MIND CONTROL TECHNOLOGY PATENTS

The following pages contain facsimile reproductions of patents that have been granted by the Patent Office of the United States of America for the purposes of mental monitoring and mind alteration:

- *Hearing Device*—United States Patent 4,858,612.
- *Apparatus and Method for remotely Monitoring and Altering Brain Waves* —United States Patent 3,951,134.
- *Biomagnetic Analytical System Using Fiber-Optic Magnetic Sensors* —United States Patent 4,951,674.
- *Brain Electrical Activity Mapping*—United States Patent 4,408,616.
- *Method of Inducing Mental, Emotional and Physical States of Consciousness, Including Specific Mental Activity, in Human Beings* —United States Patent 5,213,562.
- *Method of and Apparatus for Inducing Desired States of Consciousness* —United States Patent 5,356,368.

United States Patent No. 4,858,612—*Hearing Device*:

> ABSTRACT
>
> A method and apparatus for simulation of hearing in mammals by introduction of a plurality of microwaves into the region of the auditory cortex... A microphone is used to transform sound signals into electrical signals which are in turn analyzed and processed to provide controls for generating a plurality of microwave signals at different frequencies. The multifrequency microwaves are then applied to the brain in the region of the auditory cortex. By this method sounds are perceived by the mammal which are representative of the original sound perceived by the microphone.

You will not find a better description of the means by which voices can be electronically transmitted into a human mind. Although the text of the patent presents the invention as a therapeutic aid for individuals who have hearing impairments, the potential mind control applications of the device are

obvious.

But why stop at the mere electronic transmission of voices into the human brain? Why not electronically alter the brain waves themselves by means of radio transmissions? Consider, for example, United States Patent No. 3,951,134 – *Apparatus and Method for Remotely Monitoring and Altering Brain Waves*. The abstract says:

> ABSTRACT
> Apparatus for and method of sensing brain waves at a position remote from a subject whereby electromagnetic signals of different frequencies are simultaneously transmitted to the brain of the subject in which the signals interfere with one another to yield a waveform which is modulated by the subject's brain waves. The interference waveform which is representative of the brain wave activity is re-transmitted by the brain to a receiver where it is demodulated and amplified. The demodulated waveform is then displayed for visual viewing and routed to a computer for further processing and analysis. The demodulated waveform also can be used to produce a compensating signal which is transmitted back to the brain to effect a desired change in electrical activity therein.

Quoting again from the text of the patent:

> SUMMARY OF THE INVENTION
> The present invention relates to apparatus and a method for monitoring brain waves wherein all components of the apparatus employed are remote from the test subject. More specifically, high frequency transmitters are operated to radiate electromagnetic energy of different frequencies through antennas which are capable of scanning the entire brain of the test subject or any desired region thereof. The signals of different frequencies penetrate the skull of the subject and impinge upon the brain where they mix to yield an interference wave modulated by radiations from the brain's natural electrical activity. The modulated interference wave is re-transmitted by the brain and received by an antenna at a remote station where it is demodulated, and processed to provide a profile of the subject's brain waves. In addition to passively monitoring his brain waves, the subject's neurological processes may be affected by transmitting to his brain, through a transmitter, compensating signals. The latter signals can be derived from the received and processed brain waves.

The import of the invention could not be clearer. This patent spells out, in black and white, an electronic method and apparatus for remotely monitoring and altering the brain waves of human beings, by use of radio transmitters and computers. The subject's brain waves are electronically monitored, received, routed to a computer, modified, and then transmitted back to his/her brain, with the stated intention of altering the "electrical activity" of the subject's brain. As the patent states:

> ... the subject's neurological processes may be affected by transmitting to his brain, through a transmitter, compensating signals. The latter signals can be derived from the received and processed brain waves.

The potential for electronic mind control is transparent.

Thanks to modern electronic technology the electrical activity of the human brain can be precisely monitored and displayed. The subtle electromagnetic fields and accompanying electrical activity in the brain can be electronically monitored and recorded in real time. United States Patent No. 4,951,674—*Biomagnetic Analytical System Using Fiber-Optic Magnetic Sensors* describes one such method and apparatus:

> ABSTRACT
> A biomagnetic analytical system for sensing and indicating minute magnetic fields emanating from the brain or from any other tissue region of interest in a subject under study. The system includes a magnetic pick-up device constituted by an array of fiber-optic magnetic sensors mounted at positions distributed throughout the inner confines of a magnetic shield configured to conform generally to the head of the subject or what-

ever other body region is of interest. Each sensor yields a light beam whose phase or other parameter is modulated in accordance with the magnetic field emanating from the related site in the region. The modulated beam from each sensor is compared in an interferometer with a reference light beam to yield an output signal that is a function of the magnetic field being emitted at the related site. The output signals from the interferometer are processed to provide a display or recording exhibiting the pattern or map of magnetic fields resulting from emanations at the multitude of sites encompassed by the region.

This device makes possible the mapping of the brain's biomagnetic activity. The data can be displayed visually, on a CRT monitor (as on a computer screen), permitting a specialist to electronically peer into a person's head and to:

> ..."see" a functional image of the brain on a CRT, ... the image will be a profile of the electromganetically "active" portions of the brain, as shown by the magnetic pattern derived from data reduction...

The data can also be digitized for subsequent storage and manipulation. In the words of the patent:

> The data can also be directed to a storage medium for the purpose of recording the digitized biomagnetic data for archiving and later retrieval and processing.

Patent No. 4,951,674 goes on to say that during the data processing stage, data from:

> ... modalities such as EEG, EKG, MRI and X-ray ... can be combined with the biomagnetic data ...

In other words, the practitioner can reconcile the biomagnetic data with an individual's EEG pattern. This means a specific pattern of biomagnetic activity can be correlated with a particular pattern of electrical activity in the brain. (See the appendix at the end of the book for the complete patent. Look at illustrations 1 to 3. Note the special helmet with the magnetic sensors that fits around the head of the person whose brain's biomagnetic activity is being monitored and digitally recorded.)

United States Patent No. 4,408,616, *Brain Electrical Activity Mapping*, provides further information on how the human brain can be electronically monitored.

The patent abstract says, in part:

> Topographic displays of brain electrical activity are produced from matrices of data derived from evoked potential (EP) and steady-state responses of skull transducers ... the rate of data sampling is sufficient to capture rapid transient events ...

In other words, the transition from one mental state to another can be observed and electronically mapped. The text of the patent explains how this is done:

> Twenty electrodes (e.g., Grass gold cup) are attached to subject's skull ... Twenty leads from electrodes are connected through switch to conventional 24-channel polygraph ...

The patent succinctly explains how electrodes are attached to a person's skull and connected to a polygraph machine to record the electrical activity of their brain in real time, as it responds to various stimuli. It neatly sums up:

> ... (T)he brain electrical activity mapping system creates color topographic displays reflecting brain electrical activity using, as input, continuous electrical waveforms recorded from a number of points on the skull.

The data are then converted to digital form. Data are stored in individual files or combined with others into "group" files, so that a group profile of brain electrical activity in response to a variety of stimuli can be constructed. The stimulus may be a flashing light or something more complex, like being asked to distinguish between two similar, but slightly different, spoken words.

Over time, a library of digitized data (data that can be stored and analyzed by computer) about the electrical activity of the brains of individual people and groups of

people is built up. This is precisely the type of data that can be used to modulate a radio wave that is transmitted into a target subject's brain to alter his/her brainwaves. In principle, by using averaged data derived from group files of brain electrical activity, it should be possible to modulate radio broadcasts to affect the brain electrical activity of large numbers of a target population.

In many cases people's minds and brains have been tampered with and altered without their informed consent. Psychoactive drugs, microwaves, hypnosis, brain washing and electronic implants are some of the ways in which mind control victims have been attacked by these shadowy agencies.

Electronic and psychotronic mind control technologies are absolutely antithetical to the fundamental exercise of human freedom. Unfortunately, the patents and technologies described here are real. It is time for us all to wake up and see things as they are. A particularly insidious slavery is mental enslavement, accomplished by electronically or psychotronically altering people's thoughts, such that their very thoughts are not their own, but are ones that their self-appointed masters would have them to think.

United States Patent [19]

Stocklin

[11] Patent Number: 4,858,612

[45] Date of Patent: Aug. 22, 1989

[54] **HEARING DEVICE**

[76] Inventor: Philip L. Stocklin, P.O. Box 2111, Satellite Beach, Fla. 32937

[21] Appl. No.: 562,742

[22] Filed: Dec. 19, 1983

[51] Int. Cl.[4] A61N 1/36

[52] U.S. Cl. ..... 128/422; 178/419 S

[58] Field of Search ..... 128/419 R, 419 S, 422, 128/653, 771, 732, 741, 746, 791, 804; 340/407

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3,951,134	4/1976	Malech	128/131
4,428,377	1/1984	Zollner et al.	128/419 R

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Frye et al., "Science", vol. 181, Jul. 27, 1973, pp. 356-358.

