeate the dermal surface with a conductive medium, the electrode paste being utilized to generally assure a low electrode resistance for facilitating the production of a low-noise signal for subsequent processing by the bio-feedback apparatus **10.** The electrodes can be applied to the preselected scalp sites by using a Bentonite clay mixture or the like covered by a plastic film, the plastic film being utilized to prevent or substantially reduce the drying tendency of the clay mixture. In one form, the subject's left ear lobe and right ear lobe are then tied together for use as a reference for monopolar recording of the brain-wave potential. Finally, the electrode attachment is made by rubbing in a salt paste or the like and attaching an ear clip electrode (generally filled with salt paste) to the ear. The ground or neutral is attained via a plate electrode attached to a portion of the subject's wrist, for example. The use of electrodes and the attachment of the electrodes to various portions of the subject to detect brain-wave potentials, as generally described before, is well known in the art. It should be noted, however, that the electrodes may be attached to particular portions of the individual's scalp to obtain a particular brain-wave potential for processing by the bio-feedback apparatus **10.**

Description of FIGS. 2 Through 9

Shown in FIGS. 2 through 9 is a bio-feedback apparatus **10***a* having: a brain-wave indicator **30***a* producing an output signal **32***a* indicative of the individual's brain-wave potential; a brain-wave signal generator **34***a;* a frequency discriminator **16***a;* and a feedback signal controller **20***a*. As diagrammatically shown in FIG. **2,** the brain-wave indicator **30***a* generally includes: a reference electrode **38** providing an output signal **40**; a neutral electrode **42** providing an output signal **44**; and an active electrode **46** providing an output signal **48.** The reference electrode **38,** the neutral electrode **42,** and the active electrode **46** are, in a preferred form, each attached to preselected scalp sites of the subject for detecting and sensing brain-wave potentials, in a manner as generally described before. More particularly and for example, the reference electrode **38** can be attached to the subject's left ear lobe, the neutral electrode **42** can be attached to the subject's right ear lobe, and the active electrode **46** can be attached to a predetermined scalp site on the individual's head such as the left occipital area or the right occipital area of the individual's head, it being understood that the particular electrodes utilized and the particular attachment sites of the electrodes on the subject are determined in each application such that the electrodes **38, 42** and **46** detect and sense particular, preselected brain-wave potentials.

The output signals **40, 44** and **48** of the electrodes **38, 42** and **46** are each connected to and received by a portion of the brain-wave signal generator **34***a*. As shown in FIG. **2,** the brain-wave signal generator **34***a*, more particularly, includes: a receiver control **50** connected to the electrodes **38, 42** and **46** to receive the output signals **40, 44** and **48,** respectively, therefrom and to provide an output signal **52** in response to the received signals **40, 44** and **48**; a preamplifier **54** which is connected to the receiver control **50** receiving the receiver control output signal **52** and providing an amplified output signal **56** in response thereto; an amplifier assembly **58,** having a plurality of amplifiers, each amplifier receiving the amplified output signal **56** and providing an amplified output signal in response to the received preamplifier output signal **56**; and a sensitivity adjustment assembly **60** having a portion connected to each amplifier of the amplifier assembly **58** for adjusting the threshold level of each amplifier. The frequency discriminator **16**a includes a filter assembly **62** having a filter receiving the amplified output signal from the amplifier assembly **58,** each filter selecting and passing signals within a predetermined frequency range. The feedback signal controller **20***a* includes: a control voltage generator assembly **64** having one portion connected to one of the filters of the filter assembly **62,** each portion receiving the filter output signal from one of the filters of the filter assembly **62** and developing a feedback control voltage indicating predetermined signal presence within the frequency band of the filter connected thereto; an oscillator assembly **66** having one portion connected to a portion of the control voltage generator assembly **64** for receiving the feedback control voltages developed via the control voltage generator assembly **64,** the oscillator assembly **66** providing a plurality of oscillator output signals in response to a predetermined, received feedback control voltage from the control voltage generator assembly **64,** each oscillating output signal having an identifiable frequency indicative of a signal presence within a preselected frequency range; a volume control assembly **68** receiving the output signals from the oscillator assembly **66,** and selectively and adjustingly controlling the volume of each signal; an on-off control assembly **70** interposed between the oscillator assembly **66** and the volume control assembly **68** for selectively passing predetermined oscillating output signals from the oscillator assembly **66**; a summing amplifier **72** receiving the oscillating output signals connected thereto via the on-off control assembly **70** and providing an output signal **74** in response to the received input signals; and an output indicator **76** receiving the summing amplifier output signal **74** and providing a subject-perceivable feed-

back indication responsive to the received signal from the summing amplifier **72.**

As shown in FIG. **2,** the electrodes **38, 42** and **46** are connected to the subject such that a single brain-wave potential is sensed and detected; the single, sensed brain-wave potential constituting the controlling channel of the bio-feedback apparatus **10a.** The bio-feedback apparatus **10***a* includes three processing channels **78, 80** and **82,** each processing channel **78, 80** and **82** receiving the preamplifier output signal **56** and developing a feedback signal indicative of a controlled, predetermined signal presence.

The amplifier assembly **58,** more particularly, includes an Alpha amplifier **84,** a Beta amplifier **86,** and a Theta amplifier **88;** the Alpha amplifier **84** receiving the preamplifier output signal **56** and providing an amplified output signal **90** in response thereto; the Beta amplifier **86** receiving the preamplifier output signal **56** and providing an amplifier output signal **92** in response thereto; and the Theta amplifier **88** receiving the preamplifier output signal **56** and providing an amplifier output signal **94** in response thereto.

An Alpha sensitivity adjustment **96** is connected to the Alpha amplifier **84** to receive the amplified output signal **90** therefrom and to provide an output signal controlling the threshold level of the Alpha amplifier **84;** a Beta sensitivity adjustment **98** is connected to the Beta amplifier **86** to receive the amplified output signal **92** therefrom and provide an output signal for controlling the threshold level of the Beta amplifier **86;** and a Theta sensitivity adjustment **100** is connected to the Theta amplifier **88** to receive the amplified output signal **94** therefrom and provide an output signal for controlling the threshold level of the Theta amplifier **88.** The Alpha sensitivity adjustment **96,** the Beta sensitivity adjustment **98** and the Theta sensitivity adjustment **100** are each part of the sensitivity adjustment assembly **60,** each of the sensitivity adjustments **96, 98** and **100** controlling the threshold level of the amplifier **84, 86** and **88** connected thereto, during the operation of the bio-feedback apparatus **10a.**

The filter assembly **62** includes an Alpha filter **102,** a Beta filter **104** and a Theta filter **106.** The Alpha filter **102** is connected to the Alpha amplifier **84** to receive the amplified output signal **90,** the Alpha filter **102** being constructed, in one form, to have a pass band in the range of approximately 8.3 Hz. to 13.0 Hz. The Beta filter **104** is connected to the Beta amplifier **86** for receiving the amplified output signal **92,** and is constructed, in one form, to have a pass band in the range of approximately 14.0 Hz. to 26.0 Hz. The Theta filter **106** is connected to the Theta amplifier **88** to receive the amplified output signal **94,** and is constructed to have a pass band in the range of approximately 4.0 Hz. to 7.7 Hz. The Alpha filter **102,** the Beta filter **104** and the Theta filter **106** each have an output signal **108, 110** and **112,** respectively, and each output signal **108, 110** and **112** is a signal having a frequency within the pass band of the filter connected thereto, the filter output signals **108, 110** and **112** thereby indicating the signal presence in the sensed, detected brain-wave potential of a discrete, predetermined frequency band (corresponding to the pass band of the particular filter).

The control voltage generator assembly **64,** more particularly, includes an Alpha control voltage generator **114,** a Beta control voltage generator **116** and a Theta control voltage generator **118.** The Alpha control voltage generator **114** receives the Alpha filter output signal **120** in response thereto indicating signal presence of a signal having a frequency generally between 8.3 Hz. and 13.0 Hz. (the pass band of the Alpha filter **102**). The Beta control voltage generator **116** receives the Beta filter output signal **110** and produces a feedback control signal **122** in response thereto indicating signal presence of a signal having a frequency generally between 14.0 Hz. and 26.0 Hz. (the pass band of the Beta filter **104**). The Theta control voltage generator **118** receives the Theta filter output signal **112** and provides a feedback control signal **124** in response thereto indicating signal presence of a signal having a frequency generally between 4.0 Hz. and 7.7 Hz. (the pass band of the Theta filter **106**).

The oscillator assembly **66** includes an Alpha oscillator **126,** a Beta oscillator **128** and a Theta oscillator **130.** The Alpha oscillator **126** receives the feedback signal **120** from the Alpha control voltage generator **114** and provides an oscillating output signal **132** in response thereto; the Beta oscillator **128** receives the feedback control signal **122** of the Beta control voltage generator **116** and provides an oscillating output signal **134** in response thereto; and the Theta oscillator **130** receives the feedback control signal **124** from the Theta control voltage generator **118** and provides an oscillating output signal **136** in response thereto.

In a preferred form, the Alpha oscillator **126** is constructed to provide an output signal **132** having a frequency of approximately 800 Hz.; the Beta oscillator **128** is constructed to provide an output signal having a frequency of approximately 1100 Hz.; and the Theta oscillator **130** is constructed to provide an output signal having a frequency of approximately 600 Hz. The last-mentioned frequencies of the output signals **132, 134** and **136** of the oscillators **126, 128** and **130,** respectively, were selected, in one operational embodiment, to provide audible, subject-perceivable feedback signals which can be identified when simultaneously presented via the output indicator **76.**

The volume control assembly **68** includes volume controls **138, 140** and **142** receiving the oscillating output signals **132, 134** and **136,** respectively, each of the volume controls **138, 140** and **142** being constructed to adjust the "loudness" of the output signals **132, 134** and **136** connected thereto. The on-off control assembly **70** includes on-off controls **144, 146** and **148,** each being interposed generally between one of the oscillators **126, 128** and **130** and one of the volume controls **138, 140** and **142,** connected thereto, as shown in FIG. **2.** Each of the on-off controls **144, 146** and **148** is constructed to connect and disconnect the output signal of the oscillator connected thereto in the "on" and the "off" positions, respectively, of the on-off controls **144, 146** and **148.** In this manner, the feedback indications provided by the bio-feedback apparatus **10a** can be selectively controlled such that any one of the oscillators **126, 128** and **130** or any combination of the oscillators **126, 128** and **130** can be connected to the summing amplifier **72** and utilized to provide feedback indications for training a subject or for indicating particular physiological and psychophysiological states of the subject.

In summary, the processing channel **78** includes the Alpha amplifier **84,** the Alpha sensitivity adjustment **96,** the Alpha filter **102,** the Alpha control generator **114,** the Alpha oscillator **126,** the volume control **138**

and the on-off control **144.** In a similar manner, the processing channel **80** includes the Beta amplifier **86,** the Beta sensitivity adjustment **98,** the Beta filter **104,** the Beta control voltage generator **116,** the Beta oscillator **128,** the on-off control **146** and the volume control **140;** and the processing channel **82** includes the Theta amplifier **88,** the Theta sensitivity adjustment **100,** the Theta filter **106,** the Theta control voltage generator **118,** the Theta oscillator **130,** the on-off control **148** and the volume control **142.** The various components and assemblies of the processing channels **78, 80** and **82** cooperate to develop and provide the feedback signals **132, 134** and **136,** respectively, to the summing amplifier **72** indicating the presence of a signal having a frequency within the pass band of the Alpha filter **102,** the Beta filter **104,** and the Theta filter **106,** respectively.

The output signal **72** of the mixer or the summing amplifier **72** is indicative of and contains the oscillating output signals **132, 134** and **136,** in an "on" position of the respective on-off controls **144, 146** and **148,** the summing amplifier output signal **74** being a mix of the oscillator output signals **132, 134** and **136.** The output indicator **76** is constructed to provide subject-perceivabile audible and visual output indications indicative of signal presence at predetermined criteria and having a frequency within the pass band of the processing channels **78, 80** and **82.**

It should be particularly noted that other processing channels, similar to the processing channels **78, 80** and **82** can be incorporated in the bio-feedback apparatus **10***a* to provide a feedback indicative of signal presence of signals having frequencies within frequency band ranges other than the Alpha band, the Beta band, and the Theta band, described before. The additional processing channels can be connected in parallel with the processing channels **78, 80** and **82,** described before, each additional channel generally including the various components and assemblies identified with and connected in the processing channels **78, 80** and **82,** described above.

Referring more particularly to the receiver control **50,** as shown in FIG. **2,** the receiver control **50,** in a preferred form, can include a switching network interposed between the electrode output signals **40, 44** and **48** and the preamplifier **52** for selectively connecting the reference electrode **38,** the neutral electrode **42** and the active electrode **46** into various portions of an electrode resistance check network wherein the resistance between the reference electrode **38** and the neutral electrode **42** can be measured, in one switch position, and the electrode resistance generally between the reference electrode **38** and the active electrode **46** can be measured, in one other switch position, for example. In this form, a battery type supply voltage, for example, can be connected across the electrodes and a resistance type network can be interposed between the electrodes being tested and a meter such that the meter provides an output indication of the electrode resistance, thereby assuring that the electrical resistances of the electrodes **38, 42** and **46** are within operable tolerance limits before switching the receiver control **50** to an operate position wherein the output signals **40, 44** and **46** of the electrodes are connected to the preamplifier **54.**

The bio-feedback apparatus **10***a*, as shown in FIG. **2,** is particularly constructed to provide a compact, portable feedback type of apparatus and, in this form, the operating supply voltages for the various components and assemblies of the bio-feedback apparatus **10***a* would be supplied via a battery type of power supply. In this form, the receiver control **50** can also be constructed to include a switch position for connecting the batteries to a meter type indicator for checking the operating condition of the batteries, and a built-in battery recharger unit can also be incorporated with the bio-feedback apparatus **10***a*.

The preamplifier **54** is, in a preferred form, a differential, fixed gain type of preamplifier having a low noise level and constructed to receive low amplitude signals from the electrodes **38, 42** and **46.** Preamplifiers of this type are commercially available, and the construction and operation of such preamplifiers is well known in the art.

As shown in FIG. **3,** and, as generally described before, the preamplifier output signal **56** is applied to the input of three amplifiers or, more particularly, to the input of the Alpha amplifier **84,** the input of the Beta amplifier **86,** and the input of the Theta amplifier **88,** the amplifiers **84, 86** and **88** each being connected in parallel for receiving the preamplifier output signal **56.** The ground connection is provided via a resistor **150,** as shown in FIG. **3.**

In one form, the Alpha amplifier **84,** the Beta amplifier **86** and the Theta amplifier **88** are each of the integrated circuit type of construction and a positive power supply (not shown) is connected to each amplifier **84, 86** and **88** via the pin connections **152** and a negative power supply (not shown) is connected to each amplifier **84, 86** and **88** via the pin connections **154.** In this form, a resistor **156** connected in series with a capacitor **158,** the resistor **156** and the capacitor **158** being connected to the internal components of each amplifier **84, 86** and **88,** and a resistor **160** connected in series with a capacitor **162** and in parallel with a capacitor **164** is also connected to the internal components of each ampoifier **84, 86** and **88** for frequency compensation of the amplifiers **84, 86** and **88,** the capacitor **164** being also conected to the respective amplifier output signal, as shown in FIG. **3.** Each amplifier **84, 86** and **88** also includes a feedback loop **165** between the amplifier output signal and the negative input differential signal to each of the amplifiers **84, 86** and **88,** and a pair of diodes **166** and **168** are interposed in each feedback loop. The negative differential input to the amplifiers **84, 86** and **88** is connected to ground via a resistor **170** interposed in each ground connection.

An additional feedback loop **172** is connected between the input signal **56** and the output signal of each amplifier **84, 86** and **88,** and a resistor **174** and a variable resistor **176** are interposed in each feedback loop **172.** As shown in FIG. **3,** the feedback loop **174** is parallel to and generally included within the feedback loop **165.** Each of the amplifiers **84, 86** and **88** is generally a differential type of amplifier having two input circuits, one input circuit being the preamplifier output signal **56** and the other input circuit being controlled via the feedback loops **156** and **172** and, more particularly, being controlled via the variable resistor **176** interposed in the feedback loop **172** therein. The feedback loops **172** and the variable resistor **176** interposed therein constitute the sensitivity adjustments **96, 98** and **100** connected to the amplifiers **84, 86** and **88.** Each amplifier **84, 86** and **88** thus responds to the dif-

ference between the two input circuits connected thereto, and the sensitivity adjustments **96, 98** and **100** essentially constitute the gain control for amplifiers **84, 86** and **88,** the gain controls or sensitivity adjustments **96, 98** and **100** being, in a preferred form, calibrated in peak-to-peak microvolts and used as threshold sensitivity adjustments for the frequency bands processed through the various processing channels **78, 80** and **82.**

Thus, by selectively adjusting the variable resistors **176** of the sensitivity adjustment assembly **60,** the differential amplifiers **84, 86** and **88** are each adjusted to receive and amplify an input signal controlled by the threshold level setting of the sensitivity adjustment assembly **60** and to reject the preamplifier output signals **56** which do not exceed the minimum threshold level setting of the sensitivity adjustment assembly **60,** thereby assuring amplified output signals **90, 92** and **94** from the amplifiers **84, 86** and **88** of a minimum amplitude and assuring that the bio-feedback apparatus **10** will provide feedback signals only when receiving input signals thereto of a minimum amplitude.

The amplifier output signals **90, 92** and **94** are fed through the Alpha filter **102,** the Beta filter **104** and the Theta filter **106,** respectively, each filter **102, 104** and **106** selecting and passing only those portions of the input signal having a frequency within the pass band of the particular filter, as described before. Each filter **102, 104** and **106** is, more particularly, an active, bandpass type of filter having an elliptical response. A filter construction, typical of the construction of the Alpha filter **102,** the Beta filter **104** and the Theta filter **106,** is shown in FIG. **7,** and the filter basically comprises three cascaded, infinite-gain universal type active filter sections (referred to in FIG. 7 as a first active filter stage **180,** a second active filter stage **182,** and a third active filter stage **184**). The input signal **90** or **92** or **94** to the filters **102, 104** and **106,** respectively, is connected to the first filter stage **180** via a first feedback network comprising the resistors **186, 188** and **190** and a capacitor **192.** The feedback network connected to the first filter stage **180** is constructed to produce a frequency function (jw) axis of zero, forming an elliptic function characteristic outside the pass band at the lower frequency (f_L) of the filter pass band. The first filter stage **180,** in a preferred form, has a relatively low "Q" bandpass function with its resonant frequency (f_o) at the resonant frequency of the filter **102, 104** or **106** ("Q" being a quality factor which generally indicates the sharpness of frequency sensitivity of the filter).

The output of the first filter stage **180** is connected to the second filter stage **182** via a conductor **194** through a second feedback network comprising the resistors **196, 198** and **200** and the capacitor **202,** the second feedback network producing a frequency function (jw) axis for the elliptic function characterisitc outside the filter pass band on the upper frequency (f_u) side of the filter pass band. The second filter stage **182** is, in a preferred form, constructed to have a relatively medium Q bandpass function having its (the second filter stage **182**) resonant frequency (f_o) just below the upper frequency (f_u) response of the filters **102, 104** and **106.**

The output of the second filter stage **182** is coupled to the third filter stage **184** via conductor **204,** the output of the third filter stage **184** being the filter output signals **108** or **110** or **112** of the filters **102, 104** or **106,** respectively. The third filter stage **184** is, in a preferred form, an adjustable gain, relatively medium Q bandpass function, with its (the third filter stage **184**) resonant frequency located jsut above the lower frequency (f_L) response of the filters **102, 104, 106.** It should also be noted that, in one other form, the positioning of the second filter stage **182** and the third filter stage **184** can be reversed with respect to the diagrammatical, schematic showing of the typical filter construction in FIG. **7,** without substantially effecting the total filter response.

The filter construction, as shown in FIG. **7** and described above, is constructed to provide a filter having a relatively low pass band ripple and a substantially high or sharp rolloff rate outside the pass band, thereby providing a selective filter response to obtain a sharp channel separation between the frequency bands selected and passed by the Alpha filter **102,** the Beta filter **104** and the Theta filter **106** for processing through the parallel processing channels **78, 80** and **82,** respectively, of the bio-feedback apparatus **10***b*.

In one operational application, for example, an Alpha filter **102,** constructed in a manner as described in connection with the typical filter construction shown in FIG. **7,** and designed to pass signals having frequencies from approximately 8.0 Hz. to 13.0 Hz. has been tested to have a filter response curve substantially as shown in FIG. **8,** and a Theta filter **106,** constructed in accordance with the typical filter construction shown and described with respect to FIG. **7,** has been tested to have a filter response curve substantially as shown in FIG. **9,** wherein the Theta filter was designed to pass signals having a frequency from approximately 4.0 Hz. to 7.0 Hz. In this operational example, the voltage input to the Alpha filter and the Theta filter was approximately 0.5 volts (peak-to-peak) and the output voltage of the Theta filter and the Alpha filter was approximately 2.0 volts (peak-to-peak).

The Alpha filter **102** response curve, shown in FIG. **8,** indicates a flat-band response from approximately 8.0 Hz. to approximately 12.8 Hz., and, from the minus 2.5 db points to the notches of the Alpha filter **102,** the Alpha filter **102** had a rolloff rate of approximately 30.0 db per one-half cycle, the pass band having approximately a 0.8 db maximum ripple within the pass band.

The Theta filter **106** response curve, shown in FIG. **9,** indicates a flat-band response from approximately 4.2 Hz. to 7.9 Hz., the Theta filter **106** having an equally sharp roll-off rate at the minus 2.5 db points and an equally minimum ripple within the pass band, as shown by the Theta filter response curve.

It should also be noted that the bio-feedback apparatus **10***a* is constructed such that, when signals are being processed within the Theta band (approximately 4.0 Hz. to 8.0 Hz.) have a frequency of approximately 8.0 Hz., the Theta filter response is down to approximately 2.5 db; but, at a frequency of 9.0 Hz., the Theta filter response is down to approximately 30 db, thereby providing a minimum overlap between the frequency bands being processed via the various processing channels of the bio-feedback apparatus **10***a*. When the db level is down to approximately 10.0 db, the feedback in that particular processing channel is substantially lost or, in other words, the signal is not of a sufficient strength to indicate a signal presence in that particular processing channel. It should be noted, however, that

ther will be feedback in the other processing channels, assuming a signal presence within the frequency range or band width of the particular processing channel. Thus, the filters **102, 104** and **106** are each constructed and designed to select and finally separate the amplified incoming signals into distinct, separate processing channels with a minimum processing channel signal overlap, the signal overlap being approximately 1.0 cycle wide, in the operational example described above.

A typical control voltage generator which can be utilized as the Alpha, the Beta or the Theta control voltage generators **114, 116** or **118** (shown in FIG. **2**) is shown in FIG. **5**, and includes: a phase splitter network **208**; a rectifier network **210**; and a timing network **212**, the operating power supply (not shown) being provided to the control voltage generators **114, 116** and **118** via a pin connection **214**.

The phase splitter network **208** generally consists of a pair of resistors **216** and **218** connected to the junction **220** and a transistor amplifier **222**, the base of the transistor amplifier **222** being connected to the junction **220**. The phase splitter network **208** is generally constructed for receiving an input signal **108, 110** or **112**, respectively, from the Alpha filter **102**, the Beta filter **104** or the Theta filter **106**, respectively, and providing two output signals or waves having different phases or differing in phase relationship. Each input signal **108, 110** or **112** is coupled in one phase splitter network **208** via a capacitor **224**, and one of the phase splitter network output signals is coupled to the rectifier network **210** via a capacitor **226**, the other phase splitter network output signal being coupled to the rectifier network **210** via a capacitor **228**. The phase splitter network **208** also includes a resistor **230** connected generally between the collector of the transistor amplifier **222** and the operating power supply (not shown) connected to the pin connection **214** and a resistor **235** connected generally between the emitter of the transistor amplifier **222** and ground.