Bise, William, "Low Power Radio-Frequency and Microwave Effects on Human Electroencephalogram and Behavior", Physiol. Chem. & Physics 10 (1978).

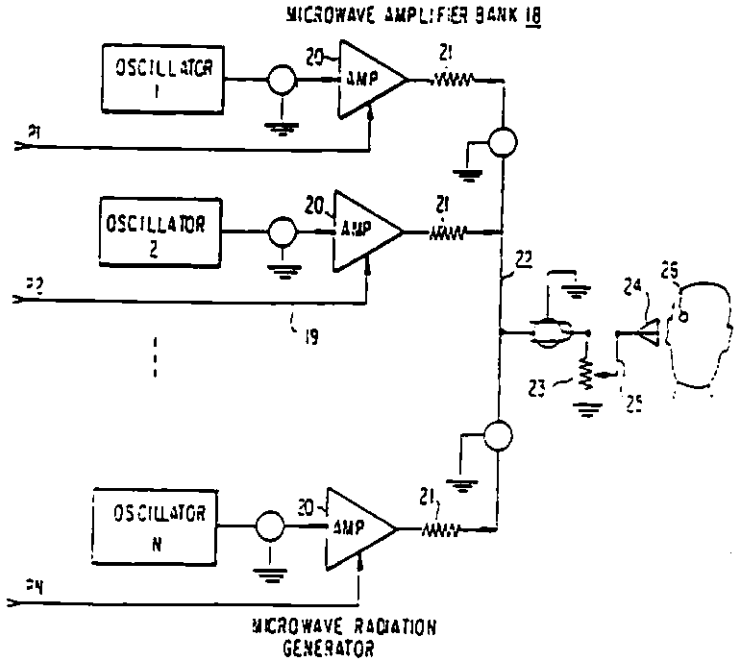
Primary Examiner—William E. Kamm

Attorney, Agent, or Firm—Wegner & Bretschneider

[57] **ABSTRACT**

A method and apparatus for simulation of hearing in mammals by introduction of a plurality of microwaves into the region of the auditory cortex is shown and described. A microphone is used to transform sound signals into electrical signals which are in turn analyzed and processed to provide controls for generating a plurality of microwave signals at different frequencies. The multifrequency microwaves are then applied to the brain in the region of the auditory cortex. By this method sounds are perceived by the mammal which are representative of the original sound received by the microphone.

29 Claims, 7 Drawing Sheets



5

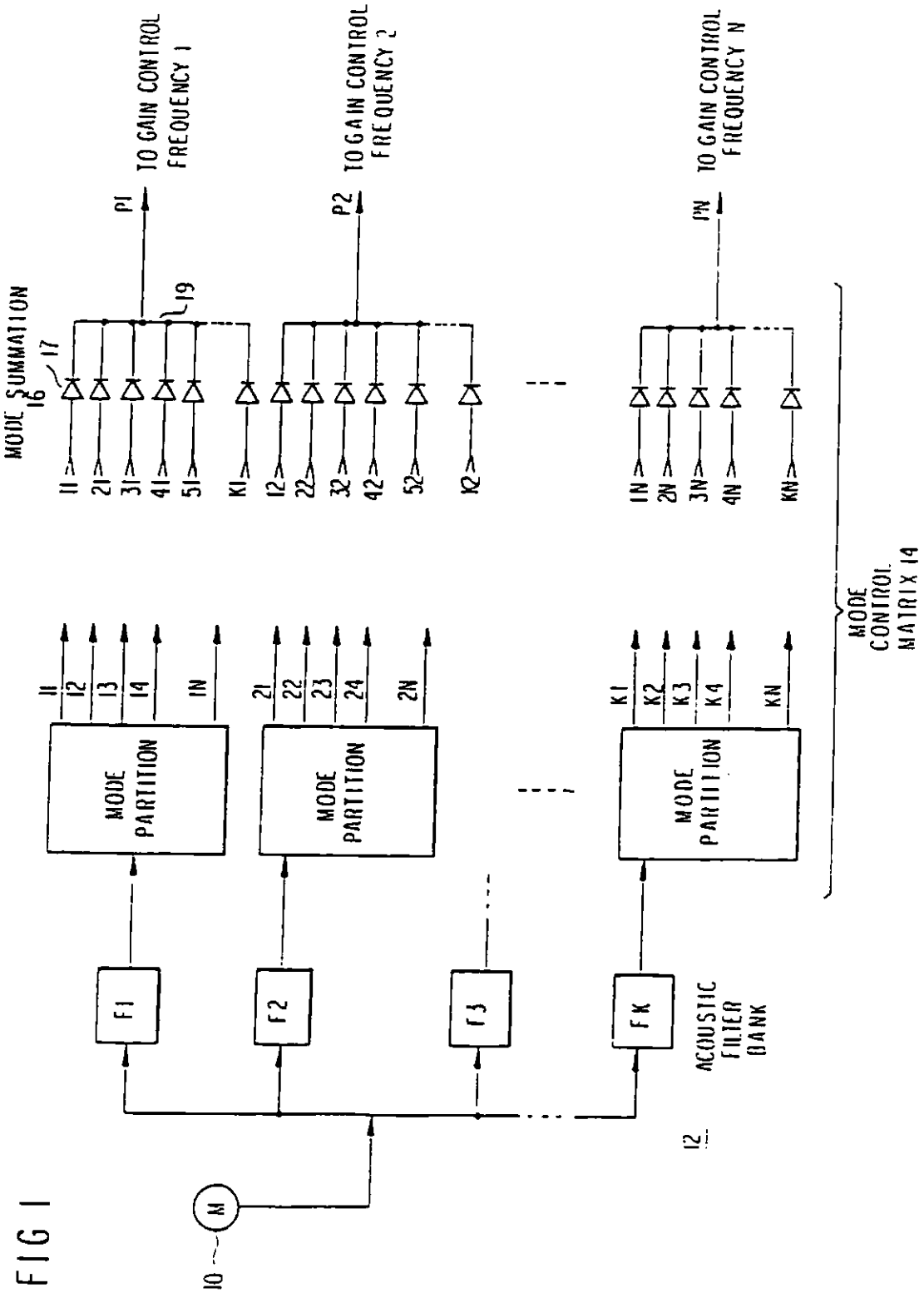

TO GAIN CONTROL FREQUENCY 1
TO GAIN CONTROL FREQUENCY 2
TO GAIN CONTROL FREQUENCY N
P1
P2
PN
MODE SUMMATION
16
17
19
11
21
31
41
51
K1
12
22
32
42
52
K2
1N
2N
3N
4N
KN
MODE CONTROL MATRIX 14
MODE PARTITION
MODE PARTITION
MODE PARTITION
11
12
13
14
1N
21
22
23
24
2N
K1
K2
K3
K4
KN
F1
F2
F3
FK
ACOUSTIC FILTER BANK
12
M
10

FIG 1

FIG. 2

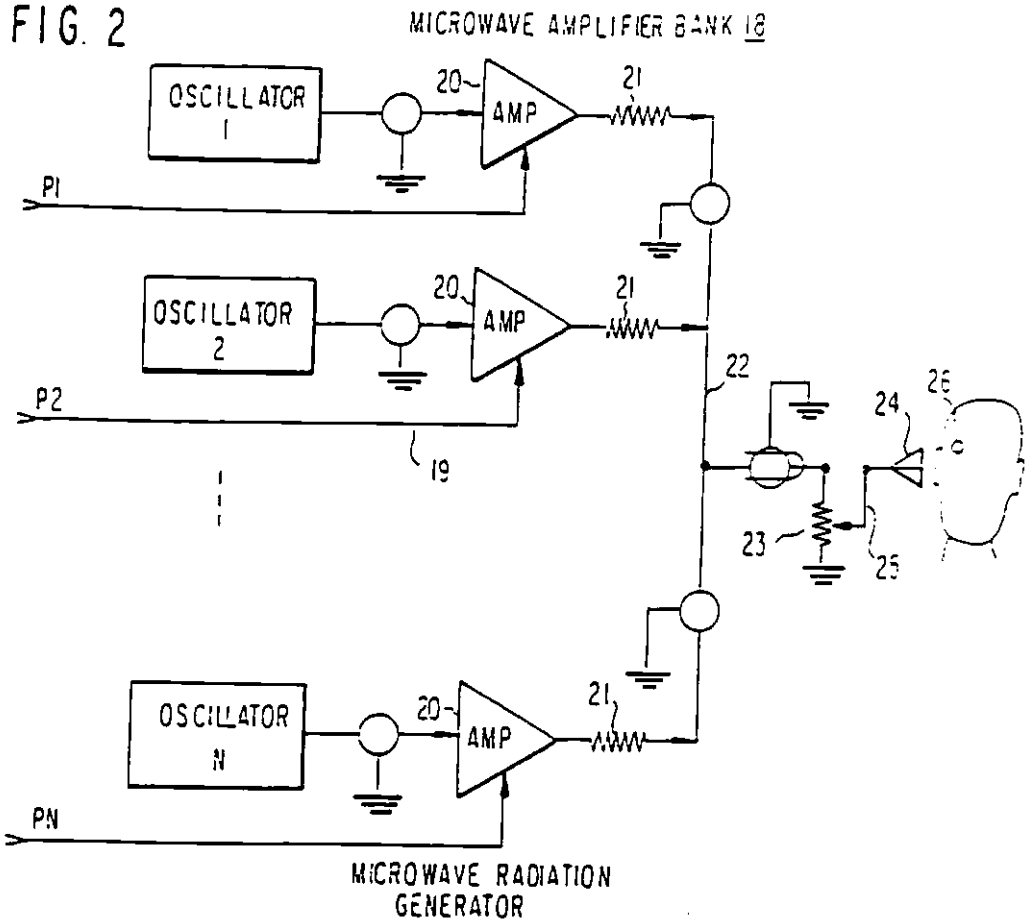

MICROWAVE AMPLIFIER BANK 18
OSCILLATOR 1
OSCILLATOR 2
OSCILLATOR N
AMP
20
21
22
23
24
25
26
P1
P2
PN
19
MICROWAVE RADIATION GENERATOR