The rectifier network **210** consists of four diodes connected to form a full-wave diode bridge type of rectifier network, one junction of the diode bridge receiving one of the phase splitter network output signals via the capacitor **226** and one other junction of the diode bridge receiving the other phase splitter network output signal via the capacitor **228**. The input signals to the diode bridge are connected to two of the diode bridge junctions, one of the diode bridge junctions, not connected to receive a phase splitter network output signal, is connected to ground, the other diode bridge junction, not connected to receive a phase splitter network output signal, is connected to an output pin connection providing the output signals **120, 122** or **124** of the control voltage generator assembly **64**, as indicated in FIGS. **2** and **5**.

The timing network **212** includes a cpacitor **236** connected in parallel with a resistor **238**, the timing network **212** being interposed generally between the rectifier network **210** and the output signal pin connection of the control voltage generator. The feedback control signal **120** or **122** or **124** of the control voltage generators **114** or **116** or **118**, respectively, are thus processed through the phase splitter network **208** and through the full-wave diode bridge rectifier network **210** and finally through the timing network **212**, the feedback control **120, 122** and **124** being produced via the control voltage generators **114, 116** and **118**, after a predetermined time delay controlled by the time constant determined by the values of the capacitor **236** and the resistor **238** of the timing network **212**. The capacitor **236** and the resistor **238** of the timing network **212** are each sized to provide a charge and discharge time constant such that a predetermined number of cycles of the filter output signals **108, 110** and **112** are requried subsequent to the feedback control voltages **120, 122** and **124**, respectively, being produced at the output of the respective control voltage generators **114, 116** and **118**, thereby assuring a signal presence within one of the processing channels **78, 80** and **82** for a predetermined, minimum period of time subsequent to a feedback signal being produced by the bio-feedback apparatus **10a**. In this manner the bio-feedback apparatus **10** substantially eliminates feedback signals being produced via a single, short duration, relatively high amplitide, sensed potential, such as signals which might be produced via muscle artifacts or the like, for example.

Thus, the sensitivity adjustment assembly **60** and the control voltage generator assembly **64** cooperate to determine and set signal criteria for each of the processing channels **78, 80** and **82** such that an input signal must have a minimum amplitude and exist for a predetermined, minimum period of time subsequent to the feedback control signals **120, 122** and **124** being initiated or generated within the particular processing channels **78, 80** and **82**. The feedback control signals **120, 122** and **124** are, more particularly, d-c control votlages, and are utilized to activate the oscillator connected thereto.

A typical oscillator **126, 128** or **130** is shown in FIG. **4**, and the feedback control signals **120** or **122** or **124** are, more particularly, connected to the base of a switching transistor **240** via a resistor **242**. The emitter of the switching transistor **240** is connected to ground and the collector of the switching transistor is connected to an oscillator network **244** via a resistor **246**. The switching transistor **240** is constructed to be normally biased in the "off" position, and to be biased in the "on" position when the feedback control signal **120** or **122** or **124** is applied thereto, thereby biasing or activating the oscillator network **244** in the "on" position, in a manner to be described in greater detail below.

The oscillator network **244** basically consists of a pair of transistor amplifiers **248** and **250**, the collector of the transistor amplifier **248** being connected to an operating power supply (not shown) via a pin connection **252** and the emitter of the transistor amplifier **248** being connected to the collector of the switching transistor **240** via the resistor **246**. The collector of the transistor amplifier **250** is connected to the operating power supply (not shown) via the pin connection **252** and the emitter of the transistor amplifier **250** is connected to ground via a resistor **254**. A resistor **256** is interposed between the transistor amplifier **248** an the pin connection **252**, and a resistor **258** is interposed between the collector of the transistor **250** and the pin connection **252**, as shown in FIG. **4**. A variable resistor **260** is interposed between the collector of the transistor amplifier **248**, and, more particularly, between the resistor **256** and the pin connection **252**, and the base of the transistor amplifier **248** is connected to the collector of the transistor amplifier **250** via a resistor **262**, a capacitor **264** being connected between the base of

the transistor amplifier **248** and the emitter of the transistor amplifier **250.** The collector of the transistor amplifier **248** is also connected to the base of the transistor amplifier **250** via a capacitor **268,** and the emitter of the transistor amplifier **248** is also connecced to the base of the transistor amplifier **250** via a variable resistor **270.**

The transistor amplifiers **248** and **250,** as shown in FIG. **4,** and the interconnecting capacitive-resistive network therebetween form the oscillator network **244,** the output signal of the oscillator network **244** having a frequency determined by the sizes of the various componets of the oscillator network **244,** as well known in the art. The variable resistor **260** is connected in the oscillator network **244** to variably and selectively control the amplitude of the oscillator output signal, and the variable resistor **270** is connected in the oscillator **244** to variably and selectively control the frequency of the oscillator output signal in an operating mode or activated position of the oscillator network **244,** during the operation of the bio-feedback apparatus **10**a. In one preferred operational embodiment, the Alpha oscillator **126** is constructed to generate and provide an output signal having a frequency of 800 Hz.; the Beta oscillator **128** is constructed to generate and provide an output signal having a frequency of 1100 Hz.; and the Theta oscillator **130** is constructed to generate and provide an output signal frequency of 600 Hz., as mentioned before.

The oscillating output signals **132, 134** or **136** are connected to the on-off controls **144, 146** and **148,** respectively, via a capacitor **276** connected on one end thereof to the emitter of the transistor amplifier **250,** generally between the connection of the capacitor **264** to the emitter of the transistor amplifier **250** and the resistor **254,** the on-off controls **144, 146** and **148** being schematically shown in FIG. **4** as an on-off type of switch. The on-off controls **144, 146** and **148** are each connected to one of the volume controls **138, 140** or **142** (the volume controls **138, 140** or **142** being schematically shown in FIG. **2** as a variable resistor). It should be noted that, in one other form, the switches **144, 146** and **148** can be eliminated and a potentiometer type of volume control can be utilized in lieu thereof, the volume of the feedback signals supplied to the summing amplifier **72** being controllable from approximately zero to a maximum level via the variable resistor or potentiometer.

The oscillator network **244** is, more particularly, a fixed frequency, constant amplitude, sinusoidal resistance-capacitance coupled type of oscillator network, and the switching transistor **240,** more particularly, is constructed such that the feedback control signals **120, 122** and **124** saturate the switching transistor **240** connected thereto, thereby biasing the switching transistor **240** in the "on" position allowing current flow through the switching transistor **240** to ground and activating the oscillator network **244.** In the "on" position of the on-off controls **144, 146** and **148,** the feedback oscillator output signals **132, 134** and **136** are each connected to the input of the summing amplifier **72,** as diagrammatically shown in FIG. **2.**

The summing amplifier **72** and the output indicator **76** of the bio-feedback apparatus **10***a* is shown in more detail in FIG. **6.** The feedback oscillator output signals **132, 134** and **136** are each connected to one of the inputs of the summing amplifier **72** via resistors **278,** one resistor **278** being interposed between the summing amplifier **72** and each feedback oscillator output signal **132, 134** and **136,** respectively. The other input of the summing amplifier **72** is connected to ground, the summing amplifier **72** thereby providing an amplifier of the type generally referred to as a "summing" or "mixer" type of amplifier. A feedback loop is provided around the summing amplifier **72,** generally between the output of the summing amplifier **72** and the signal input to the summing amplifier **72,** and a resistor **280** is interposed in the feedback loop.

The output of the summing amplifier **72** is connected to the primary side of a transformer **282** and the secondary side of the transformer **282** is connected to a speaker **284** and a headset **286.** A switch **288** is interposed between the transformer **282** and the speaker **284,** the switch **288** connecting the speaker **284** to the output of the summing amplifier **72** in the closed position thereof and disconnecting the speaker **284** from the output of the summing amplifier **72** in the open position thereof.

The summing amplifier **72** thus receives the feedback oscillator output signals **132, 134** and **136** and provides an output signal indicative of the signal mix thereof, the summing amplifier output signal being transformer coupled to the speaker **284** and the headset **286** for providing a subject-perceivable auditory type of feedback, each feedback signal indicating the presence of a sensed signal within the preset frequency ranges of one of the processing channels **78, 80** and **82.** As mentioned before, the oscillator output signals **132, 134** and **136** each have a preselected frequency such that the separate tones being simultaneously amplified and produced via the summing amplifier **72** are distinguished by the subject or, in other words, such that when two or more oscillator output signal tones are bieng produced simultaneously by two or more of the feedback processing channels **78, 80** and **82,** the simultaneously produced feedback oscillator output signals **132, 134** and **136** are individually identifiable and distinguishable by the subject. It should also be noted that the output indicator **76** can include other forms of audio feedback, and can also be constructed to produce various forms of visual feedback indications. In any event, the subject-perceivable feedback produced during the operation of the bio-feedback apparatus **10***a* is indicative of a signal presence in one of the processing channels **78, 80** and **82** wherein the signal has a minimum preset amplitude and is of a minimum predetermined duration.

Description of FIGS. 10 through 31

Shown in FIGS. **10** through **31** is a bio-feedback apparatus **10***b*, constructed similar to the bio-feedback apparatus **10** and **10***a*, described before, to sense and detect brain-waves or varying potentials produced by the subject and to process predetermined, preselected portions of the varying potential through separate processing channels to produce sugject-perceivable feedback indications indicative of various parameters related to the presence of a predetermined, identifiable signal component portion of the detected and sensed brain-wave potential from the subject. The bio-feedback apparatus **10***b* includes a brain-wave indicator **30***b*, constructed similar to the brain-wave indicator **30***a* of FIG. **2,** the brain-wave indicator **30***b* including: a reference electrode **310** attached to the subject and

providing an output signal **312**; a right electrode **314** connected to the subject and providing an output signal **316**; and a left electrode **318** connected to the subject and providing an output signal **320.**

The electrodes **310, 314** and **318** are constructed and attached to the subject in a manner similar to that described before with respect to the electrodes **38, 42** and **46** of the bio-feedback apparatus **10***a*, shown in FIG. **2.** In one operational embodiment, the right electrode **314** is, more particularly, attached to a preselected scalp site generally on the right side of the subject's head (preferably at or near the occipital area on the right side of the individual's head), and the left electrode **318** is attached to a preselected scalp site generally on the left side of the sugject's head (preferably at or near the occipital area on the left side of the subject's head). In one form, the subject's left earlobe and right earlobe are tied together, the common tie being utilized as a reference for monopolar recording of the brain-wave signals produced by the subject. This latter electrode attachment is preferably effected by rubbing in a salt paste or the like and subsequently attaching an earclip electrode, preferably filled with a salt paste or the like to each of the subject's ears. The reference electrode **310** provides the ground or neutral electrode and is, in one form, a plate type electrode attached to the subject's left wrist, for example. In any event, the reference electrode **310,** the right electrode **314,** and the left electrode **318** are each attached to the subject to sense and detect the varying potential produced by the subject's brain and to provide output signals **312, 316** and **320,** indicative of the detected, sensed varying potential of the individual's brain and, more particularly, to provide output indications indicative of the varying potential produced by the individual's brain at two separate, distinct positions.

The separately detected brain-wave potentials are sensed simultaneously by the brain-wave indicator **30***b*, and the electrode output signals **312, 316** and **320** indicative of the two separately sensed varying potentials, sometimes referred to herein as the left and the right channels, are simultaneously connected to the input of a signal input controller **322,** the signal input controller **322** receiving, amplifying and equalizing the amplitudes of the received signals and providing amplified, amplitude equalized output signals **324** and **326.** The output signal **324** is, more particularly, provided in response to the received input signals from the left side of the subject's brain (the left channel), and the output signal **326** is, more particularly, provided in response to the received signals from the right side of the subject's brain (the right channel). It should be particularly understood that the terms "left" and "right" are utilized above and below to designate separate sensing sites on the subject and to distinguish separate controlling channels of the bio-feedback apparatus **10***b* merely for the purpose of reference and signal or channel identification.

The signal input controller **322** also provides an output signal **328** responsive to the received input signals from the brain-wave indicator **30**b, the signal input controller output signal **328** being connected to and received by a permanent recorder indicator **330.** The permanent recorder indicator **330** is, in a preferred form, of the chart driven polygraph type recorder constructed to receive input signals and to provide a permanent chart type feedback indicative of preselected parameters of an input signal connected thereto, such recorder indicators being well known in the art and commercially available from such manufacturers as, for example, Beckman Instruments of Chicago, Illinois. More particularly, and with respect to the signal input controller output signal **328,** the permanent recorder indicator **330** provides a permanent chart-type output indicative of the detected sensed brain-wave potential from the two preselected scalp sites.

The signal input controller output signals **324** and **326** are connected to a left-right select switch **332,** as shown in FIG. **10.** The left-right select switch **332** receives the signal input controller output signals **324** and **326** and provides an output signal **333.** In one position, the left-right select switch **332** selectively and switchingly connects one of the signals **324** and **326** to the feedback signal controller **334** via the signal **333**; and, in one other position, the left-right select switch **332** selectively and switchingly connects both of the signals **324** and **326** to the feedback signal controller **334** via the signal **333.** The left-right select switch **332,** in a preferred form, includes switching components in various portions of the bio-feedback apparatus **10***b* to provide complete flexibility in controlling the permanent, the visual, and the audio feedback, as will be made more apparent below.

The feedback signal controller **334** is constructed to selectively separate the controlling channels **324** and **326** into separate processing channels, each processing channel receiving and processing a predetermined component or portion of the controlling channels **324** and **326,** in a manner somewhat similar to that described before with respect to the bio-feedback apparatus **10**a, shown in FIG. **2.** In one preferred form, the feedback signal controller **334** includes eight processing channels, four of the processing channels being connected to the controlling channel **324,** and the remaining four processing channels being connected to the controlling channel **326.** The band width of each of the four processing channels connected to one of the controlling channels **324** or **326,** more particularly, corresponds with preselected, identifiable, frequency components of the varying potential sensed and detected from the subject. The four processing channels connected to the controlling signal **324** and the four processing channels connected to the controlling signal **326,** each include: one channel for processing received signals within a frequency band of 0.5 Hz. to 4.0 Hz., referred to as the Delta frequency band; one channel for processing received signals within a frequency band of approximately 4.0 Hz. to 8.0 Hz., referred to as the Theta frequency band; one channel for processing received signals within a frequency band of approximately 8.0 Hz. to 13.0 Hz., referred to as the Alpha frequency band; and one channel for processing received signals within a frequency band of approximately 13.0 Hz. to 26.0 Hz., referred to as the Beta frequency band.

The feedback signal controller **334** provides output signals **336, 338, 340** and **341,** each output signal being indicative of the signal presence within the four processing channels of the controlling channel **324** or **326.** More particularly, the feedback signal controller output signal **336** is indicative of signal presence within any of the processing channels of the left controlling signal **324**; the feedback signal controller output signal **341** is indicative of signal presence within any of the

processing channels of the right controller signal **326**; and the signal controller output signals **338** and **340** are indicative of signal presence within any of the processing channels of the preselected controlling channel **324** or **326**, in one form, the output signals **338** and **340** being indicative of signal presence within any of the processing channels of each controlling channel **324** and **326**, in one other form, in a manner and for reasons which will be made more apparent below.

The feedback signal controller output signal **336** is connected to an audio signal controller **338** providing an audio output control signal **340** for activating an audio output indicator **342**, the audio output indicator **342** providing a subject-perceivable, audio type of feedback indicative of signal presence within the processing channels of the controlling channel **324** in response to the received output signal **336**. The feedback signal controller output signal **338** is connected to one of the channels of the permanent recorder indicator **330**, the permanent recorder indicator **330** receiving the feedback signal controller output signal **338** and providing a chart-type permanent output indication indicative of signal presence within the processing channels of the controlling channels **324** and **326** in response to the received output signal **338**.

The feedback signal controller output signal **340** is connected to a data reduction controller **344**, the data reduction controller **334** providing an output signal **346** in response to the received output signal **340**. The data reduction controller **344** is, more particularly, constructed to provide the output signal **346** indicative of the percentage of time during a subsequent predetermined epoch of time wherein a signal presence existed in the four processing channels of the controlling channels **324** and **326**.

The feedback signal controller output signal **338** and the data reduction controller output signal **346** are each connected to a visual output controller **348**, the visual output controller receiving the output signals **338** and **346** and providing a visual output control signal **350** in response thereto. The visual output control signal **350** is connected to a visual output indicator **352** providing a subject-perceivable, visual feedback indication of the received signals **338** and **346**, thereby being indicative of signal presence and the percentage of time during a subsequent, predetermined epoch of time wherein a signal existed in the four processing channels of the controlling channel **324** and **326**.

The feedback signal controller output signal **341** is connected to an audio output controller **354**, the audio output controller **354** receiving the output signal **341** and providing an audio controller output signal **356** in response thereto. The audio controller output signal **356** is connected to and received by an audio output indicator **358**, the audio output indicator **358** providing subject-perceivable output feedback indications indicative of signal presence in any of the four processing channels of the controlling channel **326**. It should also be noted that, in a preferred form, the audio output indicators **342** and **358** are each connected to provide a stereo and a mono mode or form of audible feedback during the operation of the bio-feedback apparatus **10b**, in a manner which will be described in greater detail below.

In general, the bio-feedback apparatus **10b** receives and processes two separate, distinct controlling channels **324** and **326** (sometimes referred to herein as the left controlling channel **324** and the right controlling channel **326**), each controlling channel **324** and **326** being responsive to and indicative of distinct, separate potentials sensed and detected at different scalp sites on the subject. The signal input controller **322**, the left-right select switch **332**, the feedback signal controller **334** and the data reduction controller **344** are each constructed to receive and process the controlling channels via a plurality of processing channels to provide selectively controlled feedback indications indicative of a plurality of combinations of the controlling channels **324** and **326**, and the processing channels therein, in a manner which will be made more apparent below.

One processing channel of the feedback signal controller **334** is diagrammatically shown in FIG. **11**, and generally includes: a filter **360**, a zero crossing detector **362**, an amplitude discriminator **364**, a comparator controller **366**, an atuomatic gain controller **368**, a tachometer network **370**, a bandpass controller **372**, a voltage controlled oscillator **374**, and a signal converter **376**, the audio output controller **338** or **354**, the audio output indicator **342** or **358**, the visual output controller **348**, the visual output indicator **352**, and the permanent recorder indicator **330** also being diagrammatically shown in FIG. **11** connected to receive signals from the single, diagrammatically illustrated processing channel of the feedback signal controller **334** for the purpose of clarity of description. It should be emphasized that the feedback signal controller **334** has, in a preferred form, eight processing channels (four processing channels connected to and associated with each controlling signal **324** and **326**, respectively), as described before.

The filter **360** receives the amplitude equalized signal from the controlling channel **324** or **326** connected thereto and provides an output signal **380** in response thereto. In a preferred form, the filter **360** is an active bandpass filter constructed to selectively pass the frequency component of the received signal within the preselected passband of the filter **360** via the filter output signal **380**. In one preferred form, each controlling channel **324** and **326** includes four filters **360**, each filter **360** being constructed and sized to selectively separate the frequency components of the received signal such that the four processing channels of each controlling channel **324** and **326** selectively receive and process signals having predetermined frequencies within the Alpha, the Beta, the Theta and the Delta frequency bands, described before.

The filter output signal **380** is connected to the zero crossing detector **362** and to a portion of the amplitude discriminator **364**. The zero crossing detector **362** provides an output signal **382** which is a control voltage indicative of the zero crossings of the filter output signal **380**. More particularly, the zero crossing detector **362** provides an output control voltage signal **382** in a "low" state each time the filter output signal crosses zero in a positive going direction and an output control voltage signal **382** in a "high" state each time the filter output signal crosses zero in a negative going direction. The zero crossing detector output signal **382** is thus indicative of the time interval between changes of the filter output signal **380** relative to positive and negative going signals of the filter output signals **380**.

The amplitude discriminator **364** receives the filter output signal and develops a control voltage output sig-

nal 384 proportional to the amplitude of a received filter output signal of a predetermined minimum amplitude level. The control voltage is held in the amplitude discriminator 364 and transferred to the amplitude discriminator output signal 384 in response to a received zero crossing detector output signal 382 in a "high" state, for reasons and in a manner to be described in greater detail below.

The comparator controller 366 receives the amplitude discriminator output signal 384 and is connected to the bandpass controller 372 via the signal path 386 therebetween for providing an output signal 387 indicative of signal presence in the particular processing channel associated therewith of a predetermined, minimum amplitude level and a predetermined, minimum signal duration. The comparator controller output signal 387 is connected to the audio output controller 338 or 354 for providing the subject-perceivable, audio output indications via the audio output indicator 342 or 358 and to the visual output controller 348 for providing subjectperceivable visual feedback indications via the visual output indicator 352, in a manner to be described in greater detail below.

The zero crossing detector output signal 382 is also connected to the tachometer network 370, the tachometer network 370 providing an output signal 388 linearly proportional to the frequency of the filter output signal 380 in response to the received zero crossing detector output signal 382. The tachometer network 370 is also constructed to provide an oscillating output signal 389 in response to the received zero crossing detector output signal 382, the oscillating output signal 389 being connected to the amplitude discriminator 364 and controllingly transferring the stored control voltage thereinto the amplitude discriminator output signal 384.

The tachometer network output signal 388, in a preferred form, is connected to the permanent recorder indicator 330 for providing a chart-type permanent feedback indicative of the frequency of the filter output signal 380, as shown in FIG. 11. The tachometer network output signal 388 is also connected to the voltage controlled oscillator 374 constructed to provide an oscillating output signal 390 in response to the received tachometer network output signal 388, the oscillating output signal 390 being indicative of a signal presence in the processing channel associated therewith, in a manner similar to that described before with respect to the oscillators 126, 128 and 130 of the bio-feedback apparatus 10*a* shown in FIG. 2.

In one form, the voltage controlled oscillator output signal 390 is triangularly shaped and, in this form diagrammatically shown in FIG. 11, the output signal 390 is connected to the signal converter 376. The signal converter 376 is constructed to provide an oscillating output signal 392 having a sine-wave type of shape in response to a received triangularly shaped voltage controlled oscillator output signal 390.

The oscillating output signal 392 is connected to the automatic gain control 368, the automatic gain control 368 automatically controlling the signal gain of the output signal 392 and connecting the voltage controlled oscillator output signal 390 to the audio output controller 338 or 354 via the output signal 394. The audio output controller 338 or 354 providing a subjectperceivable audio feedback indication via the audio output indicator 342 or 358 in response to the received voltage controlled oscillator output signal 390 via the signal converter 376, the automatic gain control 368 and the audio output controller 338 or 354.

A portion of the data reduction controller 344 for processing the four processing channels of one of the controlling channels 324 and 326 is diagrammatically shown in FIG. 12, and generally includes: an analog switch 420, a delay oscillator 422, a delay signal controller 424, an overvoltage controller 426, a counter controller 428, a clock pulse generator 430, counters 432, and a digital/analog converter 434. In one form, the bio-feedback apparatus 10*b* includes only one data reduction portion as diagrammatically shown in FIG. 12, and, in this form, only one of the controlling channels 324 and 326 is utilized to develop subject-perceivable feedback signals indicative of the percentage of time during a subsequent epoch of time wherein a signal presence existed in the sensed brain-wave potential of the selected controlling channel 324 or 326. The data reduction controller 344, in one other form, includes a parallel portion, similar to the portion shown in FIG. 12, and, in this form, each portion receives one of the four processing channels of one of the controlling channels 324 and 326 for developing subject-perceivable output feedback indications.

In either event, the analog switch 420 receives the comparator controller output signals 387 from each of the processing channels of one of the controlling channels 324 and 326 via the input signal path 436 and an input signal 438 from the delay oscillator 422, as shown in FIG. 12. The analog switch 420 is constructed to connect the delay oscillator output signal 438 to the delay signal controller 424 via the analog switch output signal 440 in response to a received signal 436 indicating signal presence in the processing channels of the controlling channel 324 or 326 connected to the analog switch 420.

The delay signal controller 424 includes a plurality of recording channels, each channel receiving and recording the delay oscillator output signal 438 via the signal path 440 when connected thereto via the analog switch 420. The analog switch 420, more particularly, connects the delay oscillator output signal 438 to one of the recording channels of the delay signal controller 424 in response to a received processing channel signal indicating signal presence, the delay signal controller 424 recording the received signals over a predetermined epoch of time. Each recording channel of the delay signal controller 424 records over a predetermined epoch of time, and the portion of each recording channel having the delay oscillator output signal 438 recorded thereon is indicative of the portion of time during the predetermined epoch of time when a signal presence existed on the processing channel associated therewith.

The recorded signals of the delay signal controller 424 are subsequently connected to the overvoltage controller 426 via the signal 442, the overvoltage controller 426 providing d-c control votlage signals via an overvoltage controller output signal 444 in response to the recorded delay oscillator output signals on the recording channels of the delay signal controller 424. The signal 436, the overvoltage controller output signal 444 and a clock pulse 446, generated via the clock pulse generator 430, are each connected to the counter controller 428, the counter controller 428 providing an output signal 448 responsive to the received overvolt-

age controller output signal **444.** In a preferred form, the counter controller **428** also includes a portion receiving the comparator controller output signal and provides an output signal indicative of the average percentage of time during which a signal presence existed in a processing channel for an epoch of time, as will be described in greater detail below.

The counters **432,** shown in FIG. **12,** are, in a preferred form, of the type generally referred to in the art as a digital type up/down counter constructed to count up and down in response to received control signals, and providing output signals in response thereto, such as a synchronous binary up-down counter commercially available from such companies as Texas Instruments of Dallas, Texas. The counter controller output signal **448** includes the clock pulse **446,** and an up-count and a down-count control signal for activating the counters **432** in the proper counter mode in response to the received overvoltage controller output signal **444.**

The counters **432** are, in one form, connected to provide what is commonly referred to as an "**8**-bit" output signal **450,** the count provided via the counter digital output signal **450** being a predetermined count, such as 1000, for example, in one operational embodiment and being determined on the general basis of a continuous count for the predetermined, controlled epoch of time. The count provided via the counter output signal **450** is digitally indicative of signal presence in the processing channels during the subsequent predetermined epoch of time. The counter controller output signal **450** is connected to the digital/analog converter **434** and the digital/analog converter **434** converts the digital counter output signal **450** to an analog voltage output signal **452** wherein the d-c level moves up (more positive) and down (more negative) in discrete steps responsive to the output count of the counters **432.** The digital/analog output signal **452** is connected to the permanent recorder indicator **330** and to the visual output controller **348,** as shown in FIG. **10** and described generally before. Assuming that each controlling channel **324** and **326** includes four processing channels, as described before, the overvoltage controller output signal **444,** the counter controller output signal **448,** the counter output signal **450,** and the digital/analog converter output signal **452,** each include a portion responsive to and indicative of one of the processing channels, the four processing channels being similarly processed in parallel through the data reduction controller **344.**

SIGNAL INPUT CONTROLLER

A preferred embodiment of the signal input controller **322** is schematically shown in FIG. **13** and generally includes: a polygraph **510** and an amplitude equalizer **512.** The electrode output signals **312, 316** and **320** are connected to the polygraph **510** and a portion of the polygraph **510** is connected to the amplitude equilizer **512,** the amplitude equalizer **512** providing the controlling channel signals **324** and **326,** described before with respect to FIG. **10.**

The left electrode output signal **320** is connected to one input of a left preamplifier **514** and the other input of the left preamplifier **514** is connected to receive the reference electrode output signal **312.** The right electrode output signal **316** is connected to one input of the right preamplifier **516** and the other input of the right preamplifier **516** is connected to receive the reference electrode output signal **312.** The left and the right preamplifiers **514** and **516** provide the initial signal preamplification, the left preamplifier **514** providing an amplified output signal **518** and the right preamplifier **516** providing an amplified output signal **520.**

The amplified output signal **518** is connected to one input of a left power amplifier **522** via a three-position switch **524,** an amplified output signal **526** from the left power amplifier **522** being connected to one channel of a write-out indicator **528.** The amplified output signal **520** is connected to one input of a right power amplifier **530** via a three-position switch **532,** an amplified output signal **534** from the right power amplifier **530** being connected to one other channel of the write-out indicator **528.**

In one form, the write-out indicator **528** is constructed to provide a graph-type permanent feedback indicative of and in response to received input signals **526** and **534** connected thereto, and constitutes a portion of the permanent recorder indicator **330** (shown in FIGS. **10** and **11**). A polygraph constructed in a manner generally described above with respect to the polygraph **510** is commercially available from such companies as Beckman Instruments of Chicago, Illinois, for example, this type of instrument being constructed to receive and record EEG signals.

In the switch position of the switches **524** and **532,** shown in FIG. **13,** the left preamplifier **514** is connected directly to the left power amplifier **522** and the right preamplifier **516** is connected directly to the right power amplifier **530,** the switches **524** and **532** being mechanically connected. The switches **524** and **532** have two other switch positions, the two other switch positions being designated in FIG. **13** via the letter references "L" and "R." In the L switch position of the switches **524** and **532,** the left preamplifier **522** is connected directly to the write-out indicator **528** via the power amplifier **522,** the right preamplifier output signal **520** being connected to ground. In the R switch position of the switches **524** and **532,** the right preamplifier **516** is connected directly to the write-out indicator **528** via the power amplifier **530,** the left preamplifier output signal **518** being connected to ground.

The left preamplifier output signal **518,** generally between the left preamplifier **514** and the switch **524,** is connected to the positive input of a left equalizer amplifier **536** via a coupling capacitor **538,** and the right preamplifier output signal **520,** generally between the right preamplifier **516** and the switch **532,** is connected to the positive input of a right equalizer amplifier **540** via a coupling capacitor **542.** The left equalizer amplifier **536** provides an output signal **544** connected to the left-right select switch **332** via a variable resistor **546,** and the right equalizer amplifier provides an output signal **548** connected to the left-right select switch **332** via a variable resistor **550,** the equalizer amplifier output signals **544** and **548** connected to the left-right select switch **332** via the variable resistors **546** and **550** being the signal input controller output signals **324** and **326** (shown in FIGS. **10** and **13**).

The equalizer amplifiers **536** and **540** each include a feedback loop having a resistor **552** interposed therein, each feedback loop being connected to the amplifier output signal and the negative input of one of the equalizer amplifiers **536** and **540.** A capacitor **554** and a resistor **556** are connected generally between the two

inputs of each equalizer amplifier **536** and **540**, and a resistor **548** is connected generally between each capacitor **554** and resistor **556** of the equalizer amplifiers **536** and **540** and to ground.

The equalizer amplifier output signals **324** and **326** are each connected to one of the inputs of the power amplifiers **522** and **530**, generally opposite the inputs thereto connected to one of the preamplifiers **514** and **516**, as shown in FIG. **13**. The power amplifiers **522** and **530** of the polygraph **510** have switch selectable inputs thereto, and are connected to the write-out indicator **528** and to the variable resistors **546** and **550** such that the amplitude of the two input channels received by the signal input controller **322** can be adjusted to a position wherein the amplitudes are substantially equal, in a manner to be made more apparent below.

The amplitude equalizer **512** thus equalizes or balances the amplitudes of the left and the right preamplifiers output signals **518** and **520**, respectively, or, more generally, equalizes and balances the amplitudes of the amplified signals detected and sensed by the left and the right electrodes **314** and **318**. The equalizing and balancing of the signals detected and sensed via the electrodes **314** and **318** provides a standard or basic amplitude facilitating the design of the various components and assemblies of the bio-feedback apparatus **10***b* to provide the various feedback signals in a more efficient, more positive and controlled manner.

It should be noted that the potentials sensed and detected by the left and the right electrodes **314** and **318** will, in some instances, vary due to the inherent construction and various connections of the electrodes **314** and **318**, including the attachment of the electrodes **314** and **318** to the subject, and, in some instances, subjects produce higher potentials on the left or the right side of the individual's head, thereby resulting in sensed detected potentials of an unbalanced or unequalized amplitude, thereby necessitating the equalizing of the reference or average amplitudes of the signals **324** and **326**. The sensed, detected potentials from the subject will, of course, have amplitude variations and these subject-produced variations remain in the controlling channels signals **324** and **326**, the controlling channel signals **324** and **326** merely being shifted or adjusted to vary about a standard, predetermined amplitude axis by adjusting the variable resistors **546** and **550** of the amplitude equalizer **512**, the predetermined reference amplitude axis being, more particularly, defined by a predetermined voltage value.

FEEDBACK SIGNAL CONTROLLER

The selected controlling channel signals **324** and **326** are connected to the feedback signal controller **334** (diagrammatically shown in FIG. **10**) via the left-right select switch **332**, one portion of the feedback signal controller **334** being shown in FIG. **14** and basically including: a comparator drive **560**, a comparator **562**, a switch drive **564**, a threshold adjust **566** and a switch network **568**. One controlling channel signal **324** and **326** is connected to the positive input of a comparator drive amplifier **570** via a dc-blocking capacitor **572**. A resistor **574** is connected in parallel with the controlling channel signal **324** or **326** input to the comparator drive amplifier **570**, the resistor **574** being connected to a variable resistor **576**.

The variable resistor **576** is connected on one side to a negative power supply (not shown) via a pin connection **578** and on the opposite side to a positive power supply (not shown) via a pin connection **580**. A resistor **582** is interposed between the variable resistor **576** and the pin connection **578**, and a resistor **584** is interposed between the variable resistor **576** and the pin connection **580**. The variable resistor **576** adjustably set to control the d-c level of the input level of the input controlling signal **324** or **326** to the comparator drive amplifier **570**, during the operation of the bio-feedback apparatus **10***b*.

The comparator drive amplifier **570** provides an amplified output signal **586** for driving a dual comparator **588**. The comparator drive **560** also includes a feedback loop connected to the comparator drive amplifier output signal **586** and to the negative input of the comparator drive amplifier **570**, a variable resistor **590** being interposed in the feedback loop. The variable resistor **590** provides a variable gain control for the comparator drive amplifier **570** for setting a predetermined voltage at which the dual comparator **588** will trip or change the state of the output signal therefrom to activate the switch network **568**, in a manner to be described in greater detail.

A capacitor **592** and a resistor **594** are connected to the negative input of the comparator drive amplifier **570**, generally between the variable resistor **590** and the comparator drive amplifier **570**. The capacitor **592** and the resistor **594** are connected in parallel with the feedback loop and provide a filtering network for the feedback input signal to the comparator drive amplifier **570**.

The comparator drive output signal **586** is connected in parallel to two comparator amplifiers **596** and **598**, the comparator amplifiers **596** and **598** constituting the amplifier networks of the dual comparator **588**. More particularly, the comparator drive amplifier output signal **570** is connected to the comparator amplifier **596** via a resistor **600** and the comparator drive amplifier output signal **570** is connected to the comparator amplifier **598** via a resistor **602**.

The negative input of the comparator amplifier **596** is connected to a positive voltage power supply (not shown) via a pin connection **604** and the positive input of the comparator amplifier **598** is connected between the resistor **608** and ground via a resistor **609**. The resistors **606** and **608** comprise a voltage divider network interposed between the positive power supply connection **604** and ground, the negative input to the comparator amplifier **596** being connected to the voltage divider network generally between the resistors **606** and **608**. The output signals of the comparator amplifier **596** and the comparator amplifier **598** are connected together to provide a single, dual-comparator output signal **610**, the dual-comparator output signal **610** being connected to the emitter of a switching transistor **611**, for reasons to be made more apparent below.

The comparator amplifier **596** includes a feedback loop connected to the output signal and to the positive input thereof, a feedback resistor **613** being interposed in the feedback loop of the comparator amplifier **596**. The comparator amplifier **598** also includes a feedback loop connected to the output signal and to the positive input of the comparator amplifier **598**, a feedback resistor **612** being interposed in the feedback loop of the comparator amplifier **598**. The feedback loop of the

comparator amplifier **588** and the comparator amplifier **598** are each connected to a negative power supply (not shown) via a pin connection **614** and a voltage limiting resistor **616** is interposed between the feedback loops and the pin connections **614.**

The comparator **562** is connected to operate as a dual-comparator or "window" comparator, the comparator **562** having a passband with an upper and a lower limit adjustably set to predetermined values such that the comparator output signal **10** remains in a "high" state when the comparator drive output signal **586** is outside or exceeds the window limits, and such that the comparator output signal **610** is turned-over or switched to a "low" state when the comparator drive output signal **586** is within the window limits of the comparator **562,** thereby producing the comparator output signal **610** indicative of a received signal **586** within the window limits. The voltage divider network comprising the resistors **606** and **608** functions to set the upper limit, and the resistors **616** and **609** function to set the lower limit of the comparator **562.** The variable gain of the comparator drive amplifier **560** facilitates the setting of the threshold level of the comparator **562.** The feedback resistor **612** cooperates with the voltage limiting resistor **616** to form a voltage divider network to reduce any "chatter" in the comparator output signal **610** which may occur, in some instances, when the comparator drive output signal **586** is near the upper and the lower window limits of the comparator **562.**

Since the comparator drive output signal **586** is an alternating current type of signal, the comparator **562** will operate to eliminate feedback when receiving signal "spikes" caused by muscle artifacts, twitches or the like, the comparator **562** detecting the high amplitude spike and switching the comparator output signal **610** to a "high" status. However, assuming the sensed, subject produced potential fed to the comparator drive **560** via the controlling channel signal **324** or **326** is such that the comparator drive output signal **586** is within the upper and the lower window limits of the comparator **562,** the comparator output signal **610** will be switched to the "low" state for activating the switch drive **564** and the switch network **568,** in a manner to be described in greater detail below.

The switch drive **564** basically includes the switching transistor **611** which is biased in the "off" position in a "high" state of the comparator output signal **610** and is biased in the "on" position when the comparator output signal **610** is in the "low" position. The base of the switching transistor **611** is connected to ground via a resistor **618,** and the collector of the switching transistor **611** is connected to a positive power supply (not shown) via a pin connection **620.** A resistor **622** is interposed between the collector of the switching transistor **611** and the pin connection **620,** and a resistor **624** is connected on one end thereof generally between the pin connection **620** and the resistor **622** and on the opposite end thereof to the base of the switching transistor **611,** generally between the resistor **618** and the switching transistor **611.**

The switch drive output signal is taken between the collector and ground of the switching transistor **611** via a conductor **626** and a ground conductor **628.** The switch drive output signal **626** is connected through a diode **630** to a timing network **631** having a capacitor **632** connected in parallel with a variable resistor **634,** the diode **630** and the timing network **631** comprising the threshold adjust **566.** The time constant of the timing network **631** (determined by the values of the capacitor **632** and the variable resistor **634**) is preset to a predetermined value such that the switch drive output signal **626** must exist or be present for a predetermined, controlled period of time subsequent to an output signal **636** being produced via the threshold adjust **566,** and such that the switch drive output signal **624** must be terminated or cease to exist for a predetermined, controlled period of time prior to terminating the threshold adjust output signal **636,** thereby assuring that the feedback provided via the bio-feedback apparatus **10*b*** will be initiated and terminated in response to a received, sensed potential having a minimum signal duration. In a preferred form, the discharge time constant is relatively longer than the charge time constant of the timing network **631** when the diode **630** is reversed biased, thereby producing a relatively fast "turn-on" time and a relatively longer "turn-off" time to hold the FET switches **638** and **640** until the artifact has subsided and a relatively normal signal has returned.

The threshold adjust output signal **636** is connected in parallel to the gate of each of two FET switches **638** and **640** via a voltage limiting resistor **642.** A capacitor **644** is connected between the source and the gate of each of the FET switches **638** and **640.** The output signal **646** of the FET switch **638** is connected to the left filters and the output signal **648** of the FET switch **640** is connected to the right filters, as indicated in FIG. **14.**

Thus, when a sensed subject-produced potential is received by the bio-feedback apparatus **10*b*** and the controlling channel signals **324** and **326** received by the comparator drive **560** are of a minimum duration, controlled by the timing network **631,** and within the upper and the lower window limits of the comparator **562,** the switching transistor **611** is biased to the "on" position and the threshold adjust output signal **636** biases the gates of the FET switches **638** and **640** to the open position, thereby providing an output signal connected in parallel to the filters in each of the four processing channels in each of the controlling channels of the bio-feedback apparatus **10*b***.

Zero Crossing Detector

Shown in FIG. **15** is a typical zero crossing detector **362,** one of the zero crossing detectors **362** being incorporated in each of the processing channels of the bio-feedback apparatus **10*b***. Each zero crossing detector **362** receives the filter output signal from one of the filters connected in one of the processing channels via a pin connection **660,** the filter output signal being connected to the base of a first transistor amplifier **662** via a resistor **664** and a capacitor **666** being connected to the base of the first transistor amplifier **662** generally between the resistor **664** and the first transistor amplifier **662,** as shown in FIG. **15.** The collector of the transistor amplifier **662** is connected to a negative power supply (not shown) via a pin connection **668** and the emitter of the first transistor amplifier **662** is connected to a positive power supply (not shown) via a pin connection **670.**

The zero crossing detector **362** also includes a second transistor amplifier **672,** the collector of the second transistor amplifier **672** being connected to the

negative power supply (not shown) via a common connection with the collector of the first transistor amplifier **662** to the pin connection **668.** The emitter of the second transistor amplifier **672** is connected to a positive power supply (not shown) via a common connection with the emitter of the first transistor amplifier **662** to the pin connection **670.** A resistor **674** is interposed between the emitter of the first transistor amplifier **662** and the pin connection **670,** and a resistor **676** is interposed between the emitter of the second transistor amplifier **672** and the pin connection **670.**

The emitter of the transistor amplifier **662** is connected to the negative input of a single comparator **678,** generally between the transistor amplifier **662** and the resistor **674,** and the emitter of the second transistor amplifier **672** is connected to the positive input of the single comparator **678,** generally between the second transistor amplifier **672** and the resistor **676.** The transistor amplifiers **662** and **672** are each high gain type of amplifiers and are each connected in the emitter-follower form, as shown in FIG. **15,** to provide an impedance matching network between the filter output signals and the single comparator **678,** the comparator **678** being a generally low input impedance device and the impedance matching network being thus sized and connected to produce a high input impedance input signal to the single comparator amplifier **678.**

The single comparator amplifier **678** provides an output control voltage signal **679** at a pin connection **680,** the single comparator amplifier **678** producing the control voltage signal **679** at the zero crossings of the input signal to the zero crossing detector **362;** that is, the filter output signal connected to the pin connection **660** of the zero crossing detector **362.** The output signal **679** of the single comparator amplifier **678** is normally in the "low" state, the output signal **679** being switched to the "high" state each time the filter input signal to the zero crossing detector **362** passes through zero on a downward slope (negative going direction) and each time the filter input signal to the zero crossing detector passes through zero on an upward slope (positive going direction—the output signal **679** returning to the "low" state each time the filter input signal to the zero crossing detector passes through zero on the upward slope.)

The single comparator amplifier output signal **679** is connected to the base of the second transistor amplifier **672** via a resistor **682,** and the base of the second transistor amplifier **672** is connected to ground via a resistor **684.** A resistor **686** and a variable resistor **688** are connected in series to the base of the second transistor amplifier **672,** the resistor **686** and the variable resistor **688** being connected in parallel with the resistor **684,** as shown in FIG. **15.** The variable resistor **688** is connected to a positive power supply (not shown) via a pin connection **690** and varyingly controls the base bias for the second transistor amplifier **672** or, in other words, controls the level at which the zero crossing detector single comparator amplifier **678** switches the state of the output signal **679** therefrom.

Thus, each zero crossing detector **362** is constructed to receive one of the alternating filter output signals at the pin connection **660** of the zero crossing detector **362** and to provide an output control voltage on each zero crossing of the filter output signal in a negative and in a position going direction via the single comparator amplifier output signal **679** of the pin connection **680.** Assuming, for example, that the variable resistor **688** is preset such that the single comparator amplifier **678** will produce a change in the output signal **679** therefrom at **50** millivolt, then the single comparator amplifier output signal **679** will change states each time the filter output signal connected thereto via the pin connection **660** passes above zero in a positive going direction by 50 millivolts and each time the filter output signal passes through zero in a negative going direction by 50 millivolts. Thus, in this example, the zero crossing detector **362** has approximately a **100** millivolt range. This type of construction is preferred in lieu of a zero crossing detector set at exactly zero to substantially reduce "chattering" in the single comparator amplifier output signal **679** and to provide a substantially more stable control voltage at the output pin connection **680** of the zero crossing detector **362.**

AMPLITUDE DISCRIMINATOR

A preferred embodiment of the amplitude discriminator **364,** generally described before with respect to FIG. **11,** is schematically shown in FIG. **16,** one of the amplitude discriminators **364** being incorporated in each processing channel of the bio-feedback apparatus **10***b.* The amplitude discriminator **364** includes a discriminator amplifier **694,** having the negative input thereto connected to receive one of the filter output signals via a pin connection **696,** a variable resistor **698** being interposed generally between the pin connection **696** and the negative input to the discriminator amplifier **694.** The positive input to the discriminator amplifier **694** is connected to a variable resistor **700** via a resistor **702,** one end of the variable resistor **700** being connected to ground and the opposite end of the variable resistor **700** being connected to a positive power supply (not shown) via a pin connection **704.**

The variable resistor **698** interposed between the filter output signal and the discriminator amplifier **694** provides a controllingly variable gain adjustment for the discriminator amplifier **694.** The variable resistor **700** connected to the positive input of the discriminator amplifier **694** adjustingly controls the d-c offset of the discriminator amplifier **694** or, in other words, provides an adjustment for shifting a discriminator amplifier output signal **706** in a positive d-c direction to overcome to some degree the forward drop of a diode **708** connected to receive the discriminator amplifier output signal **706.** In a preferred form, the variable resistor **700** is set to biasingly shift the discriminator amplifier output signal **706** in a positive direction to a position wherein a relatively small amount of current leaks through the diode **708** during the operation of the amplitude discriminator **364,** thereby substantially reducing the d-c loss through the diode **708.**

A feedback loop is connected between the negative input and the output signal of the discriminator amplifier **694** and a feedback resistor **710** is interposed in the feedback loop. The discriminator amplifier output signal **706** is connected to the source connection of a first FET switch **712** via the diode **708,** the drain connection of the FET switch **712** being connected to the gate of a second FET switch **714.** The gate of the first FET switch **712** is connected to a pin connection **716** via a resistor **718** and a capacitor **720,** the output signal **389** of the tachometer network **370** (shown in FIG. **11**) being connected to the gate of the second FET switch

714 via the pin connection 716, for reasons and in a manner which will be made more apparent below.