FIG 2a

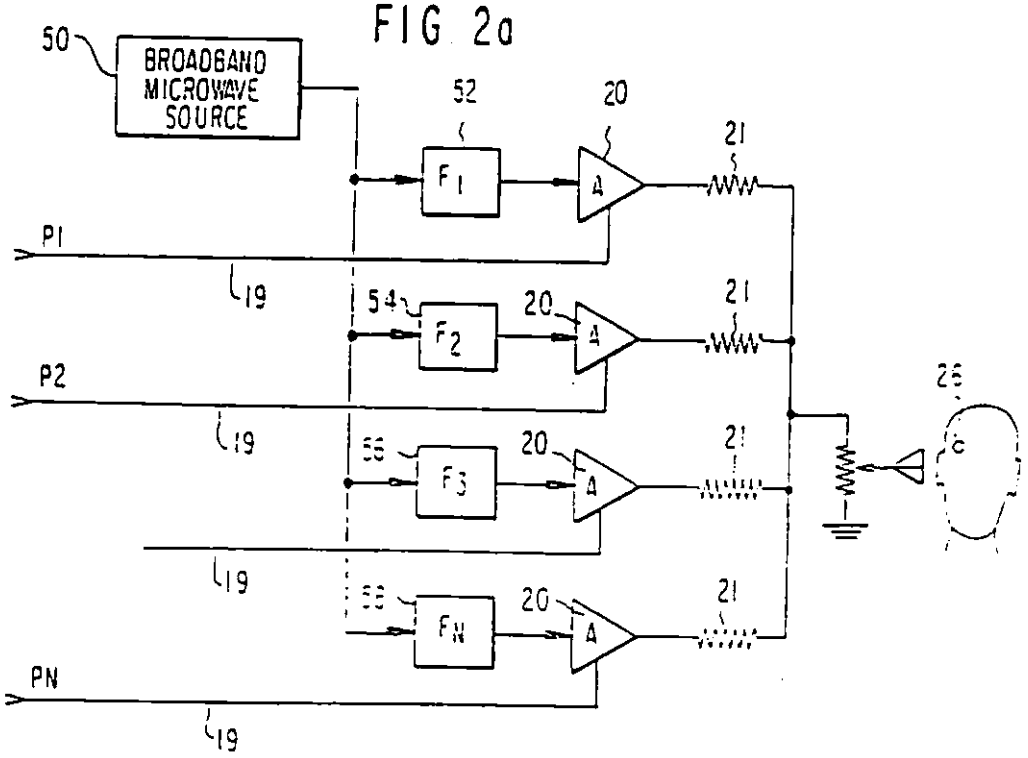

50
BROADBAND MICROWAVE SOURCE
52
54
56
58
F1
F2
F3
FN
A
20
21
26
P1
P2
PN
19

FIG. 5

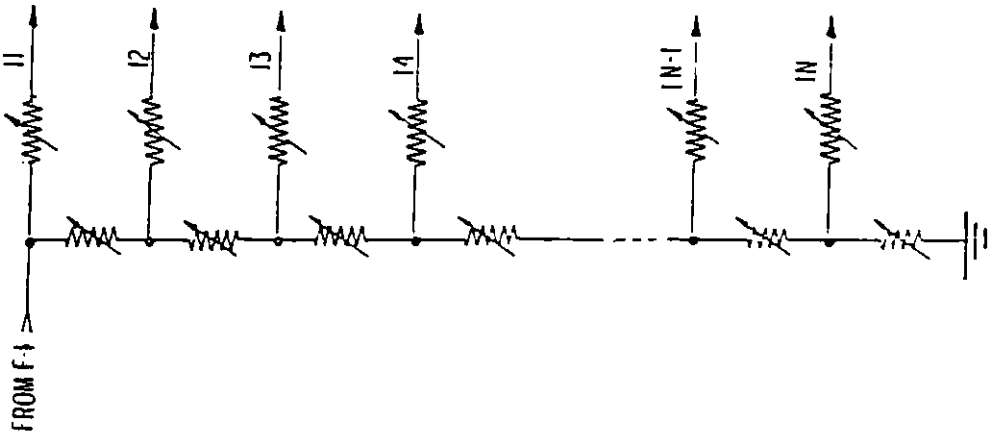


FIG. 4

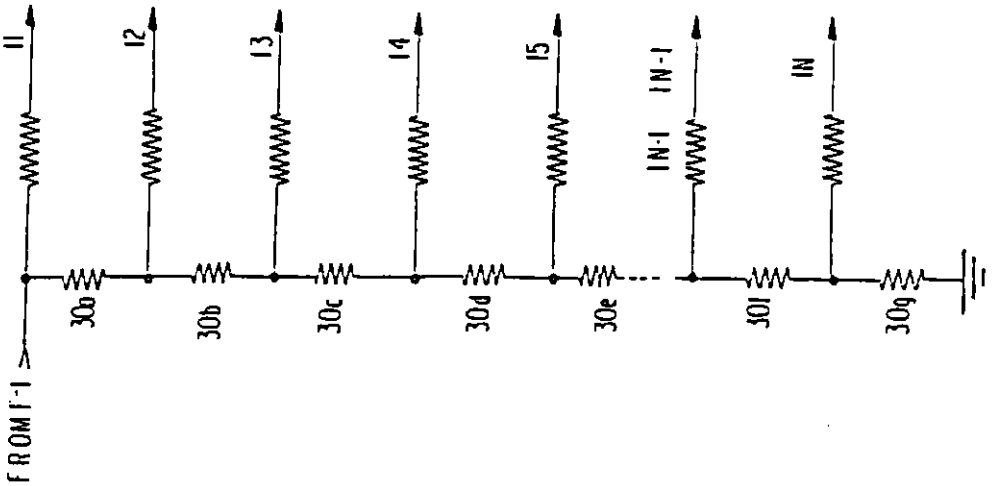


FIG 3

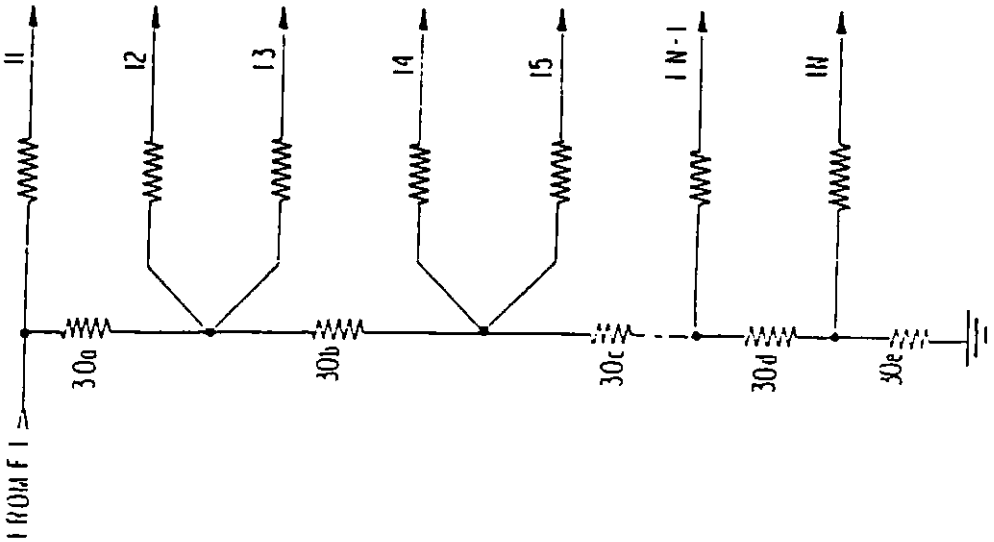


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FIG 6

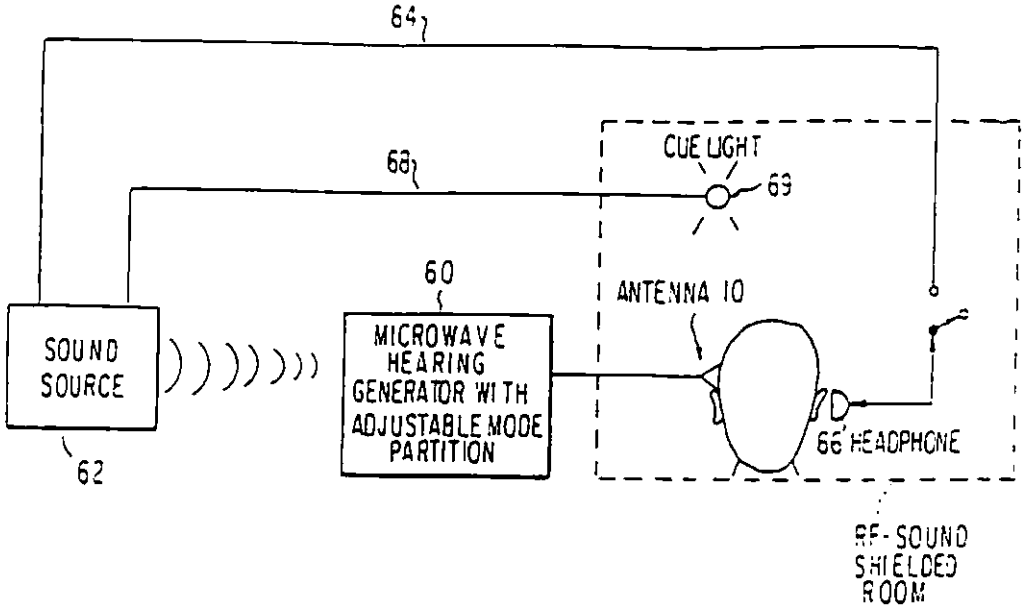
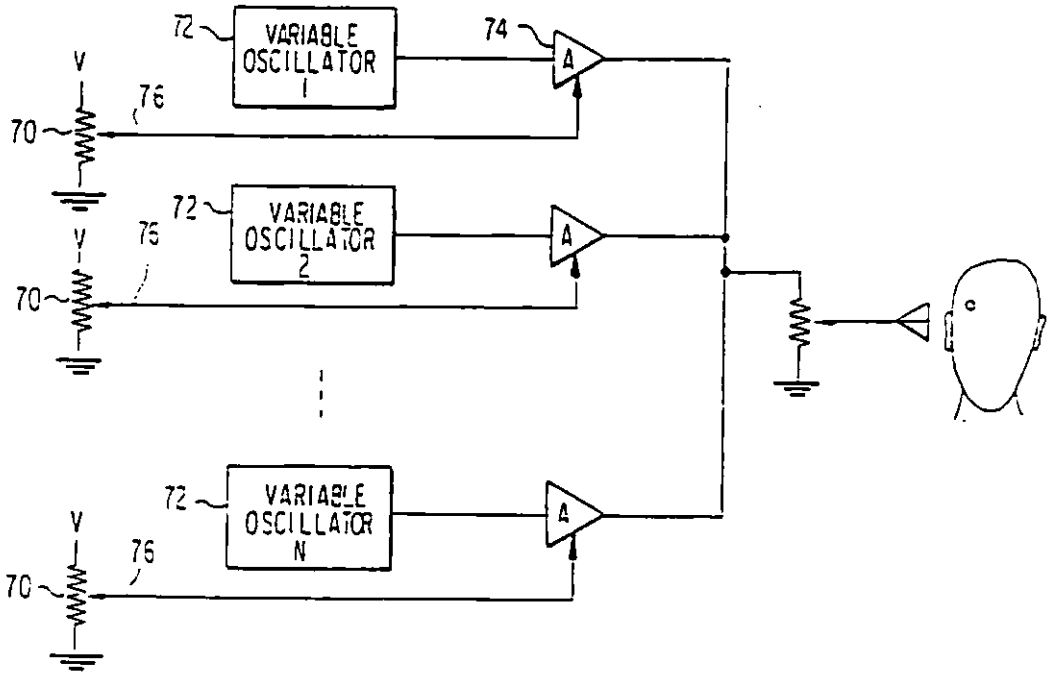

64
68
CUE LIGHT
69
60
ANTENNA 10
SOUND SOURCE
MICROWAVE HEARING GENERATOR WITH ADJUSTABLE MODE PARTITION
66 HEADPHONE
62
RF-SOUND SHIELDED ROOM

FIG 7


72
VARIABLE OSCILLATOR 1
74
A
V
76
70
72
VARIABLE OSCILLATOR 2
A
V
76
70
72
VARIABLE OSCILLATOR N
A
V
76
70

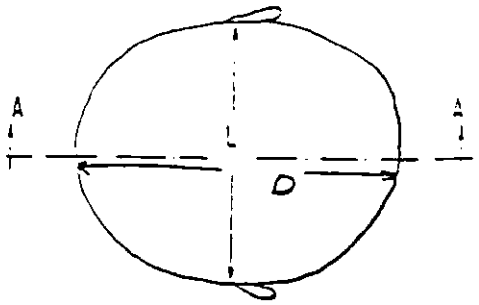
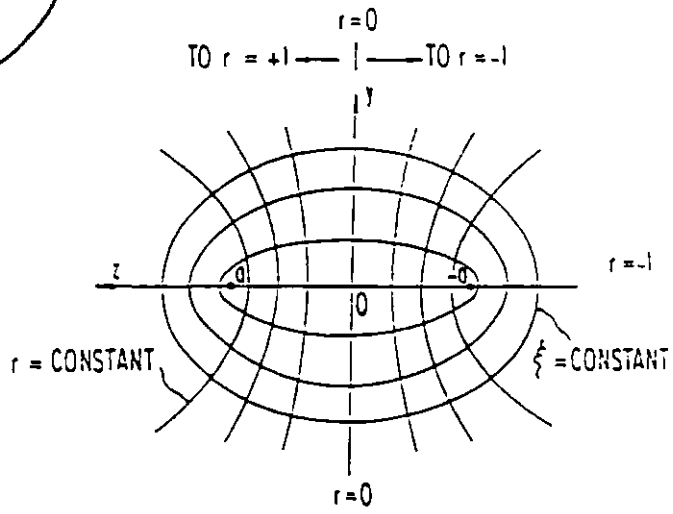
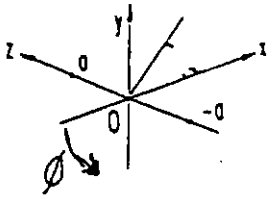


FIG. 8

FIG. 9



ξ, r, AND Ø RELATED TO CARTESIAN COORDINATES x, y, z



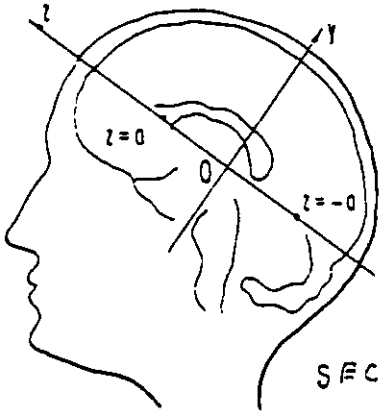


FIG. 10

SECTION A-A

TRANSFORMATION EQUATIONS

$$x = a(\xi^2 - 1)^{1/2}(1 - r^2)^{1/2}\cos\emptyset \qquad 1 \le \xi \le$$

$$y = -a(\xi^2 - 1)^{1/2}(1 - r^2)^{1/2}\sin\emptyset \qquad -1 \le \emptyset \le +1$$

$$z = a\xi r \qquad 0 \le \emptyset \le 2\pi$$

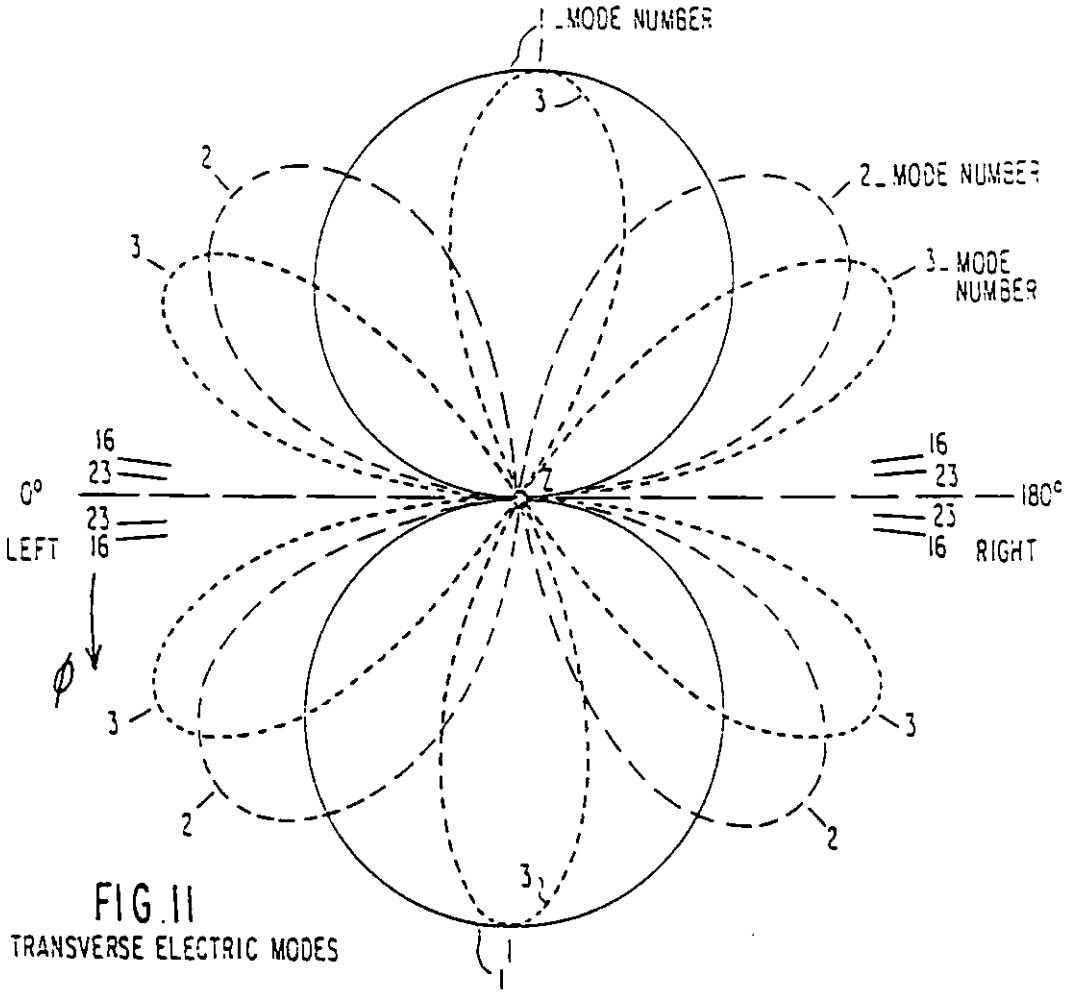


FIG. 11
TRANSVERSE ELECTRIC MODES

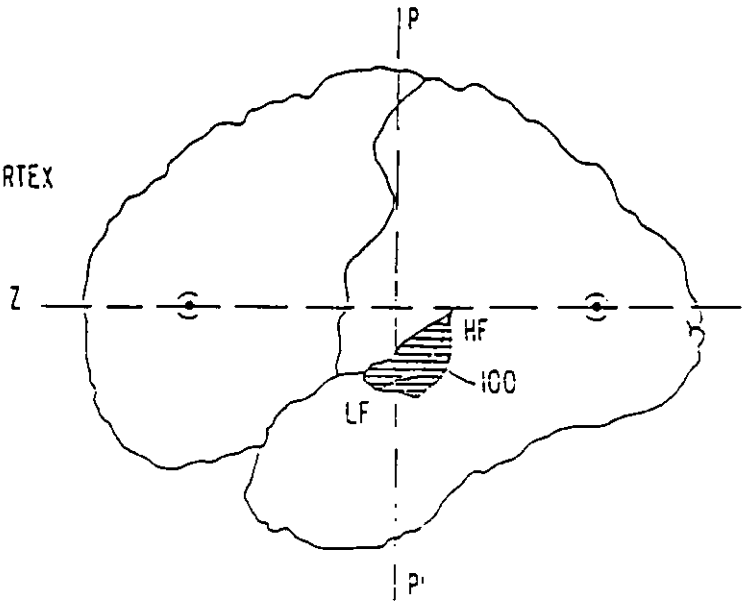


FIG. 12
PRIMARY AUDITORY CORTEX

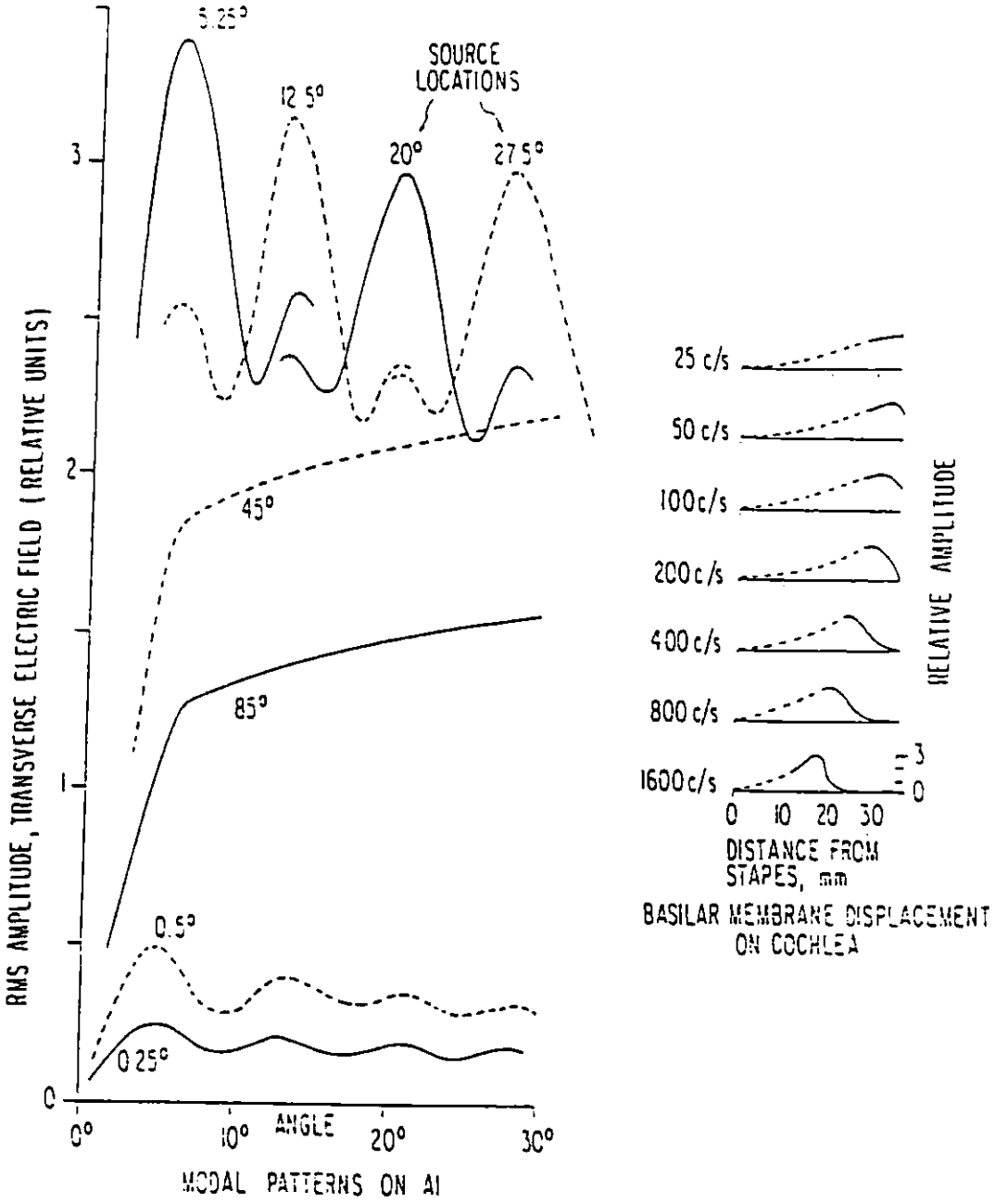

5.25°
12.5°
SOURCE LOCATIONS
20°
27.5°
45°
85°
0.5°
0.25°
RMS AMPLITUDE, TRANSVERSE ELECTRIC FIELD (RELATIVE UNITS)
0
1
2
3
0°
10°
ANGLE
20°
30°
MODAL PATTERNS ON AI
25 c/s
50 c/s
100 c/s
200 c/s
400 c/s
800 c/s
1600 c/s
3
0
0 10 20 30
DISTANCE FROM STAPES, mm
RELATIVE AMPLITUDE
BASILAR MEMBRANE DISPLACEMENT ON COCHLEA

FIG 13

12

HEARING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to devices for aiding of hearing in mammals. The invention is based upon the perception of sounds which is experienced in the brain when the brain is subjected to certain microwave radiation signals.