The cathode of the diode 708 is normally non-conducting and essentially operates as an open switch in the amplitude discriminator 364. Thus, a filter output signal received at the pin connection 696 will be shifted in a positive d-c direction an amount determined by the setting of the variable resistor 700, the received filter output signal being amplified by the discriminator amplifier 694 and the output signal 706 being passed through the diode 708 to charge a capacitor 722, connected in parallel with the discriminator amplifier output signal 706, generally between the diode 708 and the first FET switch 712. It should be noted that the diode 708 is constructed to conduct only when the received filter signal input thereto from the discriminator amplifier 694 is going in a positive direction and thus, when the received filter signal begins to swing in a negative going direction, the diode will be reversed biased and the charge will be held on the capacitor 722, for reasons which will be made more apparent below.

The collector of a switching transistor 724 is connected to the discriminator output signal 706, generally between the diode 708 and the capacitor 722, the switching transistor 724 being connected in parallel with the capacitor 722. The emitter of the switching transistor 724 is connected to ground via a common connection with the ground side of the capacitor 722. The base of the switching transistor 724 is connected to receive the output signal from the zero crossing detector 362 via a pin connection 726, a capacitor 728 and a resistor 730 being interposed generally between the switching transistor 724 and the pin connection 726. A resistor 732 and a diode 734 are each connected in parallel and connected to the base of the switching transistor 724 in parallel with the zero crossing detector input signal thereto via the pin connection 726.

Thus, as the filter output signal crosses through the preset trigger or zero level of the zero crossing detector 362 in a negative going direction, the diode 708 is reversed biased and the zero crossing detector 362 will provide output signal in a high state at the pin connection 726 biasing the switching transistor 724 in the "on" position momentarily by differentiating the positive going edge of the output signal from the zero crossing detector 362 via the network comprising the capacitor 728 and the resistors 730 and 732, and discharging the capacitor 722 to ground. The diode 708 is forward biased by the inverting amplifier 694 and charges the capacitor 722 to the peak amplitude of the negative going wave from the filter output. As the filter output signal crosses through the preset trigger or zero level of the zero crossing detector 362 in a positive going direction, the output signal of the zero crossing detector 362 changes to the low state. A negative pulse is generated by differentiating the high to low state change of the zero crossing detector 362 via the network comprising the capacitor 728 and the resistors 730 and 732. This produced pulse is shunted to ground via the diode 734 thereby preventing the reverse bias from breaking down the base emitter junction of the switching transistor 724. The switching transistor 724 remains in the "off" position, the positive going filter output signal providing a reverse bias on the diode 708 via the discriminator output signal 706. The capacitor 722 is thus continuously charged and discharged in response to a positive and negative going filter output signal during the operation of the bio-feedback apparatus 10*b*. The capacitor 722 will be charged to a new level each time the discriminator amplifier output signal 706 goes positive, assuming the capacitor 722 has been subsequently discharged.

The amplitude discriminator 364 includes a memory capacitor 736 which is connected in parallel to the drain of the first FET switch 712 and the gate of the second FET switch 714. The drain connection of the second FET switch 714 is connected to a positive power supply (not shown) via a pin connection 738 and the source connection of the second FET switch 714 is connected to a negative power supply (not shown) via a pin connection 740. A resistor 742 is interposed between the source connection of the second FET switch 714 and the pin connection 740. An output signal 746 of the amplitude discriminator 364 is connected to the source side of the second FET switch 714, generally between the second FET switch 714 and the resistor 742, as shown in FIG. 16.

The pin connection 716 or, in other words, the gate of the first FET switch 712 is connected to receive an output signal from a multi-vibrator connector in the tachometer network 370, described generally before the respect to FIG. 11 and to be described in greater detail below. The first FET switch 712 operates to transfer the charge on the capactor 722 to the memory capacitor 736 when the input signal to the gate of the first FET switch via the pin connection 716 biases the first FET switch in the "open" position, thereby essentially connecting the capacitors 722 and 736 in a parallel and transferring the charge from the capacitor 722 to the memory cpacitor 736. The FET switch 712 is biased to the non-conducting state by a resistor 744 which is connected to a negative power supply (not shown) at the pin connection 704 and a resistor 741 connected to groud, the junction of the resistors 744 and 741 is connected to the junction of the capacitor 720 and the resistor 718 connected in series between the pin connection 716 and the gate of the FET switch 712. In a preferred form, the capacitor 722 is relatively larger than the capacitor 736, and thus a charge will remain on the capacitor 722 after the transfer of the charge to the memory capactor 736, thereby necessitating the discharging of the capacitor 722 after the transferring of the charge therefrom to the memory capacitor 736 to position the capacitor 722 to receive the next charging signal produced via the discriminator amplifier output signal 706, during the operation of the bio-feedback apparatus 10b.

Thus, the first FET switch 712 of the amplitude discriminator 364 is opened and closed as controlled via the output signal of the multi-vibrator portion of the tachometer network 370 to transfer the charge of the capacitor 722 to the memory capacitor 736 after the capacitor 722 has been charged via the amplitude discrimination output signal 706 and before the discharging of the capacitor 722 in response to the zero crossing detector output signal. The charge transferred to the memory capacitor 736 feeds the gate of the second FET switch 714 which is a high impedance device. Thus, the second FET switch 714 will not drain the charge from the memory capacitor 736 and the second FET switch 714 is thus utilized in the amplitude discriminator 364 as a source follower or, in other words,

a high input impedance — low output impedance device.

Thus, the amplitude discriminator output signal **746** is a control voltage (d-c) proportional to the charge on the memory capacitor **736.** The amplitude discriminator **364** is thus essentially a positive peak reading memory circuit, the peak amplitude of each cycle of the amplitude discriminator output signal **706** being transferred to the memory capacitor **736** via a multi-vibrator output signal generated by a positive going zero crossing filter output signal.

COMPARATOR CONTROLLER

The amplitude discriminator output signal **746** is connected to the comparator controller **366,** as shown in FIG. **16** and, more particularly is connected to the negative input of a first comparator **750** via a resistor **752.** The positive input and the feedback loop of the first comparator **750** is connected to a resistor **754.** The first comparator **750** provides an output signal **756** therefrom which is normally in the "high" state, the first comparator **750** being constructed to change the first comparator signal **756** to a "low" state in response to a received amplitude discriminator output signal **746** exceeding a predetermined threshold level setting of the first comparator **750.**

The first comparator **750** includes a feedback loop connected between the output signal **756** and the positive input thereto, a feedback resistor **758** being interposed in the feedback loop. A variable resistor **760** is connected to the positive input of the first comparator **750,** generally between the resistor **754** and the first comparator **750** to controllingly adjust the minimum threshold amplitude level of the first comparator **750.** A resistor **762** is connected in series to the variable resistor **760,** and is connected to a positive power supply (not shown) via a pin connection **764.**

The comparator controller **366** also includes a second comparator **768** having an output signal **770,** the second comparator **768** being constructed such that the second comparator output signal **770** is normally in the "low" state and such that, when an input signal having a predetermined amplitude level is applied to the negative input of the comparator **768,** the second comparator **768** will change the state of the second comparator output signal **770** to a "high" state. The positive input of the second comparator **768** is connected to a variable resistor **772** to controllingly adjust the minimum threshold amplitude level of the second comparator **768.** The variable resistor **772** is connected in series with a resistor **774** to a negative power supply (not shown) via a pin connection **776.** The side of the variable resistor **772,** opposite the side thereof connected to the negative power supply, is connected to a positive power supply at the pin connection **764** via a resistor **778.**

The first comparator output signal **756** is connected to a portion of the bandpass controller **372,** the bandpass controller **372** providing a bandpass controller output signal **780** connected to the negative input of the second comparator **768** via a resistor **782.** A capacitor **784** is connected in parallel with the negative input of the second comparator **768,** generally between the second comparator **768** and the resistor **782.** The output signals **756** and **780** between the comparator controller **366** and the bandpass controller **372** constituting a portion of the signal path **386,** shown in FIG. **11** and generally described before.

When the first comparator **750** receives an incoming signal to the negative input thereto via the amplitude discriminator output signal **746** which exceeds the preset threshold level of the first comparator **750,** the state of the first comparator output signal **756** will change to the "low" state and, assuming the bandpass controller output signal **780** is initiated in response to a received first comparator output signal **756** in the "low" state, the capacitor **784** will begin to discharge at a charge rate determined by the values of the capacitor **784** and the resistor **782.** The capacitor **784** will, of course, be discharged at an exponential rate and, when the charge on the capacitor **784** reaches the preset threshold level of the second comparator **768** (determined by the setting of the variable resistor **772**), the second comparator **768** will change the state of the second comparator output signal **770** to provide a second comparator output signal **770** in a "high" state at the output pin connection **786.**

A variable resistor **788** and a resistor **789** are connected between the second comparator output signal **770** and the positive input of the second comparator **768.** A negative power supply (not shown) is connected to a pin connection **790** and to the junction between the resistor **789** and the second comparator output signal **770.**

Thus, the comparator controller **366** is constructed such that when the d-c amplitude level of the amplitude discriminator output signal **746** exceeds the predetermined threshold level setting of the first comparator **750** for a sufficient period of time to discharge the capacitor **784** to an amplitude level exceeding the threshold level setting of the second comparator **768,** the comparator controller **366** will provide an output signal **770** at the output pin connection **786** in the "high" state. In one operational example, the charge time or time constant determined by the resistor **782** and the capacitor **784** and the threshold level setting of the first comparator **750** via the variable resistor **760** is set such that the comparator controller **366** requires an incoming signal or, in other words, an amplitude discriminator output signal **746** having a duration equivalent to at least three cycles at the center band frequency, prior to activating the comparator controller output signal **770** in the "high" state. Further and considering the same operational example, in the Alpha band where the frequency range is from approximately 8.0 Hz. to 13.0 Hz., as mentioned before, the center band frequency is approximately 10.5 Hz. and thus the second comparator **768** of the comparator controller **366** will not change the state of the second comparator output signal **770** until the first comparator **750** has received an input signal above the threshold level setting determined by the variable resistor **760** for a period of time it takes for three cycles at 10.5 Hz. to pass through the first comparator **750** discharging the capacitor **784.**

In this manner, the feedback generated by the biofeedback apparatus **10***b* is controlled such that a sensed, detected potential must produce an amplitude discriminator output signal **746** which exceeds the threshold level setting of the first comparator **750** and is of a sufficient duration to activate the second comparator **768** to change the state of the second comparator output signal **770** before feedback signals are initiated. The comparator controller output signal **770** at

the pin **786** is a d-c control voltage of a predetermined amplitude level and is utilized to control the feedback signal of the bio-feedback apparatus **10***b*, in a manner to be described in greater detail below.

AUTOMATIC GAIN CONTROL

The automatic gain control **368**, shown diagrammatically in FIG. **11** and shown in more detail in FIG. **16**, is constructed to automatically control the amplitude of the feedback signal provided by the bio-feedback apparatus **10***b*, the automatic gain control **368** having an output signal provided at a pin connection **800** and receiving a signal from the voltage controlled oscillator **374** via the pin connection **804**, and being connected to a positive power supply (not shown) via pin connections **802** and **806**. The automatic gain control **368** includes an FET switch **810** having the gate connected to the amplitude discriminator output signal **746** via a resistor **812**. The source connection of the FET switch **810** is connected to the emitter of a transistor amplifier **814** via a capacitor **816**, and the drain connection of the FET switch **810** is connected to a variable resistor **818**, a capacitor **820** being connected to the drain of the FET switch **810** and to the ground side of the variable resistor **818**, as shown in FIG. **16**. The gate of a second FET switch **822** is connected to ground and the drain connection of the FET switch **822** is connected to the emitter of the transistor amplifier **814** in parallel with the first FET switch **810**, the source of the second FET switch **822** being connected to ground via a resistor **824**.

The base of the transistor amplifier **814** is connected to the voltage controlled oscillator **374** via the pin connection **804**, a capacitor **826** being interposed between the transistor amplifier **814** and the pin connection **804**. A resistor **828** is connected to the base of the transistor amplifier **814** and ground generally between the transistor amplifier **814** and the capacitor **826**. Another resistor **830** is connected to the base of the transistor amplifier **814** and the positive power supply (not shown), generally between the transistor amplifier **814** and the capacitor **826**. The collector of the transistor amplifier **814** is connected to a resistor **832**, the output of the automatic gain control **368** at the pin connection **800** being connected generally between the resistor **832** and the collector of the transistor amplifier **814**.

Each automatic gain control **368** receives the output signal from one of the voltage controlled oscillators **374** at the pin connection **804**, the voltage controlled oscillator output signal being applied across the resistor **828** when the amplitude discriminator output signal **746** is in a "high" state and of a sufficient amplitude to bias the FET switches **810** and **822** "open."

During the operation of the bio-feedback apparatus 10b, the FET switch **810** operates in the nature of a variable resistor and the FET switch **822** operates in the nature of a constant current source of, in other words, a current bias for the transistor amplifier **814**. The automatic gain control **368** receives the output from the voltage controlled oscillator **374** at the pin connection **804** and the output of the automatic gain control **368** is responsive to the input from the voltage controlled oscillator **374**, the circuitry of the automatic gain control **368** functioning to provide a voltage controlled gain to control the volume or loudness of the signal at the output pin connection **800** as a function of the received control voltage provided via the amplitude discriminator output signal **746**. Thus, the automatic gain control **368** utilizes a fixed level input provided via the voltage controlled oscillator **374** and the automatic gain control **368** controls the gain of the voltage controlled oscillator **374** through the automatic gain control **368** to the output pin connection **800** thereby controlling the volume of the feedback signal provided via the voltage controlled oscillator **374** as a function of the amplitude discriminator output signal **746**.

The variable resistor **818** provides a bias adjust to control the range of the volume level of the voltage controlled oscillator signal provided at the output pin connection **800** of the automatic gain control **368**.

TACHOMETER NETWORK

One embodiment of a typical tachometer network **370** of the bio-feedback apparatus **10***b* is schematically shown in FIG. **17**, the tachometer network **370** providing an output signal at the pin connection **834** connected to the pin connection **716** (FIG. **16**) of the amplitude discriminator **364** and receiving the zero crossing detector output signal **679** via the pin connection **836**. The tachometer network **370** includes a pair of transistor amplifiers **838** and **840**, the emitters of the transistor amplifiers **838** and **840** each being connected to a ground, and a diode **842** being interposed between the emitter of the transistor amplifier **840** and the ground connection thereof.

The base of the transistor amplifier **838** is connected to a diode **844**, the diode **844** being connected to a resistor **846** and the zero crossing detector output signal **679** being connected to the base of the transistor amplifier **838**, generally between the diode **844** and the resistor **846** via a capacitor **848** and a resistor **850**. The base of the transistor amplifier **840** is connected to a capacitor **852**, the capacitor **852** being connected to the collector of the transistor amplifier **838**. The base of the transistor amplifier **840** is also connected to a resistor **854** and a variable resistor **856**. A resistor **858** is connected to the variable resistor **856** and to the capacitor **852**, as shown in FIG. **17**, the variable resistor **856** and the resistor **858** each being connected to a negative power supply (not shown) via a pin connection **860**. The base of the transistor amplifier **838** is connected to a resistor **862** which is connected to a positive power supply (not shown) via a pin connection **864**, a resistor **866** being connected to the base of the transistor amplifier **838**, generally between the resistor **862** and the transistor amplifier **838**. The resistor **866** is also connected to the collector of the transistor amplifier **840**, the connection between the resistor **866** and the collector of the transistor amplifier **840** being connected to the negative power supply (not shown) via the pin connection **860** and connected to a conductor **868** via a resistor **870**.

The conductor **868** is connected to the positive power supply (not shown) via the pin connection **864** and a resistor **872** is interposed in the conductor **868**, generally between the connection of the resistor **870** to the conductor **868** and the pin connection **864**. The conductor **868** is also connected to ground via a capacitor **874**, the capacitor **874** being interposed in the conductor **868** generally between the connection of the resistor **870** to the conductor **868** and the ground connection thereof.

It will be apparent from the foregoing that the transistor amplifiers **838** and **840** are interconnected via the

various components to provide a monostable multi-vibrator **876**, the monostable multi-vibrator **876** being biased in the "on" (activated) and "off" (deactivated) state via the signal input thereto from the zero crossing detector **362**. The diode **844** is positioned to cooperate with the "PNP" transistor amplifier **838** to require a negative going signal to trigger the monostable multi-vibrator **876** in the "on" position, the monostable multi-vibrator **876** being thus triggered in the "on" position in response to a received zero crossing detector output signal **679** in the "low" state. In the triggered "on" position of the monostable multi-vibrator **876**, the output of the monostable multi-vibrator **876** is connected to and drives a switching transistor **880** or, in other words, the output of the monostable multi-vibrator **876** will turn the switching transistor **880** to the "on" position, since the base of the switching transistor **880** is connected to receive the output signal of the monostable multi-vibrator **876**, for reasons which will be made more apparent below.

The emitter of the switching transistor **880** is connected to ground via a resistor **882**, and is connected to the positive power supply (not shown) via a resistor **884**. The collector of the switching transistor **880** is connected to function generator **886**, the function generator **886** also being connected to the negative power supply (not shown) via the pin connection **860**. The collector of the switching transistor **880** is also connected to the collector of the switching transistor **887**, the collector of the switching transistor **887** also being connected to the function generator **886**.

The output signal of the monostable multi-vibrator **876** is also connected to the base of a switching transistor **888** via a resistor **890**, the collector of the switching transistor **888** being connected to the negative power supply (not shown) at the pin connection **860** and to the function generator **886**. The emitter of the switching transistor **888** is connected to ground via a resistor **892**, and the primary side of a transformer **894** is connected to the emitter of the switching transistor **888** via a capacitor **896**, the capacitor **896** being connected, generally between the switching transistor **888** and the resistor **892**. A resistor **898** is connected in parallel across the primary side of the transformer **894**, generally between the capacitor **896** and the primary side of the transformer **894**. The secondary side of the transformer **894** is connected to the base of the switching transistor **887** and to a common connection between the emitter of the switching transistor **887** and the emitter of a switching transistor **900**, the base of the switching transistor **900** being connected to the base of the switching transistor **887** via a conductor **902**, generally between the switching transistor **887** and the secondary of the transformer **894**. The collector of the switching transistor **900** is connected to the gate of an FET switch **904**, the common connection between the collector of the switching transistor **900** and the gate of the FET switch **904** being connected to the positive power supply (not shown) via a capacitor **906**, as shown in FIG. **17**.

The positive power supply (not shown) is connected to the emitter of a transistor amplifier **908** via a resistor **910**, the base of the transistor amplifier **908** being connected to the FET switch **904** via a diode **912**. The collector of the transistor amplifier **908** is connected to the FET switch **904** and to a negative power supply (not shown) via a pin connection **914**. The output of the tachometer network **370** is taken at a pin connection **916** generally between the resistor **910** and the emitter of the transistor amplifier **908**.

The function generator **886** is particularly constructed to cooperate with the tachometer network **370** within the frequency bands mentioned before with respect to the Alpha, the Beta, the Theta and the Delta frequency bands. A preferred embodiment of one function generator **886*a*** constructed to operate within the frequency range of approximately 4.0 Hz. to approximately 26.0 Hz. is schematically shown in FIG. **18**, and one preferred embodiment of a function generator **886*b*** constructed to operate within frequency range of approximately 0.5 Hz. to approximately 4.0 Hz.

Referring more particularly to the embodiment of the function generator **886*a*** (shown in FIG. **18**), the function generator **886*a*** includes an input pin connection **920** which is connected to the collectors of the switching transistors **880** and **887**, as shown in FIG. **17**. The input pin connection **920** is connected to a variable resistor **922** via a diode **924**, a resistor **926** and a variable resistor **928** being interposed generally between the diode **924** and the variable resistor **922**. The variable resistor **922** is connected to ground on one side thereof via a resistor **920** and to a negative power supply (not shown) at a pin connection **929** via a resistor **932**.

One side of a capacitor **934** is connected to the input signal generally between the input pin connection **920** and the diode **924**, the opposite side of the capacitor **934** being connected to the negative power supply (not shown) via the pin connection **929**. A resistor **936** and a variable resistor **938** are connected in series and are connected in parallel with the capacitor **934**.

When the monostable multi-vibrator **876** is triggered or activated in the "on" position for a predetermined time by the trigger input provided via the zero crossing detector output signal **679**, the capacitor **934** is charged to the value of the negative power supply (not shown) connected thereto via the pin connection **929**, the switching transistor **880** being subsequently biased to the "off" position. The resistor **936** and the variable resistor **938** connected in parallel with the capacitor **934** will provide a resistive bleed path for the capacitor **934**, thereby discharging the capacitor **934** therethrough. In a preferred form, the capacitor **934** and the resistors **936** and **938** are sized to provide a relatively low time constant, the potential developed across the resistors **936** and **938** by the discharging of the capacitor **934** being essentially in the form of an exponentially shaped signal or wave. The variable resistor **938** thus allows the time constant to be adjustingly set to control the slope of the exponentially shaped discharge curve of the capacitor **934**, for reasons which will be made more apparent below.

The positive side of the capacitor **934** is connected to the diode **924**, and the diode **924** will thus conduct when the anode thereof is positive with respect to the resistive biasing network essentially consisting of the resistors and the variable resistors **922**, **926**, **928**, **936** and **938**. The bias network, includes two adjustable variable resistors, the variable resistor **928** adjustably setting the high time constant and the variable resistor **938** adjustably setting the low time constant of the function generator **886*a***, the variable resistor **922** providing a bias adjustment.

As shown in FIG. **18**, there are two bleed paths around the capacitor **934**: one bleed path going

through the bias adjustment **922,** the variable resistor **928,** the resistor **926** and the diode **924**; and the other bleed path going directly from the capacitor **934** across the variable resistor **938** and the resistor **936.** Thus, in a forward biased position of the diode **926,** the diode **926** is conducting and the function generator **886***a* has one bleed rate having a predetermined slope, and when the diode **924** is non-conducting, the bleed rate or, in other words, the slope of the discharge curve of the capacitor **934** is controllingly altered by changing the rate at which the capacitor **934** is being discharged.

In general, the function generator **886***a* is constructed to change the exponentially shaped discharge curve of the capacitor **934** to match a reciprocal curve, the reciprocal discharge curve being essentially a hyperbolically shaped curve. The exponentially shaped and the hyperbolically shaped curve are approximately the same during the initial discharging of the capacitor **934** and, therefore, the function generator **886***a* is, more particularly, constructed to initiate the shaping of the exponentially shaped discharge curve at some point after the capacitor **934** initially begins discharging, thereby essentially bending the exponentially shaped discharge curve of the capacitor **934** below this "so-called break point" to shape the discharge curve of the capacitor **934** to form an essentially hyperbolically shaped discharge curve therefor, for reasons to be made more apparent below.