2. Description of the Prior Art

In prior art hearing devices for human beings, it is well known to amplify sounds to be heard and to apply the amplified sound signal to the ear of the person wearing the hearing aid. Hearing devices of this type are however limited to hearing disfunctions where there is no damage to the auditory nerve or to the auditory cortex. In the prior art, if there is damage to the auditory cortex or the auditory nerve, it cannot be corrected by the use of a hearing aid.

During World War II, individuals in the radiation path of certain radar installations observed clicks and buzzing sounds in response to the microwave radiation. It was through this early observation that it became known to the art that microwaves could cause a direct perception of sound within a human brain. These buzzing or clicking sounds however were not meaningful, and were not perception of sounds which could otherwise be heard by the receiver. This type of microwave radiation was not representative of any intelligible sound to be perceived. In such radar installations, there was never a sound which was generated which resulted in subsequent generation of microwave signals representative of that sound.

Since the early perception of buzzing and clicking, further research has been conducted into the microwave reaction of the brain. In an article entitled "Possible Microwave Mechanisms of the Mammalian Nervous System" by Philip L. Stocklin and Brain F. Stocklin, published in the TIT Journal of Life Sciences, Tower International Technomedical Institute, Inc. P.O. Box 4594, Philadelphia, Pa. (1979) there is disclosed a hypothesis that the mammalian brain generates and uses electro magnetic waves in the lower microwave frequency region as an integral part of the functioning of the central and peripheral nervous systems. This analysis is based primarily upon the potential energy of a protein integral in the neural membrane.

In an article by W. Bise entitled "Low Power Radio-Frequency and Microwave Effects On Human Electroencephalogram and Behavior", Physiol. Chemistry Phys. 10, 387 (1978), it is reported that there are significant effects upon the alert human EEG during radiation by low intensity CW microwave electromagnetic energy. Bise observed significant repeatable EEG effects for a subject during radiation at specific microwave frequencies.

SUMMARY OF THE INVENTION

Results of theoretical analysis of the physics of brain tissue and the brain/skull cavity, combined with experimentally-determined electromagnetic properties of mammalian brain tissue, indicate the physical necessity for the existence of electromagnetic standing waves, called modes in the living mammalian brain. The mode characteristics may be determined by two geometric properties of the brain: these are the cephalic index of the brain (its shape in prolate spheroidal coordinates) and the semifocal distance of the brain (a measure of its size). It was concluded that estimation of brain cephalic index and semifocal distance using external skull measurements on subjects permits estimation of the subject's characteristic mode frequencies, which in turn will permit a mode by mode treatment of the data to simulate hearing.

This invention provides for sound perception by individuals who have impaired hearing resulting from ear damage, auditory nerve damage, and damage to the auditory cortex. This invention provides for simulation of microwave radiation which is normally produced by the auditory cortex. The simulated brain waves are introduced into the region of the auditory cortex and provide for perceived sounds on the part of the subject.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the acoustic filter bank and mode control matrix portions of the hearing device of this invention.

FIG. 2 shows the microwave generation and antenna portion of the hearing device of this invention.

FIG. 3 shows a typical voltage divider network which may be used to provide mode partition.

FIG. 4 shows another voltage divider device which may be used to provide mode partition.

FIG. 5 shows a voltage divider to be used as a mode partition wherein each of the resistors is variable in order to provide adjustment of the voltage outputs.

FIG. 6 shows a modified hearing device which includes adjustable mode partitioning, and which is used to provide initial calibration of the hearing device.

FIG. 7 shows a group of variable oscillators and variable gain controls which are used to determine hearing characteristics of a particular subject.

FIG. 8 shows a top view of a human skull showing the lateral dimension.

FIG. 9 shows the relationship of the prolate spherical coordinate system to the cartesian system.

FIG. 10 shows a side view of a skull showing the medial plane of the head, section A—A.

FIG. 11 shows a plot of the transverse electric field amplitude versus primary mode number M.

FIG. 12 shows a left side view of the brain and auditory cortex.

FIG. 13 shows the total modal field versus angle for source location.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

This invention is based upon observations of the physical mechanism the mammalian brain uses to perceive acoustic vibrations. This observation is based in part upon neuro anatomical and other experimental evidence which relates to microwave brain stimulation and the perception of sounds.

It is has been observed that monochromatic acoustic stimuli (acoustic tones, or single tones) of different frequencies uniquely stimulate different regions of the cochlea. It has also been observed that there is a corresponding one to one relationship between the frequency of a monochromatic acoustic stimulus and the region of the auditory cortex neurally stimulated by the cochlear nerve under the physiologically normal conditions (tonotopicity).

It is has been observed that for an acoustic tone of a frequency which is at the lower end of the entire acous-

tical range perceivable by a person, that a thin lateral region ("Line") parallel to the medial axis of the brain and toward the inferior portion of the primary auditory cortex is stimulated. For an acoustic tone whose frequency is toward the high end of the entire perceivable acoustic range, a thin lateral region parallel to the medial axis and toward the superior portion of the primary auditory cortex is stimulated.

Neural stimulation results in the generation of a broad band of microwave photons by the change in rotational energy state of protons integral to the neuron membrane of the auditory cortex. The physical size and shape of the brain/skull cavity, together with the (semiconductor) properties (conductivity and dielectric constant) of the brain tissue provide an electromagnetic resonant cavity. Specific single frequencies are constructively reinforced so that a number of standing electromagnetic waves, each at its own single electromagnetic frequency in the microwave frequency region, are generated in the brain. Each such standing electromagnetic wave is called a characteristic mode of the brain/skull cavity.

Analysis in terms of prolate spheroidal wave functions indicates that transverse electric field components of these modes have maxima in the region of the auditory cortex. This analysis further shows that transverse electric field possess a variation of amplitude with angle in the angular plane (along the vertical dimension of the auditory cortex) and that is dependent only upon the primary mode number.

The auditory cortex in the normally functioning mammalian brain is a source of microwave modes. The auditory cortex generates these modes in accordance with the neural stimulation of the auditory cortex by the cochlear nerve. Mode weighting for any one acoustic tone stimulus is given by the amplitude of each mode along the line region of the auditory cortex which is neurally stimulated by that acoustic tone stimulus. A listing of mode weighting versus frequency of acoustic stimulus is called the mode matrix.

In this invention, the functions of the ear, the cochlear nerve, and the auditory cortex are simulated. Microwaves simulating the mode matrix are inserted directly into the region of the auditory cortex. By this insertion of simulated microwave modes, the normal operation of the entire natural hearing mechanism is simulated.

Referring now to FIG. 1 and FIG. 2 there is shown an apparatus which provides for induced perception of sound into a mammalian brain. This hearing device includes a microphone 10 which receives sounds, an acoustic filter bank 12 which separates the signals from the microphone into component frequencies, and a mode control matrix 14 which generates the mode signals which are used to control the intensity of microwave radiations which are injected into the skull cavity in the region of the auditory cortex.

The acoustic filter bank 12 consists of a bank of acoustic filters F1 through Fk which span the audible acoustic spectrum. These filters may be built from standard resistance, inductance, and capacitance components in accordance with well established practice. In the preferred embodiment there are 24 filters which correspond to the observed critical bandwidths of the human ear. In this preferred embodiment a typical list of filter parameters is given by Table I below:

TABLE I

Filter No.	Center Frequency (Hz)	Bandwidth (Hz)
1	50	less than 100
2	150	100
3	250	100
4	350	100
5	450	110
6	570	120
7	700	140
8	840	150
9	1,000	160
10	1,170	190
11	1,370	210
12	1,600	240
13	1,850	280
14	2,150	320
15	2,500	380
16	2,900	450
17	3,400	550
18	4,000	700
19	4,800	900
20	5,800	1,100
21	7,000	1,300
22	8,500	1,800
23	10,500	2,500
24	13,500	3,500

The rectifier outputs one through K are feed to K mode partition devices. The mode partitioning devices each have N outputs wherein N is the number of microwave oscillators used to generate the microwave radiation. The outputs 1 through N of each mode partition device is applied respectively to the inputs of each gain controlled amplifier of the microwave radiation generator. The function of the mode control matrix 14 is the control of the microwave amplifiers in the microwave amplifier bank 18. In the preferred embodiment thus will be 24 outputs and 24 microwave frequency oscillators.

Connected to each microwave amplifier gain control line is a mode simulation device 16 which receives weighted mode signals from the mode partition devices 14. Each mode simulation device consists of one through k lines and diodes 17 which are each connected to summing junction 19. The diodes 17 provide for isolation from one mode partition device to the next. The diodes 17 prevent signals from one mode partition device from returning to the other mode partition devices which are also connected to the same summing junction of the mode summation device 16. The diodes also serve a second function which is the rectification of the signals received from the acoustic filter bank by way of the mode partition devices. In this way each mode partition device output is rectified to produce a varying DC voltage with major frequency components of the order of 15 milliseconds or less. The voltage at the summation junction 19 is thus a slowly varying DC voltage.

The example mode partition devices are shown in greater detail in FIGS. 3, 4, and 5. The mode partition devices are merely resistance networks which produce 1 through N output voltages which are predetermined divisions of the input signal from the acoustic filter associated with the mode partition device. FIG. 3 shows a mode partitioning device wherein several outputs are associated with each series resistor 30. In the embodiment depicted in FIG. 4 there is an output associated with each series resistor only, and thus there are N series resistors, or the same number of series resistors as there are outputs. The values of the resistors in the mode partition resistor network are determined in ac-

cordance with the magnitudes of the frequency component from the acoustic filter bank 12 which is required at the summation point 19 or the gain control line for amplifiers 20.

The microwave amplifier bank 18 consists of a plurality of microwave oscillators 1 through N each of which is connected to an amplifier 20. Since the amplifiers 20 are gain controlled by the signals at summation junction 19, the magnitude of the microwave output is controlled by the mode control matrix outputs F1 through F_n. In the preferred embodiment there are 24 amplifiers.

The leads from the microwave oscillators 1 through N to the amplifiers 20 are shielded to prevent cross talk from one oscillator to the next, and to prevent stray signals from reaching the user of the hearing device. The output impedance of amplifiers 20 should be 1000 ohms and this is indicated by resistor 21. The outputs of amplifiers 20 are all connected to a summing junction 22. The summing junction 22 is connected to a summing impedance 23 which is approximately 50 ohms. The relatively high amplifier output impedance 21 as compared to the relatively low summing impedance 23 provides minimization of cross talk between the amplifiers. Since the amplitude of the microwave signal needed at the antenna 24 is relatively small, there is no need to match the antenna and summing junction impedances to the amplifier 20 output impedances. Efficiency of the amplifiers 20 is not critical.

Level control of the signal at antenna 24 is controlled by pick off 25 which is connected to the summing impedance 23. In this manner, the signal at antenna 24 can be varied from 0 (ground) to a value which is acceptable to the individual.

The antenna 24 is placed next to the subject's head and in the region of the subject's auditory cortex 26. By placement of the antenna 24 in the region of the auditory cortex 26, the microwave field which is generated simulates the microwave field which would be generated if the acoustic sounds were perceived with normal hearing and the auditory cortex was functioning normally.

In FIG. 2A there is shown a second embodiment of the microwave radiation and generator portion of the hearing device. In this embodiment a broad band microwave source 50 generates microwave signals which are feed to filters 52 through 58 which select from the broad band radiation particular frequencies to be transmitted to the person. As in FIG. 2, the amplifiers 20 receive signals on lines 19 from the mode control matrix. The signals on lines 19 provide the gain control for amplifiers 20.

In FIG. 6 there is shown a modified microwave hearing generator 60 which includes a mode partition resistor divider network as depicted in FIG. 5. Each of the mode partition voltage divider networks in this embodiment are individually adjustable for all of the resistances in the resistance network. FIG. 5 depicts a voltage division system wherein adjustment of the voltage partition resistors is provided for.

In FIG. 6, the sound source 62 generates audible sounds which are received by the microphone of the microwave hearing generator 60. In accordance with the operation described with respect to FIGS. 1 and 2, microwave signals are generated at the antenna 10 in accordance with the redistribution provided by the mode control matrix as set forth in FIG. 5.

The sound source 62 also produces a signal on line 64 which is received by a head phone 66. The apparatus

depicted in FIG. 6 is used to calibrate or fit a microwave hearing generator to a particular individual. Once the hearing generator is adjusted to the particular individual by adjustment of the variable resistors in the adjustable mode partition portion of the hearing generator, a second generator may be built using fixed value resistors in accordance with the adjusted values achieved in fitting the device to the particular subject. The sound produced by headphone 66 should be the same as a sound from the sound source 62 which is received by the microphone 10 in the microwave hearing generator 60. In this way, the subject can make comparisons between the perceived sound from the hearing generator 60, and the sound which is heard from headphone 66. Sound source 62 also produces a signal on 68 which is feed to cue light 69. Cue light 69 comes on whenever a sound is emitted from sound source 62 to the microwave generator 60. In this manner, if the subject hears nothing, he will still be informed that a sound has been omitted and hence that he is indeed perceiving no sound from the microwave hearing generator 60.

In FIG. 7 there is shown a modified microwave hearing generator which may be used to determine a subject's microwave mode frequencies. In this device, the acoustic filter bank and the mode control matrix have been removed and replaced by voltage level signal generated by potentiometers 70. Also included are a plurality of variable frequency oscillators 72 which feed microwave amplifiers 74 which are gain controlled from the signal generated by potentiometers 70 and pick off arm 76.

This modified microwave hearing generator is used to provide signals using one oscillator at a time. When an oscillator is turned on, the frequency is varied about the estimated value until a maximum acoustic perception by the subject is perceived. This perception however may consist of a buzzing or hissing sound rather than a tone because only one microwave frequency is being received. The first test of perception is to determine the subject's lowest modal frequency for audition ($M=1$). Once this modal frequency is obtained, the process is repeated for several higher modal frequencies and continued until no maximum acoustic perception occurs.

Another method of determination of a subject's modal frequencies is through anatomical estimation. This procedure is by measurement of the subject's cephalic index and the lateral dimensions of the skull. In this method, the shape is determined in prolate spheroidal coordinance.

Purely anatomical estimation of subject's modal frequencies is performed by first measuring the maximum lateral dimension (breadth) L FIG. 8, of the subject's head together with the maximum dimension D (anterior to posterior) in the medial plane of the subject's head. D is the distance along Z axis as shown in FIG. 10. The ratio L/D, called in anthropology the cephalic index, is monotonically related to the boundary value ξ_0 defining the ellipsoidal surface approximating the interface between the brain and the skull in the prolate spheroidal coordinate system. ξ_0 defines the shape of this interface: ξ_0 and D together give an estimate of a, the semi-focal distance of the defining ellipsoid. Using ξ_0 and a, together with known values of the conductivity and dielectric constants of brain tissue, those wavelengths are found for which the radial component of the electric [illegible] the boundary condition that it is zero at ξ_0.

These wavelengths are the wavelengths associated with the standing waves or modes; the corresponding frequencies are found by dividing the phase velocity of microwaves in brain tissue by each of the wavelengths.

A subject's microwave modal frequencies may also be determined by observing the effect of external microwave radiation upon the EEG. The frequency of the M equal 1 mode may then be used as a base point to estimate all other modal frequencies.

A typical example of such an estimation is where the subject is laterally irradiated with a monochromatic microwave field simultaneous with EEG measurement and the microwave frequency altered until a significant change occurs in the EEG, the lowest such frequency causing a significant EEG change is found. This is identified as the frequency of the M=1 mode, the lowest mode of importance in auditory perception. The purely anatomical estimation procedure (FIGS. 8, 9, 10) is then performed and the ratio of each modal frequency to the M=1 modal frequency obtained. These ratios together with the experimentally-determined M=1 frequency are then used to estimate the frequencies of the mode numbers higher than 1. The prolate spheroidal coordinate system is shown in FIG. 9. Along the lateral plane containing the x and y coordinates of FIG. 9, the prolate spheroidal coordinate variable ϕ (angle) lies FIGS. 9 and 10. Plots of the transverse electric field amplitude versus primary mode number m are shown in FIG. 11. The equation is

$$E_{transverse}(m, \phi) = E_o \sin(m\,\phi)$$

The "elevation view" FIG. 12, of the brain from the left side, shows the primary auditory cortex 10. The iso-tone lines and the high frequency region are toward the top of 100 and the low frequency region toward the bottom of 100.

The formula I, set forth below is the formula for combining modes from an iso-tone line at $\phi = \phi j$ being excited to obtain the total modal field at some other angular location ϕ. For this formula, if we let J=1 (just one iso-tone single frequency acoustic stimulus line), then it can be shown that ALL modes (in general) must be used for any ONE tone.