The capacitor **934** is charged via the switching transistor **880** which was triggered "on" by the monostable multi-vibrator **876,** in a manner described before. The capacitor **934** is subsequently discharged for the period of time between positive going zero crossings of the filter output and the monostable multi-vibrator **876** is in the deactivated status until triggered by a subsequent zero crossing detector output signal **679.**

Thus, the zero crossing detector **362** provides an output trigger signal **679** to the input of the monostable multi-vibrator **876** thereby activating the monostable multi-vibrator **876** and biasing the switching transistor **880** in the "on" position to charge the capacitor **934** of the function generator **886.** Since the capacitor **934** is charged in response to the zero crossing detector output signal **679** and allowed to discharge until the next zero crossing detector output signal **679,** the voltage level of the charge remaining on the capacitor **934** will be proportional to the time between the zero crossings of the filter output signal or, in other words, a voltage proportional to the time between the zero crossings and of the sensed potential. The beginning of each monostable multi-vibrator timing period turns off the switching transistor **888** causing the voltage on the discharging capacitor **934** in the function generator **886***a* to be transferred to the memory capacitor **906,** as will be described in greater detail below. The capacitor **874** cooperates with the resistors **870** and **872** producing a delay in turning on the switching transistor **880** after the beginning of the monostable multi-vibrator timing period. The capacitor **934** is charged for a period of time approximately equal to the monostable multivibrator timing period, a period of time sufficient to fully charge the capacitor **934.** At the end of the monostable multi-vibrator timing period, the capacitor **934** is discharged through the resistive network of the function generator **886***a*, in a manner as described before. The resistive network of the function generator **886***a* alters or shapes the exponentially shaped discharge curve of the capacitor **934** to provide a reciprocal thereof or, in other words, to provide a discharge curve or voltage linearly proportional to the frequency of the incoming, sensed potential from the subject.

The output of the function generator **886** is thus going to be a control voltage linearly proportional to the frequency of the sensed, detected potential from the subject, and that control signal is connected to the collector of the switching transistor **887** having its emitter tied in common with the switching transistor **900,** the switching transistors **887** and **900** operating in the nature of a switch in the tachometer network **370** during the operation of the bio-feedback apparatus **10***b*. The triggering of the switching transistor **888** to the "off" position or the "non-conducting" position provides a signal to the transformer **894,** thereby biasing the switch formed by the switching transistors **887** and **900** to the "on" position, transferring the charge on the capacitor **934** to the memory capacitor **906** of the tachometer network **370.** The capacitor **906,** shown in FIG. **17,** of the tachometer network **370** thus essentially operates in the nature of a memory capacitor **906,** the switch formed by the transistors **887** and **900** providing a high impedance input to prevent the prematurely bleeding-off of the charge on the memory capacitor **906** during the operation of the bio-feedback apparatus **10***b*.

The transferred charge on the memory capacitor **906** of the tachometer network **370** is thus a voltage proportional to the frequency of the sensed, detected potential from the subject. The triggering of the switching transistor **888** or, in other words, the biasing of the switching transistor **888** to the non-conducting state is controlled via the output of the monostable multivibrator **876,** since the base of the switching transistor **888** is tied to the output pin connection **834** of the multi-vibrator **876.**

As mentioned before, the output of the multivibrator **876** at the pin connection **834** is connected to the pin connection **716** of the amplitude discriminator **364,** shown in FIG. **16,** for controlling the transferring of the charge on the capacitor **722** to the memory capacitor **736** of the amplitude discriminator **364.** Therefore, the voltage proportional to the amplitude of the sensed, detected potential from the subject is transferred to the memory capacitor **736** at substantially the same time as the voltage proportional to the frequency of the sensed detected potential from the subject is transferred to the memory capacitor **906** of the tachometer network **370.** The discharging of the memory capacitor **906** opens the FET switch **904** and connects the memory capacitor **906** in parallel with the output load resistor **910** to provide the tachometer network output signal **918** at the pin connection **916,** the tachometer network output signal **918** being a d-c voltage linearly proportional to the frequency of the sensed, detected potential from the subject.

Shown in FIG. **19** is another embodiment of a function generator **886***b* connected in the tachometer network **370,** shown in FIG. **17,** in lieu of the function generator **886***a*, shown in FIG. **18.** The function generator **886***b*, shown in FIG. **19,** is more particularly, constructed to operate in the frequency range of 0.5 Hz. to 4.0 Hz.; however, the function generator **886***b* operates in the tachometer network **370** in a manner substantially the same as the function of the function generator **886***a;* that is, to provide an output signal linearly pro-

portional to the frequency of the sensed potential from the subject for driving the switch formed by the switching transistors **887** and **900** to the "conducting" or "on" position and transferring the charge from a capacitor **940** of the function generator **886***b* to the memory capacitor **906** of the tachometer network **370.** The function generator **886**b includes a pin connection **942** which is connected to the collector of the switching transistor **880** and **887,** in a manner similar to that described before with respect to the input pin connection **920** of the function generator **886***a*.

The input pin connection **942** of the function generator **886***b* is connected to a variable resistor **944** via a diode **946,** a resistor **948** and a variable resistor **950.** The variable resistor **944** is connected to the ground via a resistor **952,** and to a negative power supply (not shown) at a pin connection **954** via a resistor **956.**

A variable resistor **958** is connected to ground via a resistor **960,** and the variable resistor **958** is connected to the negative power supply (not shown) at the pin connection **954** via a resistor **962.** The variable resistor **958** is thus connected in series with the resistors **960** and **962** and this resistive network is connected in parallel with the resistive network formed by the variable resistor **944** and the resistors **952** and **956** (shown in FIG. **19**). The variable resistor **958** is connected to the capacitor **940** via a variable resistor **964,** a resistor **966** and a diode **968,** the diode **968** being connected to the capacitor **940** generally between the input pin connection **942** and the diode **946.**

A variable resistor **970** is connected to ground via a resistor **972,** and is connected to the negative power supply (not shown) at the pin connection **954** via a resistor **974.** The variable resistor **970** is connected to the capacitor **940,** generally at a common connection between the capacitor **940** and the diode **968,** and a variable resistor **976** connected in series to a resistor **978** is interposed between the variable resistor **970** and the connection between the variable resistor **970** and the common connection between the variable resistor **970,** the capacitor **940** and the diode **968,** as shown in FIG. **19.**

The function generator **886***b*, shown in FIG. **19,** is constructed to operate in a manner similar to that described before with respect to the function generator **886***b*, shown in FIG. **18,** the salient difference being that the function generator **886***b* includes an intermediate control for shaping the exponentially shaped discharge curve of the capacitor **940** to a hyperbolically shaped curve linearly proportional to the frequency of the sensed potential from the subject. The variable resistor **964** controls the high limit of the time constant of the function generator **886***b*, the variable resistor **976** controls the low limit of the time constant of the function generator **886***b*, and the intermediate control (generally between the high and the low limit time constant settings) is provided via the variable resistor **950.** Thus, the variable resistor **976** controls one bleed rate of the capacitor **940,** the variable resistor **964** controls one other bleed rate of the capacitor **940** and the variable resistor controls yet another bleed rate of the capacitor **940.**

When the monostable multi-vibrator **876** is activated via a trigger input at the pin connection **836** from the zero crossing detector **362,** the switching transistor **880** is biased in the "on" position, thereby charging the capacitor **940** of the function generator **886***b* to a value equal to the negative power supply, the capacitor **940** then discharging to a voltage proportional to the period of time between the zero crossings of the sensed potential from the subject. The capacitor **940** is subsequently discharged, and initially both diodes **946** and **968** are conducting as the capacitor **940** discharges. The capacitor **940** will continue to discharge and, at some first break point preset by the variable resistor **964,** the diode **968** will cut-off or stops conducting and, in this position, the capacitor **940** is discharging through the diode **946** and through the variable resistor **976** simultaneously, the low variable resistor **976** and the intermediate variable resistor **950** controlling the slope or rate at which the capacitor **940** is discharging. Subsequently, the capacitor **940** will discharge to a second break point where the diode **946** cuts off or stops conducting and, in this position, the capacitor **940** is discharging only through the low variable resistor **976,** the low variable resistor **976** controlling the slope or the rate at which the capacitor **940** is discharging thereby shaping the discharge curve of the capacitor **940** to provide an output d-c voltage linearly proportional to the frequency of the sensed potential from the subject. Thus, the function generator **886**b provides two distinct break points, the slope or rate of discharge of the capacitor **940** being changed at each break point. The two break points are utilized in the function generator **886**b because of the substantially large range of signal frequencies received by the function generator **886***b;* that is, signal frequencies from approximately 0.5 Hz. to approximately 4.0 Hz. (a frequency range of approximately eight to one).

The function generator **886***b* operates in the tachometer network **370** (shown in FIG. **17**) in a manner similar to that described before with respect to the function generator **886***a*, shown in FIG. **18,** to transfer the charge on the capacitor **940** to the memory capacitor **906** of the tachometer network **370,** the transferred charge on the memory capacitor **906** cooperating to provide the tachometer output signal **918,** a d-c voltage linearly proportional to the frequency of the sensed potential from the subject. In one form (shown in FIG. **11**), the output signal **388** of the tachometer network **370** is connected to the permanent recorder indicator **330,** thereby providing a permanent chart-type feedback indication indicative of the frequency of the sensed potential from the subject, this particular feedback being provided for only one of the controlling channels **324** or **326,** in one other form.

VOLTAGE CONTROLLED OSCILLATOR

The output signal **918** of each tachometer network **370** is connected to one of the voltage controlled oscillators **374** via pin connections **980** (FIG. **20**) and **916** (FIG. **17**), a preferred embodiment of a typical voltage controlled oscillator **374** being shown in FIG. **20.** The voltage controlled oscillator **374** includes a non-inverting amplifier **982** having the positive input thereto connected to a variable resistor **984** and the negative input thereto connected to a resistor **986,** the resistor **986** being connected to ground.

The negative input of the non-inverting amplifier **982** is connected to a variable resistor **988** via a resistor **990,** the resistor **990** and the variable resistor **988,** as shown in FIG. **20.**

The variable resistor **988** is connected to a positive power supply (not shown) via a pin connection **992** and

to a negative power supply (not shown) via a pin connection **984**. The non-inverting amplifier **982** includes a feedback loop connected to an amplifier output signal **996** and to the negative input of the non-inverting amplifier **982**, a feedback resistor **998** being interposed in the feedback loop.

The variable resistor **984** is connected to the non-inverting amplifier **982** such that a predetermined percentage of the incoming tachometer output signal **918** is connected to the positive input of the non-inverting amplifier **982**. The variable resistor **988** provides a variable, controlled voltage to the negative input of the non-inverting amplifier **982** for providing the proper d-c offset therefor.

The non-inverting amplifier **982** thus provides a control voltage output signal **996** in response to the received tachometer output signal **918**. The control voltage output signal **996** is connected to the negative input of a unity-gain type of inverting amplifier **1000** via a resistor **1002**, the control voltage output signal **996** also being connected to one junction of a diode bridge network **1004** via a resistor **1006**, as shown in FIG. **20**.

The inverting amplifier **1000** provides an inverted output signal **1008** connected to one other junction of the diode bridge **1004** via a resistor **1010**. The inverting amplifier **1000** includes a feedback loop between the output signal **1008** and the negative input thereto, a feedback resistor **1012** being interposed in the feedback loop.

The resistor **1002** and the feedback resistor **1012** are each sized to provide a precision gain control for the inverting amplifier **1000** such that the inverted output signal **1008** therefrom corresponds to the output signal **996** of the non-inverting amplifier **982**; but, inverted with respect to polarity. The first diode bridge network **1004** is thus driven by the d-c control voltage output signal **918** from the tachometer network **370** by utilizing the unity-gain inverting amplifier **1000** to provide the opposite polarity signal.

The voltage controlled oscillator **374** also includes a second diode bridge **1014** having one junction connected to a positive power supply (not shown) via a pin connection **1016**, a resistor **1018** being interposed between the second diode bridge **1014** and the pin connection **1016**, and a negative power supply (not shown) connected to a pin connection **1020**, a resistor **1022** being interposed between the second diode bridge **1014** and the pin connection **1020**. One junction of the second diode bridge **1014** is connected to an output signal **1024** of an amplifier **1026**, and one other junction is connected to the positive input of the amplifier **1026**.

The amplifier **1026** includes a feedback loop between the output signal **1024** therefrom and the negative input thereto, a feedback resistor **1028** being interposed in the feedback loop. The negative input of the amplifier **1026** is connected to ground via a resistor **1030**.

The output signal **1024** of the amplifier **1026** is connected to one junction of the first diode bridge **1004** and the opposite junction of the first diode bridge **1004** is connected to the negative input of an integrator amplifier **1032**, the positive input to the integrator amplifier **1032** being connected to ground, as shown in FIG. **20**. The integrator amplifier **1032** provides an output signal **1034** and a capacitor **1036** is connected between the output signal **1034** and the negative input of the amplifier **1032**.

The integrator amplifier output signal **1034** is connected to the positive input of the amplifier **1026** via a variable resistor **1038**, the positive input to the amplifier **1026** and the variable resistor **1038** each being connected to ground via a pair of diodes **1040** and **1042**, the diodes **1040** and **1042** functioning to control the amplitude of the amplifier output signal **1024**.

During the operation of the voltage controlled oscillator **374**, the output signal **1024** of the amplifier **1026** alternates between a positive and a negative predetermined amplitude controlled by the two diodes **1040** and **1042** clamping the positive input of the amplifier **1026** to ground. When the amplifier output signal **1024** is positive, a positive input signal is applied to one junction of the diode bridges **1004** and **1014** simultaneously for positioning two of the diodes in each diode bridge **1004** and **1018** in the conducting state and the remaining two diodes being reversed biased, thereby connecting the positive control voltage output signal **996** to the integrator amplifier **1032** via the resistor **1006**. In this position, the integrator amplifier output signal **1032** is driven at a linear slope in a negative going direction.

The integrator amplifier output signal **1034** will continue in a negative direction until the magnitude of the negative going integrator amplifier output signal **1034** is increased to a predetermined level to drive the positive input to the amplifier **1026** negative, thereby causing the amplifier output signal **1024** to switch from a positive to a negative signal. The variable resistor **1038** is interposed between the integrator amplifier **1032** and the amplifier **1026** to adjustably control the amplitude of the signal required to drive the amplifier **1026** in an opposite direction, thereby controlling the amplitude of the voltage controlled oscillator output signal **1034**.

When the positive input of the amplifier **1026** is driven negative by the integrator amplifier output signal **1034**, the amplifier output signal **1024** will go negative. In this position, the operation of the voltage controlled oscillator **374** is essentially reversed, since the first diode bridge **1004** will now be driven by a negative input voltage from the inverting amplifier **1000** connected thereto via the resistor **1010**. When the first diode bridge **1004** is driven via the negative output signal **1008**, a negative input signal is applied to the integrator amplifier **1032**, thereby causing the voltage controlled oscillator output signal **1034** to be driven in the positive direction at a linear slope. The integrator amplifier output signal **1034** will continue going in a positive direction until the output signal **1034** reaches a predetermined, positive amplitude level causing the positive input to the amplifier **1026** to go positive, thereby switching the state of the amplifier output **1024** to the positive state, described before.

The two diode bridges **1004** and **1014**, the amplifier **1026**, the inverting amplifier **1000** and the integrating amplifier **1032** are each connected to provide an oscillating type of output signal **1034** which is triangularly shaped. The tachometer network output signal **918** thus controls the slope of the integrator amplifier output signal **1034** by applying different voltage inputs to the integrator amplifier **1032**. Since the first diode bridge **1004** requires a positive supply voltage to one junction input and a negative supply voltage to the opposite junction input, the inverter amplifier **1000** is uti-

lized to invert the control voltage signal **996** produced via the tachometer network output signal **916** in such a manner that the tachometer network output signal **918** controls the first diode bridge **1004** by supplying both the positive and the negative supply voltages thereto.

The voltage controlled oscillator **374** is further constructed to oscillate at a rate (the rate at which the integrator amplifier output signal **1034** changes slope) which is substantially equal to the frequency of the sensed potential from the subject multiplied by a predetermined factor, such as ten times the frequency of the sensed potential from the subject, for example.

In summary, the voltage controlled oscillator **374** converts the step type voltage of the tachometer network output signal **918** to a triangularly shaped voltage controlled oscillator output signal **1034** having a frequency equal to a predetermined multiple of the frequency of the incoming tachometer network output signal **918** and, since the tachometer network output signal **918** is linearly proportional to the frequency sensed potential from the subject, the voltage controlled oscillator output signal **1034** is proportional to the frequency of the sensed potential from the subject. The salient reason that the voltage controlled oscillator **374** is constructed to multiply the frequency of the tachometer network output signal **918** by a predetermined factor is to obtain a voltage controlled oscillator output signal **1034** oscillating at a frequency within the audible frequency spectrum.

The voltage controlled oscillator output signal **1034** is connected to the signal converter **376** which is constructed to receive the triangularly shaped wave form of the voltage controlled oscillator output signal **1034** and to convert that received signal shape to a substantially sine-wave shape of oscillating signal at the output pin connections therefrom **1046** and **1048.** The output pin connection **1046** is connected to the automatic gain control **368** at the input pin connection **804** (shown in FIG. **16**) via an a-c coupling voltage divider network comprising a capacitor **1050** connected in series with a resistor **1052** and a resistor **1054** connected between the resistor **1052** and the output pin connection **1046** and to ground.

The signal converter **376** is also connected to a positive power supply (not shown) at a pin connection **1056** via a resistor **1058** and a resistor **1060** is connected in parallel with the resistor **1058,** the output pin connection **1048** being connected between the resistor **1050** and the signal converter **1076,** as shown in FIG. **20.** The signal converter output signal at the output pin connection **1048** is also substantially sine-wave shaped, and is **180** degrees out-of-phase with respect to the signal converter output signal at the pin connection **1046,** the signal converter output signal **1048** being recorded or utilized for feedback, in some applications.

BANDPASS CONTROLLER

Each processing channel of the bio-feedback apparatus **10***b* includes a bandpass controller **372,** a preferred embodiment of the bandpass controller **372** being shown in FIG. **21.** The bandpass controller **372** receives one of the tachometer network output signals **918** via the input pin connection **1070.** The tachometer network output signal **918** is connected to the base of a transistor amplifier **1072** via a resistor **1074,** a resistor **1076** being connected to the base of the transistor amplifier **1072,** generally between the resistor **1074** and the transistor amplifier **1072.** The collector of the transistor amplifier **1072** is connected to a negative power supply (not shown) via a pin connection **1078,** and the emitter of the transistor amplifier **1072** is connected to ground via a resistor **1080.** The transistor amplifier **1072** is thus connected in the emitter-follower form to provide an impedance matching network **1082** for driving a low input impedance dual-comparator **1084,** in a manner similar to that described before with respect to the comparator drive **560** and the dual-comparator **588,** shown in FIG. **14.**

The dual-comparator **1084** includes a first comparator amplifier **1086** and a second comparator amplifier **1088.** The positive input of the first comparator amplifier **1086** is connected to the emitter of the transistor amplifier **1072,** generally between the transistor amplifier **1072** and the resistor **1080** via a resistor **1090,** the emitter of the transistor amplifier **1072** also being connected to the negative input of the second comparator **1088** via a resistor **1092.** The negative input of the first comparator **1086** is connected to a variable resistor **1094,** the variable resistor **1094** being connected to a negative power supply (not shown) via a pin connection **1096.** The first comparator **1086** includes a feedback loop connected to the output signal thereof and to the positive input thereto and a feedback resistor **1098** is interposed in the feedback loop. The second comparator **1088** includes a feedback loop connected to the output signal therefrom and to the positive input thereto, a feedback resistor **1100** being interposed in the feedback loop around the second comparator **1088.** The positive input to the second comparator **1088** is connected to a variable resistor **1102,** the variable resistor **1102** being connected to a negative power supply (not shown) via a pin connection **1104.**

The output signals of the first comparator **1086** and the second comparator **1088** are connected to provide a single, dual-comparator output signal **1106.** The dual-comparator output signal **1106** is connected to one input of a first "NAND" gate **1108,** the other input of the NAND gate **1108** being connected to a positive power supply (not shown) via a pin connection **1110.**

The first NAND gate **1108** has an output signal **1112** which is connected to one input of a second NAND gate **1114,** the other input of the second NAND gate **1114** being connected to an output signal **1116** from a third NAND gate **1118.** One input of the third NAND gate **1118** is connected to the positive power supply (not shown) via the pin connection **1110,** and the other input to the third NAND gate **1118** is connected to receive the first comparator output signal **756** from the comparator controller **366** (shown in FIG. **16**). The second NAND gate **1114** provides the output signal **780** which is connected to the negative input of the second comparator **768** of the comparator controller **366,** as described before with respect to FIG. **16.** In one form, the output signal **1112** of the first NAND gate **1108** is connected to a portion of the audio output controller **354** via a pin connection **1120** for providing audio feedback in a manner to be made more apparent below.

During the operation of the bio-feedback apparatus **10***b*, the variable resistor **1094** adjustably sets an upper amplitude limit and the variable resistor **1102** adjustably sets a lower amplitude limit of the dual-

comparator **1084.** The dual-comparator **1084** constructed such that the dual-comparator output signal **1106** is in a "low" state when the tachometer network output signal **918** input thereto via the transistor amplifier **1072** is within the preset upper and lower amplitude limits of the dual-comparator **1084,** and such that the dual-comparator output signal **1106** is in a "high" state when the tachometer network output signal **918** input thereto via the transistor amplifier **1072** exceeds or is outside the preset upper and lower amplitude limits of the dual-comparator **1084.**

The bandpass controller **372** is thus controlled via a d-c voltage linearly proportional to the frequency of the sensed potential from the subject (the tachometer network output signal **918**). The dual-comparator output signal **1106** is inverted via the first NAND gate **1108,** and thus the output signal **1112** is "high" or one when the received tachometer network output signal **918** produces a dual-comparator output signal **1106** within the upper and the lower limits of the dual-comparator **1084,** and the output signal **1112** is "low" when the received tachometer network output signal **918** produces a dual-comparator output signal **1106** outside the upper and the lower limits of the dual comparator **1084.**

The third NAND gate **1118** receives the first comparator output signal **756** of the comparator controller **366** and, therefore, when the first comparator output signal **756** is positive or "high," the capacitor **784** starts charging through the resistor **782** (shown in FIG. **16**). If both inputs to the second NAND gate **1114** are "high," the second NAND gate output signal **780** is "low." The NAND gate network comprising the first, the second and the third NAND gates **1108, 1114** and **1118** is thus essentially interposed between the first comparator **750** and the second comparator **768** of the comparator controller **366** and functions in the nature of a switch during the operation of the bio-feedback apparatus **10***b*.

Although the filter **360** of each processing channel provides a relatively selective frequency range for discriminating the signals to be processed in the separate processing channels of the bio-feedback apparatus **10***b*, the frequency proportional d-c control voltage provided via the tachometer output signal **918** if fed through the dual-comparator **1084,** which provides a "high" dual-comparator output signal **1106** when the tachometer network output signal **918** exceeds the threshold level settings of the dual-comparator **1084,** the dual-comparator **1084** functioning to further filter the varying potential input from the subject and having a substantially high rejection ratio (operating within a control frequency range at the upper and the lower limits of approximately one-fourth of a cycle, for example).

AUDIO FEEDBACK

A portion of the audio output controller **354** is schematically shown in FIG. **22,** the audio output controller **354** having input pins **1124, 1126** and **1128.** The input pin connection **1124** is connected to the pin connection **120** (FIG. **21**) of the bandpass controller **372** (normally "high" and switched to "low" indicating signal presence); the input pin connection **1126** is connected to the comparator controller output signal **770** (normally "low" and switched to "high" indicating signal presence); and the input pin connection **1128** is connected to a positive power supply (not shown).

The input pin connection **1124** is connected to the base of a drive transistor **1132** via a diode **1134.** The input pin connection **1126** is connected to the base of the drive transistor **1132** via a diode **1136,** and a two position switch **1138** is interposed between the pin connection **1126** and the diode **1136.** The input pin connection **1128** is connected to the base of the drive transistor **1132** via a diode **1140,** and a two position switch **1142** is interposed between the diode **1140** and the pin connection **1128.** The diodes **1134, 1136** and **1140** are, more particularly, connected in parallel to the base of the drive transistor **1132** and form a "diode-or" gate between the drive transistor **1132** and the incoming signals connected to the base thereof, wherein the drive transistor **1132** will be biased in the "off" position when any one of the diodes **1134, 1136** or **1140** is forward biased or conducting.