FORMULA I
RMS TRANSVERSE ELECTRIC FIELD IN ANGULAR PLANE, $f(0)$

$$f(0) = \left[\sum_{m=1}^{M} \left(\sin(m\theta) \cdot \sum_{j=1}^{J} e^{-|\theta-\theta_j|/\Delta\theta_m} \sin(m\theta_j) \right)^2 \right]^{\frac{1}{2}}$$

ϕ = ANGLE (0° LATERAL)
ϕ_j = LOCATION OF j-TH SOURCE (TOTAL NUMBER J)
$\Delta\phi_m$ = ATTENUATION LENGTH (IN ANGLE) OF m-TH MODE
m = PRIMARY MODE NUMBER (HIGHEST MODE M)

FIG. 13 shows the resulting total modal field versus angle ϕ for source location ϕ at 5.25°, 12.5°, etc. With reference to the set of curves at the left top of this figure. A spacing of approximately 7.25° in ϕ corresponds to a tonal difference of about 1 octave. This conclusion is based on the side-lobes of pattern coming from ϕ=5.25°, etc. The total filed (value on y-axis) falls considerably below the top curves for source locations well below 5.25° (toward the high acoustic stimulus end) and also as the source of frequency goes well above 30° (low frequency end). ϕ is plotted positive downward from 0° at lateral location as indicates in FIG. 11.

Resistor weightings are obtained from the $|\sin(m[\phi-\phi j])|$, Formula I. The scale between acoustic frequency and ϕ must be set or estimated from experiment. Approximately 5.25±1° corresponds to a tonal stimulus at about 2 kHz (the most sensitive region of the ear) since this source location gives the highest electric field amplitude.

The apparatus of FIG. 7 may also be used to determine values for a hearing device which are required for a particular subject. Once the modal frequencies have been estimated, the device of FIG. 7 which includes variable microwave oscillators may be used to determine values for the oscillators which match the subject, and to determine resistance values associated with the mode partition devices of the mode control matrix.

In FIG. 7 manual control of the amplifier gain is achieved by potentiometers 76. In this manner the amplifier gains are varied about the estimated settings for an acoustic tone stimulus in the region of two thousand Hertz (2 kHz) until maximum acoustic perception and a purest tone are achieved together. The term purest tone may also be described as the most pleasing acoustic perception by the subject. This process may be repeated at selected frequencies above and below 2 kHz. The selected frequencies correspond to regions of other acoustic filter center frequencies of the subject. When modal frequency (oscillator frequency) and gain set values (setting a potentiometer 76) are noted, it is then possible to calculate fixed oscillator frequencies and control resistor values for the adjusted hearing device for this particular subject.

In the event the subject has no prior acoustic experience, that is deaf from birth, estimated resistor values must be used. Also, a complex acoustic stimulation test including language articulation and pairs of harmonically related tones may be developed to maximize the match of the hearing device parameters for those of this particular subject.

Typical components for use in this invention include commercially available high fidelity microphones which have a range of 50 Hz to 15 kHz with plus or minus 3 dB variation.

The audio filters to be used with the acoustic filter bank 12 are constructed in a conventional manner, and have Q values of about 6. The filters may also be designed with 3 dB down points (½ the bandwidth away from the center frequency) occurring at adjacent center frequency locations.

The diodes 17 in the mode control matrix which provide isolation between the mode partition circuits are commercially available diodes in the audio range.

The microwave oscillators 1 through N and the microwave amplifiers 20 are constructed with available microwave transistors which can be configured either as oscillators or amplifiers. Examples of the transistors are GaAsFET field effect transistors by Hewlitt Packard known as the HFET series or silicone bipolar transistors by Hewlitt Packard known as the HXTR series.

All the cable between the oscillators, the microwave amplifiers, and the antenna should be constructed with either single or double shielded coaxial cable.

The antenna 24 for directing microwave signals to the audio cortex 26 should be approximately the size of the auditory cortex. A typical size would be one and

one half CM high and one half to one CM wide. The antenna as shown is located over the left auditory cortex. but the right may also be used. Since the characteristic impedance of the brain tissue at these microwave frequencies is close to 50 ohms, efficient transmission by commercially available standard 50 ohm coax is possible.

The invention has been described in reference to the preferred embodiments. It is, however, to be understood that other advantages, features, and embodiments may be within the scope of this invention as defined in the appended claims.

What is claimed is:

1. A sound perception device for providing induced perception of sound into a mammalian brain comprising in combination:

means for generating microwave radiation which is representative of a sound to be perceived, said means for generating including means for generating a simultaneous plurality of microwave radiation frequencies and means for adjusting the amplitude of said microwave radiation frequencies in accordance with the sound to be perceived; and

antenna means located in the region of the auditory cortex of said mammalian brain for transmitting said microwave energy into the auditory cortex region of said brain.

2. A hearing device for perception of sounds comprising in combination:

means for generating a signal representative of sounds;

means for analyzing said signal representative of said sounds having an output;

means for generating a plurality of microwave signals having different frequencies having a input connected to said output of said means for analyzing said signals, having an output;

means for applying said plurality of microwave signals to the head of a subject, and

whereby the subject perceives sounds which are representative of said sounds.

3. The apparatus in accordance with claim 2 wherein said means for generating a signal is a microphone for detecting sound waves.

4. The apparatus in accordance with claim 2 wherein said means for applying said plurality of microwave signals is an antenna.

5. The apparatus in accordance with claim 4 wherein said antenna is placed in the region of the auditory cortex of the subject.

6. The apparatus in accordance with claim 2 wherein the subject is a human being.

7. The apparatus in accordance with claim 2 wherein said means for analyzing said signal comprises:

an acoustic filter bank for dividing said sounds into a plurality of component frequencies; and

a mode control matrix means for providing control signals which are weighted in accordance with said plurality of component frequencies, having an output connected to said means for generating a plurality of microwave signal inputs.

8. The apparatus in accordance with claim 7 wherein said acoustic filter bank includes a plurality of audio frequency filters.

9. The apparatus in accordance with claim 8 wherein said audio frequency filters provide a plurality of output frequencies having amplitudes which are a function of said signal representative of sounds.

10. The apparatus in accordance with claim 9 wherein said amplitudes are the weighted in accordance with transform function of the signal representative of sounds.

11. The apparatus in accordance with claim 7 wherein said mode control matrix device includes a voltage divider connected to each of said plurality of said audio frequency filters.

12. The apparatus in accordance with claim 11 wherein each of said voltage dividers has a plurality of outputs which are connected in circuit to said means for generating a plurality of microwave signals.

13. The apparatus in accordance with claim 2 wherein said means for generating a plurality of microwave signals comprises a plurality of microwave generators each having a different frequency and means for controlling the output amplitude of each of said generators.

14. The apparatus in accordance with claims 2 wherein said means for generating a plurality of microwave signals comprises a broad band microwave source and a plurality of filters.

15. The apparatus in accordance with claim 13 wherein said generators each comprise a microwave signal source and a gain controlled microwave amplifier.

16. The apparatus in accordance with claim 13 wherein said means for analyzing output is connected to said means for controlling microwave amplifier output amplitudes.

17. The apparatus in accordance with claim 13 wherein analyzing includes K audio frequency filters.

18. The apparatus in accordance with claim 17 wherein there are N microwave generators.

19. The apparatus in accordance with claim 18 including a mode partitioning means which provides N outputs for each of said K audio frequency filters.

20. The apparatus in accordance with claim 19 wherein said N amplifiers each have K inputs from said mode partitioning means.

21. The apparatus in accordance with claim 20 wherein said N amplifiers have K inputs less the mode partitioning means outputs which are so small that they may be omitted.

22. The apparatus in accordance with claim 20 wherein said mode partitioning output device outputs each include a diode connected to each microwave amplifier gain control to provide isolation between all outputs.

23. The apparatus in accordance with claim 20 wherein said K audio frequency filters are chosen to correspond to the critical bandwidths of the human ear.

24. The apparatus in accordance with claim 20 wherein said N microwave generators are each adjustable in frequency output.

25. The apparatus in accordance with claim 18 wherein the frequency of each N microwave generators is determined by anatomical estimation.

26. The apparatus in accordance with claim 18 wherein the frequency of the lowest frequency microwave generator is chosen by determination of the effect of external microwave generation on the EEG of the subject.

27. The apparatus in accordance with claim 18 wherein the frequency of each of said N microwave generators corresponds to the subject's microwave modal frequencies.

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28. The apparatus in accordance with claim 27 wherein the subject's modal frequencies are determined by measurement of the subject's cephalic index and the lateral dimensions of the skull.

29. The apparatus in accordance with claim 28 wherein the subject's lowest modal frequency is determined by varying the frequency of the lowest frequency microwave generator about the estimated value until a maximum acoustic perception is obtained by the subject.

* * * * *

United States Patent [19]

Malech

[11] 3,951,134

[45] Apr. 20, 1976

[54] **APPARATUS AND METHOD FOR REMOTELY MONITORING AND ALTERING BRAIN WAVES**

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[73] Assignee: **Dorne & Margolin Inc.**, Bohemia, N.Y.

[22] Filed: **Aug. 5, 1974**

[21] Appl. No.: **494,518**

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

[51] Int. Cl.[2] A61B 5/04

[58] Field of Search ..