The emitter of the drive transistor **1132** is connectd to ground via a resistor **1144,** and the collector of the drive transistor **1132** is connected to a positive power supply (not shown) via a pin connection **1146.** A resistor **1148** is connected to the base of the drive transistor **1132** and to the positive power supply (not shown) via the pin connection **1146,** and a resistor **1150** is connected to the base of the drive transistor **1132** and to ground.

The drive transistor **1132** is connected to a relay operated switch **1152** having a switch arm **1154** and an operating coil **1156** for energizing the relay operated switch **1152** in the "on" position of the drive transistor **1132.** The operating coil **1156** is interposed in the connection between the collector of the drive transistor **1132** and the positive power supply (not shown), and a diode **1158** is connected in parallel across the operating coil **1156.**

The relay coil **1156** operates the relay operated switch **1152** to connect the oscillating output signal at the pin connection **800** of the automatic gain control **368** (FIG. **16**) to the audio feedback of the bio-feedback apparatus **10***b*, the output signal of the automatic gain control **368** being the voltage controlled oscillator output signal **1034** or, more particularly, the signal converter output signal (FIG. **20**) having an automatically adjusted signal gain via the automatic gain control **368.** The oscillating output signal from the automatic gain control **368** is connected to a capacitor **1160,** an input pin connection **1162,** and to an energized switch position **1164** of the relay operated switch **1152,** the switch arm **1154** contacting a de-energized switch position **1168** in a deenergized position of the relay operated switch **1152** (shown in FIG. **22**).

It should be particularly noted that the controlling signals connected to input pin connections **1124, 1126** and **1128,** the interconnecting diode-or gate network, the drive transistor **1132** network, the relay operated switch **1152,** the pin connection **1162,** the switch arm **1154** and the two cooperating switch positions **1164** and **1168** have been shown in FIG. **22** for only one of the processing channels of one of the controlling channels **324** and **326.** In the bio-feedback apparatus **10***b*, the above-mentioned portion of the audio feedback controller **354** is duplicated to receive controlling signals from all four of the processing channels of one of the controlling channels **324** and **326,** each portion being connected and operating in a manner similar to

that described above and below with respect to the one processing channel. More particularly, there are four switches **1138**, each switch connected to the diode **1136** and to one of the comparator controller output signals **770**, and the switches are mechanically connected for simultaneous positioning and the relay operated switch **1152** includes four switch arms **1154**, each switch arm **1154** being operated via the relay coil **1152** simultaneously with the switch arm **1154** (shown in FIG. **22**) to connect the oscillating output signal from one of the automatic gain controls **368** to the audio output controller **354** in an energized position of the relay operated switch **1152.** It should be further noted that the portion of the audio controller **354**, described above, is duplicated in the bio-feedback apparatus **10***b* to receive the four processing channels of the other one of the controlling channels **324** and **326**, the four processing channels of each controlling channel **324** and **326** operating to independently activate a subject-perceivable audio feedback during the operation of the bio-feedback apparatus **10***b*, for reasons and in a manner to be made more apparent below.

In the energized position of the relay operated switch **1152**, the oscillating output signals formed by the voltage controlled oscillators **374** and the signal converters **376** are each connected to one of the inputs of a mixer amplifier **1170** via a resistor **1172** and a variable resistor **1174**, as shown in FIG. **22**, Thus, in the "on" position of the switch **1142** and in the position of the switches **1138** disconnecting the pin connections **1126** from the diodes **1136** (only one pin connection **1126**), one diode **1136** and one switch **1138** being shown in FIG. **22**), the drive transistor **1132** will be continuously biased "on" independent of a detected signal presence in any of the processing channels, thereby energizing the relay operated switch **1152.** When the switches **1138** are moved to the switch position connecting the pin connections **1126** to the diodes **1136**, the drive transistor **1132** will be biased "on" only in response to a detected signal presence in any one of the four processing channels via the signal input to the pin connection **1124.** The switches **1138** thus have one switch position wherein a subject-perceivable audio feedback signal is generated via the bio-feedback apparatus **10**b even when the signal presence criteria of amplitude and duration indicates a no-signal presence, which may be useful in some applications.

The input of the mixer amplifier **1170**, opposite the input thereof receiving the oscillating signals indicative of a signal presence in a particular processing channel is connected to ground via a resistor **1176**, a mixer amplifier output signal **1173** being connected to the pin connection **1175.** A feedback loop is connected between the mixer amplifier output signal **1173** and the signal input thereto, and a feedback resistor **1178** is interposed in the feedback loop.

The mixer amplifier output signal **1173** and the frequency of each oscillating signal produced in each processing channel of the controlling channels are sized with respect to the frequency ranges produced thereby in a manner similar to that described before with respect to the mixer or summing amplifier **72** (shown in FIG. **6**) of the bio-feedback apparatus **10***a*, such that each output tone is subject-perceivable, yet produced simultaneously on the mixer amplifier output signal **1173** at the output pin connetion **1175.** The mixer amplifier **1170** and the four processing channel input signals thereto via the resistors **1172** and the variable resistors **1174** provide the mixer amplifier output signal **1173** for one of the controlling channels **324** and **326.** The bio-feedback apparatus **10***b* also includes a second mixer amplifier and the components connecting the four processing channel input signals thereto to provide the mixer amplifier output signal therefrom for the one other of the controlling channels **324** and **326** (only one being shown in FIG. **22** for the purpose of clarity of description).

The mixer amplifier output signal of one of the controlling channels **324** and **326** is connected to a pin connection **1182** (shown in FIG. **23**), and to a first audio amplifier **1184** via conductors or signal paths **1183** and **1185** through a relay operated switch **1186.** The mixer amplifier output signal of the other one of the controlling channels **324** and **326** is connected to pin connection **1188** and to a second audio amplifier **1190** via conductors or signal paths **1189** and **1191** through the relay operated switch **1186**, as shown in FIG. **23.** A switch **1192** has a first switch position **1194** and a second switch position **1196**, the first switch position **1194** being connected to the pin connection **1182** via a conductor **1195** and the second switch position **1196** being connected to the pin connection **1188** via a conductor **1197.**

Shown in FIG. **23**, the relay operated switch **1186** includes an operating coil **1198** operably connected to a plurality of switch arms, generally designated by the reference **1200.** The switch arms **1200** are each mechanically connected, and the switch **1186** has a mono-switch position **1202** and a stereo-switch position **1204**, each of the switch arms **1200** being simultaneously switched to the mono-switch position **1202** and the stereo-switch position **1204** via the relay coil **1198**, of the relay operated switch **1186.**

The relay coil **1198** is connected to one switch arm of a mechanically operated switch **1208** via a resistor **1210**, the mechanically operated switch **1208** having a plurality of switch arms (three of the switch arms being shown in FIG. **23**) and each switch arm being associated with a mono-switch position **1212** and a stereo-switch position **1214.**

One of the stereo-switch positions **1214** of the switch **1208** is connected to a positive power supply (not shown) via a conductor **1216** at a pin connection **1218**, the conductor **1216** being also connected to the stereo-switch position **1214** of one of the other switch arms of the switch **1208** which is connected to a lamp indicator **1220** via a conductor **1222**, as shown in FIG. **23.**

The first audio amplifier **1184** receives an incoming signal via the conductor **1185** and provides an amplifier output signal **1226** connected to a first speaker **1228.** The second audio amplifier **1190** receives an incoming signal via the conductor **1191** and provides an amplified output signal **1230** connected to a second speaker **1232.** It should be particularly noted that the audio amplifier output signals **1226** and **1230** are also, in a preferred form, connected in parallel to a first and second earphone of a headset (not shown) to provide a subject-perceivable audio feedback following the first and the second speakers **1228** and **1232.**

During the operation of the bio-feedback apparatus **10**b, when the switch **1208** is moved to position the switch arm thereof in the stereo-switch positions **1214**, the positive power supply (not shown) connected to the pin connection **1218** is connected to the relay coil

1198 energizing the relay operated switch 1186 and moving the switch arms 1200 thereof to the stereo-switch positions 1204. The switch 1192 may be in either position 1194 or 1196, shown in FIG. 23, and one of the controlling channel mixer amplifier output signals is connected to the first audio amplifier 1184 via the conductors 1183 and 1185 and the other one of the controlling channel mixer amplifier output signals is connected to the second audio amplifier 1190 via the conductors 1189 and 1191. Thus, in the energized stereo-position of the relay operated switch 1186 and in either position of the switch 1192, the first speaker 1228 provides subject-perceivable audio feedback signals indicative of the presence of signals within predetermined frequency bands of the detected potential from the subject via one of the electrodes 314 and 318, and the second speaker 1232 provides subject-perceivable audio output indications indicative of the presence of signals within predetermined frequency bands in the detected potential from the subject via the other one of the electrodes 314 and 318. In this stereo-position of the mechanically operated switch 1208, the lamp indicator 1220 is also connected to the positive power supply via the conductors 1222 and 1216, thereby providing a visual output indication indicative that the biofeedback apparatus 10*b* is operating in the stereo-mode.

When the switch arms of the switch 1208 are each moved to the mono-switch positions 1212, the relay coil 1198 is de-energized thereby moving each of the switch arms 1200 to the mono-switch positions 1202. In the mono-switch position of the relay operated switch 1186, the controlling channel mixer amplifier output signals at the pin connection 1182 and 1188 are selectively switched to the audio amplifiers 1184 and 1190 by the switch 1192, switch 1192 being a section of the left-right select relay under control of the left-right select switch. In this position of the switch 1186, one of the controlling channel mixer amplifier output signals is connected to each of the audio amplifiers 1184 and 1190 by moving the switch 1192 to the switch position 1194 or 1196, the switch 1192 being utilized to select one of the controlling channels 324 and 326 to control the aduio feedback.

ANALOG SWITCH AND DELAY SIGNAL CONTROLLER

The output signal 770 of the comparator controller 366 in each processing channel of one of the controlling channels 324 and 326 is connected to the analog switch 420 of the data reduction controller 344 (FIGS. 10 and 12) and, more particularly, to one of the input pin connections 1240 thereof, as shown in FIG. 24. Each input pin connection 1240 is connected to one switching transistor 1242 via a resistor 1244, the emitter of each switching transistor being connected to ground and the collector of each switching transistor 1242 being connected to the gate of one of the FET switches 1246 via a resistor 1248. The gate of each FET switch 1246 is also connected to a positive power supply (not shown) at the pin connection 1250 via a resistor 1252, the output signal 438 from the delay oscillator 422 (shown in FIG. 12) being connected to the pin connection 1255 of the analog switch 420. As shown in FIG. 24, the source connection of each of the FET switches 1246 are connected in common and the drain connection of each of the FET switches 1246 is connected to one of the output pin connections 1254, each of the output pin connections 1254 of the analog switch 420 being connected to one recording channel of the delay signal controller 424.

Thus, each of the FET switches 1246 are biased in the "closed" position in a non-conducting or "off" position of the switching transistor 1242 connected thereto and are each biased in the "open" position in a conducting or "on" position of the switching transistor 1242 connected thereto. Each switching transistor 1242 receives the output signal 770 from one of the comparator controllers 366, the comparator controller output signals 786 biasing the switching transistor 1242 connected thereto into the "on" or conducting position and opening the FET switch 1246 connected thereto when a signal presence is detected in the processing channel having the predetermined signal amplitude and duration controlled by the feedback signal controller 334. In the "open" position of the FET switches 1246, the output signal 438 from the delay oscillator 422 is connected to one of the recording channels of the delay signal controller 424 via the output pin connections 1254, each switching transistor 1242 controlling the position of the FET switches 1254 connected thereto.

The delay signal controller 424 (FIG. 12) receives the output signals from the analog switch 420 at the pin connections 1254 (shown in FIG. 24), each recording channel of the delay signal controller 424 being connected to one of the pin connections 1254 to receive the delay oscillator output signal 438 indicating signal presence in one particular processing channel of one of the controlling channels 324 and 326. The delay oscillator output signal 438 is recorded for a predetermined period of time, referred to as an "epoch" interval of time. Thus, each recording channel of the delay signal controller 424 has recorded signal presence in the processing channels, the recorded signal presence being retained by the delay signal controller 424, and subsequently connectd to the overvoltage controller 426, during the operation of the bio-feedback apparatus 10*b*.

In one form, the delay signal controller 424 can be a tape recorder having four recording channels and four playback channels, a loop being made in the tape between the recording heads defining the epoch period of time. In one other form, digital shift registers can be utilized to develop the delay signal controller output signal 442, the digital shift registers being also connected to receive the clock pulse 446 for controlling the shifting position of each of the digital shift registers. In this latter form, the signal synchronization is enhanced since the delay oscillator 422 would no longer be required and the digital circuitry would all be controlled by the single clock pulse generator 430.

OVERVOLTAGE CONTROLLER

The overvoltage controller 426 receives the delayed signals 442 from the delay signal controller 424, recorded over the last predetermined epoch period of time, the delayed output signals 442 being, more particularly, connected to an overvoltage comparator 1260, shown in FIG. 25. The overvoltage comparator 1260 is constructed similar to the dual-comparator 1084 of the comparator controller 372 (shown in FIG. 21 and described before), the overvoltage comparator 1260 having an output signal 1262 which is normally

"low" and which is switched to a "high" state when receiving an output signal **442** from the delay signal controller **424** within the upper and the lower amplitude limits set by the variable resistor adjustments of the dual-comparator of the overvoltage comparator **1260.**

The output signal **1262** of the overvoltage comparator **1260** is connected to the base of a switching transistor **1264** by a resistor **1266,** the emitter of the switching transistor **1264** being connected to ground and the collector of the switching transistor **1264** being connected to a positive power supply (not shown) via a pin connection **1268** and a resistor **1270.** The collector of the switching transistor **1264** is connected to the base of a switching transistor **1272** via a resistor **1274,** the emitter of the switching transistor **1272** being connected to ground and the collector of the switching transistor **1272** being connected to a positive power supply (not shown) via a pin connection **1267** and a resistor **1278.**

The collector of the switching transistor **1272** is connected to the anode of a diode **1280,** the cathode of the diode **1280** being connected to a transistor amplifier **1282** via a resistor **1284,** and a variable resistor **1286** connected in parallel with a capacitor **1288** is connected in parallel with the resistor **1284** of the transistor amplifier **1282,** as shown in FIG. **25.**

The transistor amplifier **1282** is connected in the emitter-follower form, the collector of the transistor amplifier **1282** being connected to a positive power supply (not shown) via a pin connection **1290** and the emitter of the transistor amplifier **1282** being connected to an output pin connection **1292** having a resistor **1294** connected in parallel thereto to ground. It should be noted that the portion of the overvoltage controller **426** shown in FIG. **25** is constructed for only one of the processing channels of one of the controlling channels **324** and **326,** and there is one such portion for receiving signals from each of the four processing channels of the controlling channels **324** and **326** in the bio-feedback apparatus **10***b*.

When the overvoltage comparator **1260** is receiving an output signal **442** from the delay signal controller **424,** the overvoltage comparator output signal **1262** is in the "high" state biasing the transistor amplifiers **1264** and **1272** to the "on" or conducting position, the oscillator delay signal controller output signal **442** being utilized to generate a d-c output control voltage signal at the emitter of the transistor amplifier **1282** or, in other words, at the output pin connection **1292.**

COUNTER CONTROLLER, COUNTERS AND DIGITAL/ANALOG CONVERTER

A preferred embodiment of one of the counter controllers **428** of the bio-feedback apparatus **10b** is schematically shown in FIG. **26,** the counter controller **428** having an input pin connection **1300** receiving the clock pulse **446** generated by the clock pulse generator **430** (shown in FIG. **12**); an input pin connection **1302** receiving a signal **1304** controlled by the comparator controlling output signal **770** connected at pin **1418** (shown in FIG. **28**), the signal **1304** at the input pin connection **1302** being in the "high" state when signal presence is detected in the processing channel connected thereto; and an input pin connection **1306** connected to and receiving the control voltage output signal **444** of the overvoltage controller provided at the pin connection **1292** (shown in FIG. **25**).

The clock pulse **446** is connected to a plurality of series-connected inverting gates **1308,** the output signal of the last of the series-connected inverting gates **1308** being connected to one input of a four-input first NAND gate **1310.** The plurality of inverting gates **1308** are interposed in the clock pulse **446** input line to the first NAND gate **1310** to delay the clock pulse for a predetermined interval of time for aligning the clock pulse **446** with the other control signals in the logic circuitry of the counter controller **428.** The control signal **1304** connected to the input pin connection **1302** is connected to one other input of the four-input first NAND gate **1310** via a conductor **1312,** the conductor **1312** also being connected to an output pin connection **1314** for controlling the "up" count position of the counters **432,** as will be made more apparent below.

The overvoltage controller output signal connected to the pin connection **1306** is connected to one input of a second four-input NAND gate **1320,** and the clock pulse **446** from the last series-connected inverting gate **1308** is connected to one of the inputs of the second four-input NAND gate **1320.** The control signal on the conductor **1312** is connected to an inverter **1322,** the output of the inverter **1322** being connected to one of the inputs of the NAND gate **1324,** and one of the inputs of the second four-input NAND gate **1320.** The control signal on the conductor **1318** is connected to an inverter **1326,** the ouput of the inverter **1326** being connected to the other input of the NAND gate **1324** and to one of the inputs of the four-input NAND gate **1310.** The output of the NAND gate **1316** and the output of the NAND gate **1324** are each connected to one of the inputs of a NAND gate **1328,** the output of the NAND gate **1328** being connected to a NAND gate **1330** and the other input of the NAND gate **1330** being the clock pulse received at the pin connection **1300** of the counter controller **428.** The gates **1316, 1324** and **1328** are connected in an exclusive "OR" configuration. The gates **1322** and **1326** are used to produce the "NOT" functions as the signals connected to the pin connections **1302** and **1306,** respectively.

The output of the NAND gate **1330** is connected to and received by a monostable multi-vibrator **1332,** the output of the monostable multi-vibrator **1332** being connected to one of the inputs of the first and second four-input NAND gates **1310** and **1320.** The monostable multi-vibrator **1332** is utilized to inhibit the clock pulse at the last gate of the delay line (comprising the gates **1308**) from clocking the counter at the change over of count directions for the first clock pulse to substantially maintain the count correct. The output signals from the first and the second four-input NAND gates **1310** and **1320** are each connected to one input of a NAND gate **1334.** The output signal of the NAND gate **1334** is connected to an output connection **1335,** the output signal at the pin connection **1335** being the clock pulse **446,** in one position. The inverted output signal **1304** from the inverter **1322** is connected to an output pin connection **1336** for controlling the "down" count of the counters **432.**

As shown in FIG. **27,** the counters **432** have input pin connections **1340, 1342,** and **1344**; the pin connection **1340** being connected to the pin connection **1335** (FIG. **26**) and receiving the clock pulse **446**; the pin connection **1342** connected to the pin connection **1314** (FIG. **26**) and receiving the up-count signal from the counter controller **428**; and the pin connection **1344**

connected to the pin connection **1336** and receiving the down-count control signal from the counter controller **428.** The counters **432,** in a preferred form, are a commercially available up-down type of counter such as the binary up-down serial carrier counter available from such companies as Texas Instruments Company of Dallas, Texas.

The counters **432** have three modes of operation: count-up, count-down, and no-count, the operational modes of the counters **432** being controlled via the received signals at the input pin connection s **1340, 1342** and **1344** of the counters **432.** The counters **342** are positioned in the count-up mode to count up to a predetermined number in response to a received clock pulse **446** at the pin connection **1340,** a received count-up signal at the pin connection **1342** indicating a sensed signal presence of a predetermined minimum amplitude and duration producing a comparator controller output signal **770** and no delayed signal presence producing a delay signal controller output signal **442.** The counters **432** are positioned in the count-down mode in response to a received clock pulse **446** at the pin connection **1340,** and a received count-down signal at the pin connection **1344** indicating a delay signal presence of a predetermined minimum amplitude and duration producing a delay signal controller output signal **442** and no signal presence for producing a comparator controller output signal **770.** The counters **432** are positioned in the no-count mode when the comparator controller **366** is producing an output signal **770** indicating signal presence of a predetermined minimum amplitude and duration and the delay signal controller **424** is producing an output signal **442** indicating a delayed signal presence of a predetermined minimum amplitude and duration; the counters **432** being also positioned in the no-count mode when there is no signal presence for producing the comparator controller output signal **770** and no delayed signal presence for producing the delay signal controller output signal **442.**

The counters **432** are, in one form, connected to provide an eight-bit output signal each bit being connected to one of the counter output pin connections, generally designated by the reference **1346** in FIGS. **27** and **28.** The output bit signals **1346** are, in a preferred form, NOT signals or, in other words, each output bit signal is "low" indicating a counted bit and "high" indicating a zero.

The counter output bit signals at the pin connections **1346** are each connected to the digital/analog converter **434** and, more particularly, each output bit from the counter **432** is connected to the base of one of the switching transistors **1348** via a resistor **1350,** as shown in FIG. **27.** The emitter of each of the switching transistors **1348** is connected to ground and the collector of each of the switching transistors **1348** is connected to a positive power supply (not shown) at a pin connection **1352** via a resistor **1354.** The collectors of the switching transistors **1348** are connected in parallel to an operational amplifier **1356** via a voltage dropping resistor **1358, 1360, 1362, 1364, 1366, 1368, 1370** and **1372,** respectively. The voltage dropping resistors **1358** through **1372** provide a controlled current to the current node of the operational amplifier **1356,** and are sized to provide a predetermined, controlled voltage drop there-across such that the total input signal to the operational amplifier **1356** provides an operational amplifier output signal **1374** indicative of the total count from the counters **432.**

The output signal **1374** from the operational amplifier **1356** is connected to the base of a transistor amplifier **1380** via a resistor **1382,** the operational amplifier **1356** thus providing the base biasing for the transistor amplifier **1380.** The transistor amplifier **1380** is connected in the emitter-follower form such that a current flows across a resistor **1384** connected to the emitter thereof, the resistor **1384** being connected to a negative power supply (not shown) via a pin connection **1386.** The collector of the transistor amplifier **1380** is connected to a positive power supply (not shown) at a pin connection **1388** via a resistor **1390.**

The output signal of the digital/analog converter **434** is taken at the pin connection **1392** which is connected to the emitter of the transistor amplifier **1380.** A feedback loop is connected about the digital/analog output signal at the pin connection **1392** and to the input signal to the operational amplifier **1356,** a feedback resistor **1394** being interposed in the feedback loop.

The other input of the operational amplifier **1356** is connected to ground via a resistor **1396,** and a diode **1398** to the operational amplifier **1356** input signal and to ground in parallel with the resistor **1396.** The resistors **1358–1372** are also connected in parallel to a variable resistor **1400** via current limiting resistor **1401,** the variable resistor **1400** being connected to a positive power supply (not shown) via a pin connection **1402** and to a negative power supply (not shown) via a pin connection **1404.**

The digital/analog converter **434,** shown in FIG. **27,** receives the counter output signal **450** (each counter output bit being "high" when the counter connected thereto has a zero count thereon) via the pin connections **1346,** and each "high" counter output signal at the pin connection **1346** connected thereto biases the switching transistor **1348** connected thereto "on." In the "off" or "non-conducting" position of any of the switching transistors **1348,** the voltage drop across the resistor **1358–1372** connected to the "non-conducting" switching transistor is controlled by the reference voltage supplied via the pin connection **1352,** thereby controlling the input signal to the operational amplifier **1356,** as will be made more apparent below.

The voltage dropping resistors **1358–1372** are sized such that, when each of the switching transistors **1348** is biased "on," indicating all of the counters have been reset to zero, the output signal at the pin connection **1392** indicates a "zero" count, the variable resistor **1400** being initially adjusted to set the output signal **1374** of the operational amplifier **1356** to provide zero count indication at the pin connection **1392.**

During the operation of the bio-feedback apparatus **10***b*, when one of the output pin connections **1346** is "low" indicating a count on the counter connected thereto, the switching transistor **1348** connected to that counter output pin connection **1346** is biased "off." In the "non-conducting" or "off" position of any one of the switching transistors **1348,** the resistor **1358–1372** connected to the conducting switching transistor **1348** is then connected in series with the resistor **1354** connected thereto causing a voltage drop thereacross connecting a positive signal to the current node of the operational amplifier **1356.** When the operational amplifier **1356** receives a positive signal at the current node

thereof, the diode **1398** will be forward biased and conducting, and the voltage drop thereacross is applied to the positive input of the operational amplifier **1356.** The operational amplifier output signal **1374** is proportional to the current being supplied to the current node thereof which is controlled by the resistive values of the resistors **1358–1372** connected to the switching transistors **1348** in the non-conducting or "off" position.

The operational amplifier **1356** provides the base biasing for the transistor amplifier **1380** which is connected in the emitter-follower form providing an output current across the resistor **1384** for controlling the digital/analog converter output signal **452** at the pin connection **1392.** The digital/analog converter output signal **452** is thus an analog d-c voltage indicative of the count from the counters **432,** thereby being indicative of a detected signal presence or, more particularly, an average percentage of signal presence detected in one of the preceding epochs of time compared with the signal presence being then detected in that particular processing channel.

In the operation of the bio-feedback apparatus **10***b*, there is one digital/analog converter **434** connected in each processing channel, in one form. In one preferred form, each digital/analog converter output signal **452** is connected to a meter light projection device for providing a visual feedback, each of the light projection devices having a meter movement consisting of a light projected on a screen via a translucent, colored bar wherein the screen is preferably colored green and the translucent bar is preferably colored red so that a black bar is projected on the screen, the movement of the black bar providing a visual feedback indicative of the percentage of signal presence produced by the subject for the preceding epoch of time in the processing channel connected thereto.

One other portion of the counter controller **428** is shown schematically in FIG. **28,** this logic gating portion of the counter controller **428** being referred to before with respect to FIG. **26** and the comparator controller controlled signal **1304.** More particularly, the output bit signals from the counters **432** at the pin connections **1346** (shown in FIGS. **27** and **28**) are each connected to a multiple-input NAND gate **1410.**

The multiple input NAND gate **1410** provides an output signal in a "high" state if any one of the input signals thereto from the counters **432** is in a "low" state or a digital zero. The output signal from the multiple-input NAND gate **1410** is connected to one of the inputs of a NAND gate **1412,** the other input to the NAND gate **1412** being provided via the output signal of a NAND gate **1414.** One of the inputs of the NAND gate **1414** is connected to a positive power supply (not shown) via a pin connection **1416** and the other input to the NAND gate **1414** is connected to the comparator controller output signal **770** via the pin connection **1418.** The output signal **1304** from the NAND gate **1412** is provided at an output pin connection **1420.**

Thus, when the comparator controller output signal **770** at the pin connection **1418** is "high," the output signal from the gate **1414** is "low." In this position, when all of the counter output pin connection **1346** is "high" indicating a zero count on the counters **432,** the output of the multiple-input NAND gate **1410** is "low," thereby providing an output signal **1304** in the "high" state at pin connections **1420** (FIG. **28**) and **1312** (FIG. **26**) and at the pin connection **1314** providing a "high" count-up signal to the counters **432.** In this same position of the counter output signals, when the comparator output signal **770** is "low," the output signal **1304** of the NAND gate **1412** is "high," thereby providing an output signal at the "high" count-up signal at the pin connection **1314** to the counters **432.** Thus, if the counter has a zero count, the counter is prevented from counting down under any given control signal and, therefore the counter cannot count from zero to a maximum in one step. The count-up from zero count control assures that noise will not produce an erroneous output signal or percentage.

The operation of the portions of the counter controller **428** shown in FIGS. **26** and **28** is illustrated in TABLE I, below, wherein:

A "low" state is represented by a digital 0;
A "high" state is represented by a digital 1;
The clock pulse is represented by the combination 10; and
The inverted clock pulse is represented by the combination 01.

TABLE I

Count on any one of counters		1	2	3	4				
All counters zero						1	2	3	4
Clock pulse in	1300	10	10	10	10	10	10	10	10
Singal presence	1418	1	1	0	0	1	1	0	0
Delay signal presence	1306	1	0	0	1	1	0	0	1
Count-up	1314	1	1	0	0	1	1	1	1
Count-down	1336	0	0	1	1	1	0	0	0
Clock pulse out	1335	0	10	0	10	0	10	0	0
Output of gates									
(Fig. 28)	1410	1	1	1	1	0	0	0	0
(Fig. 28)	1414	0	0	1	1	0	0	1	1
(Fig. 28)	1412	1	1	0	0	1	1	1	1
(Fig. 26)	1322	0	0	1	1	0	0	0	0
(Fig. 26)	1326	0	1	1	0	0	1	1	0
(Fig. 26)	1324	1	1	0	1	1	1	1	1
(Fig. 26)	1316	0	1	1	1	0	1	1	1
(Fig. 26)	1328	1	0	1	0	1	0	0	0
(Fig. 26)	1330	01	11	01	11	01	11	11	11
(Fig. 26)	1310	11	01	11	11	11	01	11	11
(Fig. 26)	1320	11	11	11	01	11	11	11	11
(Fig. 26)	1334	0	10	0	10	0	10	0	0

The counters **432** will count-up when signal presence is indicated by a comparator controller output signal **770** and delay signal controller **424** is not producing an output signal **442.** If the signal presence indicated by the comparator controller output signal **770** continues to exist for the epoch of time, the counters **432** will count-up to the full preset count; and, if the signal presence indicated by the comparator controller output signal **770** continues, the counter controller **428** will be receiving the signal presence indicated by the comparator controller output signal **770** and the delay signal presence via the delay signal controller output signal **442,** thereby activating the counter controller **428** to position the counter **432** in a no-count position holding the full count thereon indicating the subject is producing one predetermined signal component **100** per cent. In this position, the comparator controller output signal **770** must return to a "low" state before the delay signal controller output signal **442** will then start the counters **432** counting down. If the comparator controller output signal **770** remains in the low state for the epoch of

time, the delay signal controller output signal **442** will cause the counters **432** to count down to a zero count. At that point, the counters **432** will be forced to an up count state by the action of the count control circuitry of FIG. **28.** By the same token, if the signal presence indicated by the comparator controller output signal **770** is again returned to the "high" state and if a delayed signal presence is still being produced via the delay signal controller output signal **442,** the counters **432** will be positioned in a no-count position and the percentage indicated will be held thereon. Thus, the data reduction controller **344** of the bio-feedback apparatus **10***b* is constructed such that the delayed signal presence indicated by the delay signal controller output signal **442** is essentially compared with the signal presence indicated by the comparator controller output signal **770** to produce a sliding epoch, the count on the counters **432** produced via the presence signal being indicative of the average percentage of signal presence produced by the subject during the preceding epoch of time.

In the "zero" position of each of the counters **432,** the multiple-input NAND gate **1410** and the gates **1414** and **1412** cooperate such that the clock pulse is connected to the counters **432** in only one position; that is, when a signal presence exists via the comparator controller output signal **770** and the delay signal controller **424** is not producing an output signal **442.** In this position, the counter controller **428** connects the clock pulse **446** and the count-up signal via the pin connection **1314** to the counters **432,** as indicated in TABLE I above. The multiple-input NAND gate **1410** and the gates **1414** and **1412** prevent the counters **432** from counting down through zero and indicating a false reading full count.

The NOT outputs at the pin connections **1346** are connected to the digital/analog converter **434** and, thus, the pin connections **1346** are in the "high" state when the counter of the counters **432** connected thereto has a zero count thereon. In the "low" state of any of the counter pin connections **1346,** the switching transistor **1348** is biased in a "non-conducting" position, thereby supplying current to the current node of the operational amplifier **1356** via one of the voltage dropping resistors **1358** through **1372** connected to the non-conducting switching transistor **1348.** The resistance value of voltage dropping resistor determines the current supplied to the operational amylifier **1356** and the operational amplifier **1356** converts the received current to an analog voltage at the output signal **1374** therefrom for driving the transistor amplifier **1380,** thereby providing a negative analog voltage at the output pin connection **1392.**

The foregoing description of the counter controller **428,** the counters **432** and the digital/analog converter **434** has been directed to one processing channel of one of the controlling channels **324** and **326,** for the purpose of clarity of description. In the bio-feedback apparatus **10***b* there are counter controllers, counters, and digital/analog converters for controlling feedback in each of the four processing channels of each of the controlling channels **324** and **326** or, in one form, for controlling the feedback in each of the four processing channels of one preselected controlling channel **324** or **326.**

VISUAL FEEDBACK

A portion of the visual output controller **348** is shown in FIG. **29** and basically comprises: a meter drive network **1426** including an operational amplifier **1428** having the positive input connected to a variable resistor **1430** and the negative input connected to a variable resistor **1432** via a resistor **1434,** the connection between the negative input of the operational amplifier **1428** and the variable resistor **1432** being connected to ground via a resistor **1436.**

The variable resistor **1430** is connected to ground on one side thereof and the opposite side is connected to a pin connection **1438** to provide the input signal to the operational amplifier **1428,** the input signal being provided via the digital/analog converter output signal **452** (FIG. **12**). A feedback resistor **1440** is connected to the output signal **1442** and to the negative input of the operational amplifier **1428,** thereby providing a feedback loop about the operational amplifier **1428.** A diode **1444** is connected in parallel with the feedback resistor **1440** and a diode **1446** is connected to the negative input of the operational amplifier **1428,** the cathode of the diode **1446** being connected to a variable resistor **1448.** The variable resistor **1448** is connected to a negative power supply (not shown) at a pin connection **1450** via a resistor **1452.** The variable resistor **1432** is connected to a negative power supply (not shown) at a pin connection **1454** via a resistor **1456.** The output signal **1442** of the operational amplifier **1428** is connected to a meter **1458** and to an output pin connection **1460,** which in a preferred form is connected to the permanent recorder indicator **330** (shown in FIG. **11**).

The digital/analog converter output signal **452** drives the operational amplifier **1428,** the operational amplifier output signal **1442** being connected to the meter **1458** such that the meter needle deflection provides a visual feedback indicative of the average percentage of time during the epoch when a signal presence was being produced in the processing channel connected thereto. The variable resistor **1430** controls the total deflection of the meter **1458** by controlling the input signal to the operational amplifier **1428,** the diodes **1444** and **1446** control the limits of the output signal **1442,** thereby providing a meter deflection protection to preventing overdriving the meter **1458.** The portion of the visual feedback controller **348** is shown in FIG. **29** for controlling one of the processing channels, the biofeedback apparatus **10***b*, in one form, including duplicate portions for controlling visual feedback in each of the processing channels.

Another portion of the visual output controller **348** is shown in FIG. **30,** and includes a frequency meter drive network **1461** having a pin connection **1462** connected to a negative power supply (not shown), the pin connection **1462** being connected to a resistor **1464** in series, with a voltage divider network **1466.** The voltage divider network **1466** is connected to a mechanically operated switch having a switch arm **1468** via three switch positions **1470, 1472** and **1474,** each switch position connecting a different, predetermined negative bias through the switch arm **1468** when the switch arm **1468** is selectively switched into contact therewith.

The switch arm **1468** is connected to one contact of a relay **1476** having a relay arm **1478,** the other relay contact being connected to receive the tachometer network output signal **378** via a pin connection **1480.** The relay **1476** has an operating coil **1482** connected to a

positive power supply (not shown) at a pin connection **1484** via a resistor **1486,** the operating coil **1482** being also connected to the collector of a switching transistor **1488.** The emitter of the switching transistor **1488** is connected to ground, and the base is connected to receive the comparator controller output signal **770** at the pin connection **1490** via a resistor **1488.**

The relay arm **1478** is connected to a meter drive **1494** driving a meter **1496** connected thereto. The meter drive **1494** and the meter **1496** are constructed and operate similar to the meter drive **1426** and the meter **1458,** shown in FIG. **29** and described before.

The tachometer output signal **378** is connected to the normally open contact of the relay **1476** and, when a "high" comparator controller output signal **770** is connected to the switching transistor **1488,** the switching transistor **1488** is biased "on" energizing the relay coil **1482** and connecting the tachometer output signal **378** to the meter drive **1494** via the relay arm **1478.** In this position, the meter **1496** provides a visual feedback indicative of the frequency of the signal component in the processing channel connected thereto when the comparator controller output signal **770** is "high" indicating signal presence in the processing channel.

In the de-energized position of the relay coil **1482,** the relay arm **1478** engages the relay contact connecting the voltage divider network **1466** to the meter drive **1494.** The switch positions **1470, 1472** and **1474** of the voltage divider network **1466** provide a centering bias to the meter drive **1494,** in the de-energized position of the relay **1476** to prevent meter-needle movement or, in other words, to drop the meter needle back to a preset centered position. The portion of the visual output controller **348** is shown in FIG. **30** for controlling visual feedback in one of the processing channels, the bio-feedback apparatus **10***b*, in one form, including duplicate portions for controlling visual feedback in each of the processing channels.

One other portion of the visual output controller **348** is schematically shown in FIG. **31,** having input pin connections **1500, 1502, 1504,** and **1506** each connected to one of the comparator controller output signals **770** of each processing channel, each input pin connection being connected to one of the switching transistors **1508** via a resistor **1510.** The collector of each switching transistor **1508** is connected to one of the relay coils **1512** of a relay **1514** via a resistor **1516,** and a diode **1518** is connected in parallel with each relay coil **1512.** The energized contact position of each relay **1514** is connected to a lamp indicator (not shown) at one of the output pin connections **1520, 1522, 1524** and **1526,** and each relay contact arm is connected to a power supply (not shown) via a pin connection **1528.**

Thus, when signal presence is indicated in any one of the processing channels the comparator controller output signal **770** of that processing channel biases one of the switching transistors **1508** "on" energizing the relay coil **1512** connected thereto and moving the relay **1514** to the energized position. In the energized position, the lamp indicator (not shown) is connected to the power supply (not shown) via the pin connection **1528** and the pin connection **1520, 1522, 1524** or **1526** connected to the energized relay **1514,** thereby providing a visual output indication indicative of signal presence of a predetermined minimum amplitude and duration in one of the processing channels. The portion of the visual output controller **348** shown in FIG. **31** controls the visual feedback for four of the processing channels of one of the controlling channels **324** and **326,** the bio-feedback apparatus **10**b, in one form, including a duplicate portion for controlling visual feedback for the one other of the controlling channels **324** and **326.**

Changes may be made in the construction and the arrangement of the various parts or the elements of the embodiments as disclosed herein without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A bio-feedback apparatus for sensing the brain-wave potentials produced by a subject and providing feedback signals in response thereto, the apparatus comprising:

a brain-wave indicator detecting and sensing brain-wave potentials, and providing an output signal responsive thereto;

a preamplifier receiving the brain-wave indicator output signal and providing an amplified output signal responsive thereto;

a plurality of processing channels, each processing channel receiving the preamplifier output signal and providing a feedback signal responsive thereto, each processing channel comprising:

a passband filter, having a predetermined passband, receiving the preamplifier output signal and providing an output signal responsive to a frequency component of the received signal within the passband; and

means receiving the passband filter output signal and providing an output signal indicative of signal presence in the processing channel, including:

an oscillator, interposed in each processing channel, each oscillator in each processing channel receiving the passband filter output signal and generating an output signal having a distinct, separately identifiable frequency in response thereto, the oscillator output signals indicating signal presence in the processing channels;

a feedback indicator receiving the output signals indicative of the signal presence from each of the processing channels and providing subject-perceivable feedback signals responsive thereto, the feedback indicator including:

a summing amplifier receiving the oscillator output signal from each of the oscillators in each processing channel and providing a single output signal in response to the received oscillator output signals; and

an output indicator receiving the summing amplifier output signal and providing a subject-perceivable output indication responsive thereto.

2. The bio-feedback apparatus of claim **1** wherein the means receiving the passband filter means output signal is defined further to include:

a full-wave rectifier providing an output signal in response to a received input signal;

means connected to the full-wave rectifier receiving the passband filter output signal and providing an input signal to the full-wave rectifier;

a timing network receiving the full-wave rectifier output signal and providing a feedback control voltage

in response to a received signal of a predetermined minimum duration thereby substantially eliminating feedback indications produced via relatively short duration sensed brainwave potentials; and

switch means having an "on" and an "off" condition connected to the timing network and the oscillator, the switch means receiving the feedback control voltage and being biased in the on condition in response thereto activating the oscillator in the "on" condition, the oscillator providing the output signal indicating signal presence in the processing channels.

3. The bio-feedback apparatus of claim **2** wherein each processing channel is defined further to include:

an amplifier receiving the preamplifier output signal and providing an amplified output signal in response thereto; and

sensitivity adjustment means connected to the amplifier controlling the threshold sensitivity setting of the amplifier connected thereto, the amplifier providing an amplifier output signal in response to a received preamplifier output signal having an amplitude exceeding the threshold setting of the sensitivity adjustment means connected thereto.

4. A bio-feedback apparatus for sensing the brainwave potentials produced by a subject and providing the feedback signals in response thereto, the apparatus comprising:

a brain-wave indicator sensing the brain-wave potentials, and providing an output signal responsive thereto;

a preamplifier receiving the brain-wave indicator output signal and providing an amplified output signal responsive thereto;

a plurality of processing channels, each processing channel receiving the preamplifier output signal and providing a feedback signal responsive thereto, each processing channel comprising:

a passband filter, having a predetermined passband, receiving the preamplifier output signals and providing an output signal responsive to a frequency component of the received signal within the filter passband;

means receiving the passband filter output signal and providing an output signal indicating signal presence in the processing channel, including:

comparator means, having an upper and a lower amplitude threshold limit, receiving the passband filter output signal and providing an output signal in response to a received preamplifier output signal, the comparator means output signal being "low" when receiving a preamplifier output signal having an amplitude level within the upper and the lower amplitude threshold limits of the comparator means;

switch drive means receiving the comparator means output signal, having a biased "on" and a biased "off" condition, the switch drive means being biased in the "on" condition when receiving a "low" comparator means output signal;

a threshold adjust means connected to the switch drive means receiving the switch drive means output signal in an "on" condition of the switch drive means and providing an output signal when receiving a switch drive means output signal of a predetermined minimum duration, the threshold adjust means output signal being terminated via the switch drive means output signal remaining switched to the "off" position for a predetermined minimum period of time; and

switch network means connected to the threshold adjust means having an "on" and an "off" condition, the switch network means biased in the "on" condition when receiving a threshold adjust means output signal indicating signal presence in the particular processing channel; and

feedback indicator means receiving the output signals indicative of signal presence from each of the processing channels and providing subject-perceivable feedback signals responsive thereto and indicative thereof.

5. The bio-feedback apparatus of claim **4** wherein the means in each processing channel receiving the passband filter output signal and providing an output signal indicating signal presence in the processing channel is defined further to include:

amplitude discriminator means receiving the passband filter output signal and providing an output signal substantially proportional to the amplitude of the received passband filter output signal; and

comparator controller means receiving the amplitude discriminator output signal and providing "high" output signal in response to a received amplitude discriminator output signal having a predetermined duration indicating signal presence in the processing channel, the comparator controller output signal being connected to the feedback indicator means for providing subject perceivable feedback signals in response to a comparator controller means "high" output signal.

6. The bio-feedback apparatus of claim **5** wherein the means in each processing channel receiving the passband filter output signal and providing an output signal indicating signal presence in the processing channel is defined further to include:

zero crossing detector means receiving the passband filter output signal and providing a "high" output signal in response to a negative going zero crossing of the passband filter output signal and a "low" output signal in response to a positive going zero crossing of the passband filter output signal;

tachometer network means receiving the zero crossing detector means output signal providing an output signal substantially linearly proportional to the frequency of the received zero crossing detector means output signal; and means receiving the tachometer network output signal and providing an oscillating output signal having a frequency corresponding to a multiple of the frequency of the sensed potential indicated by the tachometer network output signal; and

wherein the feedback indicator means receives the oscillating output signal corresponding to a multiple of the frequency of the sensed potential and provides a subject-perceivable feedback signal responsive thereto indicating signal presence in the particular processing channel.

7. The bio-feedback apparatus of claim **6** wherein the means in each processing channel receiving the passband filter output signal and providing an output signal indicating signal presence in the processing channel is defined further to include:

automatic gain control means receiving the amplitude discriminator output signal and the oscillating output signal corresponding to a multiple of the frequency of the sensed potential, the automatic gain control means controlling the volume of the received oscillating signal in response to the received amplitude discriminator output signal and providing an output signal corresponding to received oscillating signal having the volume thereof controlled in response to the received amplitude discriminator output signal; feedback indicator means is defined further to include an audio output indicator receiving the automatic gain control output signal and providing audible subject-perceivable feedback signal responsive thereto.

8. The bio-feedback apparatus of claim **7** wherein the means providing an oscillating output signal in response to a received tachometer network output signal is defined further to include:

non-inverting amplifier means receiving the tachometer network means output signal and providing an amplified output signal in response thereto;

unity-gain inverting amplifier means receiving the non-inverting amplifier output signal and providing an inverted output signal in response thereto;

first diode bridge means connected to and receiving the non-inverting amplifier means output signal and the unity-gain inverting amplifier means output signal;

amplifier means having an output signal connected to the first diode bridge means;

second diode bridge means connected to the amplifier means providing an output signal driving the amplifier means;

integrator amplifier means connected to the first diode bridge means and providing a triangularly shaped output signal, the integrator amplifier means output signal being connected to the amplifier means controlling the amplitude of the triangularly shaped signal produced by the integrator amplifier means; and

signal converter means receiving the integrator amplifier means output signal and providing a sine-wave shaped output signal in response thereto, the signal converter means output signal being connected to automatic gain control means and providing the oscillating signal input connected thereto.

9. The bio-feedback apparatus of claim **6** wherein the means in each processing channel receiving the passband filter output signal and providing the output signal indicating signal presence in the processing channel is defined further to include:

bandpass controller means, having a high and a low threshold setting and providing a "high" and a "low" output signal, receiving the tachometer network means output signal and providing a "low" output signal in response to a received tachometer network means output signal within the high and the low threshold setting of the bandpass controller means; and

wherein the comparator controller means receives the bandpass controller means output signal, the comparator controller providing a "high" output signal in response to a received "low" bandpass controller means output signal indicating signal presence in the processing channel within the high and the low threshold settings of the bandpass controller means output signal.

10. The bio-feedback apparatus of claim **9** wherein the tachometer network means includes: an oscillator means having an "on" and an "off" condition, the oscillator means receiving the zero crossing detector means output signal and being biased in the "on" condition in response thereto providing an oscillator means output signal; and wherein the amplitude discriminator means is defined further to include:

discriminator amplifier means receiving the passband filter means output signal and providing an amplified output signal responsive thereto;

diode means connected to and receiving the discriminator amplifier means output signal, the diode means being forward biased and conducting when receiving a positive going discriminator amplifier means output signal and being reversed biased and nonconducting when receiving a negative going discriminator amplifier means output signal;

capacitor means receiving the discriminator amplifier means output signal and being charged in response thereto in a conducting condition of the diode means;

memory capacitor means receiving the charge on the capacitor means when connected thereto;

first gate means having an opened and a closed condition connected between the capacitor means and the memory capacitor means, the first gate means receiving the oscillator output signal via the tachometer network means and being biased open in response thereto connecting the capacitor means and the memory capacitor means;

switching means connected to the capacitor means having an "on" and an "off" condition and receiving the zero crossing detector means output signal, the switching means being biased in the "on" condition in response to a received zero crossing detector means output signal in the "high" state discharging the capacitor means connected thereto; and

second gate means having an opened and a closed condition connected to the memory capacitor means and to the amplitude discriminator means, the charge on the memory capacitor means biasing the second gate means opened and providing the amplitude discriminator means output signal.

11. The bio-feedback apparatus of claim **10** wherein the tachometer network means is defined further to include:

switching means, having an "on" and an "off" condition, and receiving the tachometer oscillator means output signal and being biased "on" in response thereto;

function generator means connected to the switching means and having a portion charged in the "on" condition of the switching means, the charged portion being discharged in the "off" condition of the switching means, the function generator means providing an output signal proportional to the frequency of the sensed brain-wave potential in the discharging condition thereof;

memory capacitor means connected to the portion of the function generator charged in the "on" condition of the switch means and receiving the charge discharged from the function generator means when connected thereto; and

switching means connected to the function generator means and to the memory capacitor means, having an "on" and an "off" condition, the switching means receiving the oscillator output signal of the tachometer network means and being biased "on" in response thereto connecting the discharging function generator to the memory capacitor means.

12. The bio-feedback apparatus of claim **11** wherein the function generator means is defined further to include:

capacitor means connected to the switching means and being charged in the "on" condition of the switching means;

a resistive network bleed path connected to the capacitor means having a relatively low time constant;

a resistive network bleed path connected to the capacitor means having a relatively high time constant; and

diode means, having a forward biased and a reverse biased condition, connected to the high time constant resistive network bleed path, the capacitor means discharging through the high time constant resistive network bleed path in a forward biased condition of the diode means and through the low time constant resistive network bleed path in a reverse biased condition of the diode means, the discharging curve of the capacitor means being linearly proportional to the frequency of the sensed brain-wave potential.

13. The bio-feedback apparatus of claim **12** wherein the function generator means is defined further to include:

a resistive network bleed path connected to the capacitor means having an intermediate time constant; and

diode means connected to the intermediate time constant resistive network bleed path, the capacitor means discharging through the high and the intermediate time constant resistive networks in a forward biased condition of the diode means connected therein, the capacitor means discharging through the intermediate and the low time constant resistive networks in a reverse biased condition of the diode means connected to the high time constant resistive network, and the capacitor means discharging through the low time constant resistive network in a reverse biased condition of the two diode means.

14. The bio-feedback apparatus of claim **9** wherein the comparator controller means is defined further to include:

first comparator means, having a predetermined threshold setting, receiving the amplitude discriminator output signal and providing an output signal in a "low" state in response to a received amplitude discriminator output signal having an amplitude level exceeding the threshold setting of the first comparator means;

second comparator means receiving the first comparator means output signal and connected to the capacitor means, having a predetermined threshold setting and providing a comparator controller means output signal in a "high" state in response to the capacitor means connected thereto being discharged to a potential exceeding the threshold setting of the second comparator means; and

capacitor means connected to the second comparator means and to the bandpass controller means discharging in a "low" state of the first comparator means output signal and in a "low" state of the bandpass controller means output signal.

15. The bio-feedback apparatus of claim **14** wherein the bandpass controller means is defined further to include:

dual-comparator means, having a predetermined high and a low threshold limit, receiving the tachometer network means output signal and providing a "low" output signal when receiving a tachometer network means output signal within the high and the low threshold limit; and

gate means receiving the dual-comparator means output signal and the first comparator means output signal from the comparator controller means, the gate means being connected to the second comparator means of the comparator controller means and connecting a "low" output signal to the capacitor means when receiving a "low" dual-comparator means output signal.

16. The bio-feedback apparatus of claim **9** wherein the bandpass controller means includes: gate means inverting the bandpass controller means output signal and providing a "low" output signal in response to a received tachometer network means output signal within the high and the low threshold setting of the bandpass controller means; and wherein the feedback indicator means is defined further to include:

mixer amplifier means receiving the automatic gain control means output signals connected thereto and providing an amplified output signal responsive thereto;

relay means interposed between the mixer amplifier means and the automatic gain control means output signal of each processing channel, the relay means connecting each automatic gain control means output signal to the mixer amplifier means in an energized condition thereof; and

drive transistor means connected to the relay means having an "on" and an "off" condition and energizing the relay means in the "on" condition thereof, the drive transistor means receiving each comparator controller means output signal and each output signal of the gate means of each bandpass controller means;

diode means connected between the drive transistor means and the comparator controller means output signal and between the drive transistor means and the output signal of the gate means of each bandpass controller means, the drive transistor means being biased "on" in response to a received "high" output signal of the gate means of the bandpass controller means and a received "high" amplitude discriminator means output signal.

17. The bio-feedback apparatus of claim **9** wherein the feedback indicator means is defined further to include:

amplifier means having an "on" and an "off" condition receiving the comparator controller means output signal and being biased "on" in response to a comparator controller means output signal in the "high" state;

meter means receiving the tachometer network means output signal, providing a visual feedback signal indicating the frequency of the sensed brainwave potential; and

relay means interposed between the tachometer network means and the meter means, connecting the tachometer network means output signal to the meter means in an energized condition thereof, the relay means connected to the amplifier means and being energized in a biased "on" condition of the amplifier means.

18. The bio-feedback apparatus of claim **5** wherein the means in each processing channel receiving the passband filter output signal and providing an output signal indicating signal presence in the processing channel is defined further to include:

data reduction controller means receiving the comparator controller means output signal indicating signal presence in the processing channel, and having a portion monitoring signal presence in the processing channel over a predetermined epoch period of time. and providing an output signal indicating the percentage of time signal presence existed in the processing channel during a subsequent predetermined period of time, an epoch period of time; and

wherein the feedback indicator is defined further to include a portion receiving the output signal indicating the percentage of time signal presence existed in the processing channel and providing a feedback indication in response thereto.

19. The bio-feedback apparatus of claim **18** wherein the data reduction means is defined further to include:

delay oscillator means generating an output signal;

analog switch means receiving the comparator controller means output signal and the delay oscillator means output signal, the analog switch means providing the delay oscillator output signal when receiving a comparator controller means output signal in a "high" state;

delay signal controller means receiving the delay oscillator means output signal via the analog switch means and recording the received delay oscillator means output signal for the predetermined epoch period of time; and

means receiving the delay signal controller means output signal and the comparator controller means output signal providing an output signal indicating the average percentage of time signal presence existed in the processing channel for the preceding predetermined epoch period of time in response to the received comparator controller means output signal and the received delay signal controller means output signal; and

wherein the feedback indicator means includes a portion receiving the output signals indicating the average percentage of time signal presence existed in each processing channel and provides a subject-perceivable feedback signal response thereto.

20. The bio-feedback apparatus of claim **19** wherein the portion of the feedback indicator means providing the output signal indicative of the average percentage of time signal presence existed in the processing channel is defined further to include:

counters for counting up to a predetermined number and counting down to zero, the counters providing a digital output signal indicative of the count registered therein and having a count-up mode, a count-down mode, and a hold mode, the counters positioned in the count-up mode in response to a received count-up signal and positioned in the count-down mode in response to a received count-down signal;

overvoltage controller means providing a "high" and "low" output signal, and having an upper and a lower threshold limit, the overvoltage controller means receiving the delay signal controller means output signal and providing a "high" output signal in response to a received delay signal controller means output signal within the upper and the lower threshold limits; and

counter controller means connected to the counters and receiving the overvoltage controller means output signal and the comparator controller output signal, the counter controller means providing an output count-up signal in response to a comparator controller means output signal in the "high" state and an overvoltage controller means output signal in the "low" stage, and an output count-down signal in response to a received comparator controller means output signal in a "low" state and an overvoltage controller means output signal in a "high" state, the digital output signals of the counters providing the output signal indicating the average percentage of time signal presence existed in the processing channel.

21. The bio-feedback apparatus of claim **20** wherein the portion of the feedback indicator means providing the output signal indicative of the average percentage of time signal presence existed in the processing channel is defined further to include:

a digital/analog converter receiving the counters output signal and providing an analog voltage output signal responsive thereto indicating the percentage of time signal presence existed in the processing channel.

22. The bio-feedback apparatus of claim **21** wherein the feedback indicator means includes:

meter drive network means receiving the digital-/analog converter output signal and providing an output signal responsive thereto; and

meter means receiving the meter drive network means output signal and providing a visual feedback indicating the average percentage of time signal presence existed in the processing channel connected thereto in response to the received meter drive network output signal.

23. The bio-feedback apparatus of claim **21** defined further to include: clock pulse generator means generating a clock pulse output signal therefrom; and wherein the counters are further defined to provide output signals in the "low" state in response to a count being registered thereon and to provide output signals in the "high" state in response to a zero count being registered thereon, the counters being positioned in the count-up mode in response to a received count-up signal and a clock pulse and in the count-down mode in response to a received count-down signal and a clock pulse; and wherein the counter controller means receives the clock pulse output signal and the counters output signal, the counter controller means being defined further to include:

gate means receiving the clock pulse output signal, the comparator controller means output signal, the overvoltage controller means output signal and the counters output signals and providing an output count-up signal and a clock pulse in response to a comparator controller means output signal in the "high" state and an overvoltage controller means output signal in a "low" state, an output count-down signal and a clock pulse in response to a received comparator controller means output signal in a "low" state and an overvoltage controller means output signal in a "high" state, in response to at least one "low" counters output signal, and providing an output count-up signal and a clock pulse in response to received counters output signal in the "high" state and a received comparator means output signal in a "high" state.

24. The bio-feedback apparatus of claim **18** wherein the brain-wave indicator means includes: means detecting and sensing the brain-wave potentials produced at at least two preselected scalp sites, the brain-wave indicator means providing a controlling channel output signal indicating the sensed brain-wave potential at each scalp site; and wherein the preamplifier means receives the controlling channel output signals and provides amplified output signals responsive thereto; and wherein the bio-feedback apparatus includes: an amplitude equalizer, having a portion varying received signals about a preset amplitude reference axis, receiving and varying the amplified controlling channel output signals about the predetermined common amplitude reference axis providing the equalized amplified controlling channel output signals therefrom; and wherein processing channels include a plurality of processing channels receiving each controlling channel output signal and providing a feedback signal responsive to each received controlling channel output signal indicating signal presence in the processing channel.

25. The bio-feedback apparatus of claim **24** wherein the feedback indicator means is defined further to include:

first audio means providing subject-perceivable audible feedback signals responsive to a received signal input thereto;

second audio means providing subject-perceivable audible feedback signals responsive to a received signal input thereto; and

switch means connected to and receiving the feedback signals of each controlling channel output signal, the switch means connected to the first and the second audio means and having one switch position connecting the feedback signal from one controlling channel output signal to the first audio means and the feedback signal from one other controlling channel output signal to the second audio means, and one other switch position connecting the feedback signals from one of the controlling channel output signals to the first and the second audio means.

26. A bio-feedback apparatus for sensing the brain-wave potentials produced by a subject and providing feedback signals in response thereto, the apparatus comprising:

a brain-wave indicator detecting and sensing the brain-wave potentials, and providing an output signal responsive thereto;

a processing channel receiving the brain-wave indicator output signal and providing a feedback signal responsive thereto, the processing channel comprising:

frequency discriminator means having a predetermined passband, receiving the brain-wave indicator output signals and providing an output signal responsive to the frequency component of the received signal within the passband of the frequency discriminator means;

means receiving the frequency discriminator means output signal and providing an output signal indicating signal presence in the processing channels;

a data reduction controller means receiving the output signal indicating signal presence in the processing channel and providing an output signal indicating the percentage of time signal presence exists in the processing channel for a subsequent predetermined epoch period of time, the data reduction controller means including:

delay oscillator means generating an output signal;

analog switch means receiving the output signal indicating signal presence in the processing channel and the delay oscillator means output signal, the analog switch means providing the delay oscillator means output signal in response to a received output signal indicating signal presence in the processing channel;

delay signal controller means receiving the delay oscillator means output signal from the analog switch means and recording the received delay oscillator means output signal for the predetermined epoch period of time and providing an output signal responsive thereto; and

means receiving the delay signal controller means output signal indicating signal presence in the processing channel during the predetermined epoch period of time and providing an output signal indicating the average percentage of time signal presence existed in the processing channel for the predetermined epoch period of time, including:

counters for counting up to a predetermined number and counting down to zero, the counters providing a digital output signal indicating the count registered therein and having a count-up mode, a count-down mode, a hold mode, the counters being in the count-up mode when receiving a received count-up signal and being in the count-down mode when receiving a count-down signal;

overvoltage controller means providing a "high" and a "low" output signal, and having a predetermined upper and a lower threshold limit, the overvoltage controller means receiving the delay signal controller means output signal and providing a "low" output signal in response to a received delay signal controller means output signal within the upper and the lower threshold limits of the overvoltage controller means; and

counter controller means connected to the counters and receiving the overvoltage controller means output signal indicative of signal presence in the processing channel, the

counter controller means providing an output count-up signal when receiving an over-voltage controller means output signal in the "low" state indicating signal presence in the processing channel, and an output count-down signal when receiving an overvoltage controller means output signal in a "high" state, the count registered in the counters indicating the percentage of time signal presence existed in the processing channel during the predetermined epoch period of time; and

feedback indicator means receiving the output signal indicating the percentage of time signal presence existed in the processing channel and providing a subject-perceivable feedback signal responsive thereto.

27. The bio-feedback apparatus of claim **26** wherein the means providing the output signal indicating the average percentage of time signal presence existed in the processing channel is defined further to include:

a digital/analog converter receiving the counters output signal and providing an analog voltage output signal responsive thereto indicating the percentage of time signal presence existed in the processing channel.

28. The bio-feedback apparatus of claim **27** defined further to include: clock pulse generator means generating a clock pulse output signal therefrom: and wherein the counters are further defined to provide output signals in the "low" state in response to a count being registered thereon and to provide output signals in the "high" state in response to a zero count being registered thereon, the counters being positioned in the count-up mode in response to a received count-up signal and a clock pulse and in the count-down mode in response to a received count-down signal and a clock pulse; and wherein the counter controller means receives the clock pulse output signal and the counters output signal, the counter controller means being defined further to include:

gate means receiving the clock pulse output signal, the comparator controller means output signal, the overvoltage controller means output signal and the counters output signals and providing an output count-up signal and a clock pulse in response to an output signal indicative of signal presence in the processing channel and an overvoltage controller means output signal in a "low" state, an output count-down signal and a clock pulse in response to a received overvoltage controller means output signal in a "high" state, in response to at least one "low" counters output signal, and providing an output count-up signal and a clock pulse in response to a received output signal indicative of signal presence in the processing channel, in response to received counters output signals in the "high" state.

29. A bio-feedback apparatus for sensing the brain-wave potentials produced by a subject and providing feedback signals in response thereto, the apparatus comprising:

brain-wave indicator means detecting and sensing the brain-wave potentials and providing an output signal responsive thereto;

preamplifier means receiving the brain-wave indicator means output signal and providing an amplified output signal responsive thereto;

passband filter means, having a predetermined passband, receiving the preamplifier output signal and providing an output signal responsive to a frequency component of the received signal within the filter means passband;

zero crossing detector means receiving the passband filter means output signal and providing a "high" output signal in response to a positive going zero crossing of the passband filter means output signal and a "low" output signal in response to a negative going zero crossing of the passband filter means output signal;

tachometer network means receiving the zero crossing detector means output signal providing an output signal proportional to the frequency of the received zero crossing detector means output signal;

means receiving the tachometer network means output signal and providing an oscillating output signal having a frequency corresponding to a multiple of the frequency of the sensed potential indicated by the tachometer network means output signal;

amplitude discriminator means receiving the passband filter means output signal and providing an output signal substantially proportional to the amplitude of the received passband filter means output signal;

comparator controller means receiving the amplitude discriminator means output signal and providing "high" output signal in response to a received amplitude discriminator means output signal having a predetermined minimum duration, in one position thereof;

bandpass controller means having a predetermined high and a predetermined low threshold setting and providing a "high" and a "low" output signal, receiving the tachometer network means output signal and providing a "low" output signal in response to a received tachometer network means output signal within the high and the low threshold settings of the bandpass controller means, the bandpass controller means output signal connected to the comparator controller means and the comparator controller means providing the output signal therefrom in the "high" state of the bandpass controller means output signal; and

feedback indicator means connected to the comparator controller means receiving the comparator controller means output signal and providing subject-perceivable feedback signals in response to a received "high" comparator controller means output signal.

30. The bio-feedback apparatus of claim **29** wherein the tachometer network means includes: an oscillator means having an "on" and an "off" condition, the oscillator means receiving the zero crossing detector means output signal and being biased in the "on" condition in response thereto providing an oscillator means output signal; and wherein the amplitude discriminator means is defined further to include:

discriminator amplifier means receiving the passband filter means output signal and providing an amplified output signal responsive thereto;

diode means, having a forward biased and a reverse biased condition, connected to and receiving the discriminator amplifier means output signal, the diode means being forward biased and conducting

when receiving a positive going discriminator amplifier means output signal and being reversed biased and nonconducting when receiving a negative going discriminator amplifier means output signal;

capacitor means receiving the discriminator amplifier means output signal and being charged in response thereto in a conducting condition of the diode means;

memory capacitor means receiving the charge on the capacitor means when connected thereto;

first gate means having an opened and a closed condition connected between the capacitor means and the memory capacitor means, the first gate means receiving the oscillator output signal via the tachometer network means and being biased open in response thereto connecting the capacitor means and the memory capacitor means;

switching means connected to the capacitor means having an "on" and an "off" condition and receiving the zero crossing detector means output signal, the switching means being biased in the "on" condition in response to a received zero crossing detector means output signal in the "high" state discharging the capacitor means connected thereto; and

second gate means having an opened and a closed condition connected to the memory capacitor means and to the amplitude discriminator means, the charge on the memory capacitor means biasing the second gate means opened and providing the amplitude discriminator means output signal.

31. The bio-feedback apparatus of claim **30** wherein the tachometer network means includes:

switching means, having an "on" and an "off" condition, and receiving the tachometer oscillator means output signal and being biased "on" in response thereto;

function generator means connected to the switching means and having a portion charged in the "on" condition of the switching means, the charged portion being discharged in the "off" condition of the switching means, the function generator means providing an output signal proportional to the frequency of the sensed brain-wave potential in the discharging condition thereof;

memory capacitor means connected to the portion fo the function generator charged in the "on" condition of the switch means and receiving the charge discharged from the function generator means when connected thereto; and

switching means connected to the function generator means and to the memory capacitor means, having an "on" and an "off" condition, the switching means receiving the oscillator means output signal of the tachometer network means and being biased "on" in response thereto connecting the discharging function generator to the memory capacitor means.

32. A bio-feedback apparatus for sensing the brain-wave potentials produced by a subject and providing feedback signals in response thereto, the apparatus comprising:

brain-wave indicator means detecting and sensing the brain-wave potentials at two preselected sites, and providing a controlling channel output signal indicating the sensed brain-wave potential at each site;

preamplifier means receiving the controlling channel output signals and providing amplified output signals responsive thereto;

a plurality of processing channels, some of the processing channels receiving one of the controlling channel output signals and providing a feedback signal responsive thereto, some of the other processing channels receiving one other of the controlling channel output signals and providing a feedback signal responsive thereto, each of the processing channels comprising:

frequency discriminator means, having a predetermined passband, receiving the preamplifier output signal and providing an output signal responsive to a predetermined frequency component of the received preamplifier output signal having a frequency within the passband of the frequency discriminator means; and

means receiving the frequency discriminator means output signal and providing an output signal indicating signal presence in the processing channel, comprising:

first audio means providing subject-perceivable audible feedback signals responsive to a received signal input thereto;

second audio means providing subject-perceivable audible feedback signals responsive to a received signal input thereto; and

switch means receiving the feedback signals of each controlling channel output signal and connected to the first and the second audio means, the switch means having one switch condition connecting the feedback signal from one controlling channel output signal to the first audio means and the feedback signal from one other controlling channel output signal to the second audio means, and one other switch condition connecting the feedback signals from one of the controlling channel output signals to the first and the second audio means.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,821,949 Dated July 2, 1974

Inventor(s) Rex A. Hartzell; Duane L. Callies; Wendell H. Spencer; Darrell D. Albright; and Elmer E. Green

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Column 1, line 25, "voluntary" should be --One--.

In Column 3, line 66, "position" should be --portion--.

In Column 4, line 31, "29" should be --30--.

In Column 4, line 34, "19" should be --10--.

In Column 5, line 43, "as" should be --an--.

In Column 12, line 40, "ampoifier" should be --amplifier--.

In Column 12, line 42, "conected" should be --connected--.

In Column 13, line 60, "Q" should be --"Q"--.

In Column 14, line 2, "Q" should be --"Q"--.

In Column 14, line 4, "jsut" should be --just--.

In Column 15, line 1, "ther" should be --there--.

In Column 15, line 57, "cpacitor" should be --capacitor--.

In Column 15, line 67, insert the word "signals" before "120, 122 and 124".

In Column 16, line 8, "requried" should be --required--.

In Column 16, line 32, "votlages" should be --voltages--.

In Column 16, line 58, "an" should be --and--.

In Column 17, line 5, "connecced" should be --connected--.

In Column 17, line 13, "ponets" should be --ponents--.

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CERTIFICATE OF CORRECTION

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Inventor(s) Rex A. Hartzell; Duane L. Callies; Wendell H. Spencer; Darrell D. Albright; and Elmer E. Green

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Column 18, line 59, "sugject-perceivable" should be --subject-perceivable--.

In Column 19, line 15, "sugject's" should be --subject's--.

In Column 23, line 21, "subjectperceivable" should be --subject-perceivable--.

In Column 23, lines 65 and 66, "subjectperceivable" should be --subject-perceivable--.'

In Column 24, line 59, "votlage" should be --voltage--.

In Column 26, line 36, the words "In the L switch" should be--In the"L" switch--.

In Column 26, line 40, "R" should be --"R"--.

In Column 34, line 26, "the" should be --with--.

In Column 34, line 39, "groud" should be --ground--.

In Column 35, line 16, insert a comma after the word "particularly".

In Column 37, line 57, the words "source of" should be --source or--.

In Column 54, line 40, "connectd" should be --connected--.

In Column 55, line 18, "1267" should be --1276--.

In Column 55, line 46, "oscillator" should be --oscillating--.

In Column 55, line 60, "controlling" should be --controller--.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,821,949 Dated July 2, 1974

Inventor(s) Rex A. Hartzell; Duane L. Callies, Wendell H. Spencer; Darrell D. Albright; and Elmer E. Green

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In Column 60, Table I, line 4 of the Table, "Singal" should be --Signal--.

In Column 60, Table I, across from Count-down, the sixth of nine columns, "1" should be --0--.

In Column 62, line 47, "biofeedback" should be --bio-feedback--.

In Column 67, line 11, after "signal;" insert --and wherein the--.

In Column 77, line 47, "fo" should be --of--.

Signed and sealed this 17th day of December 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents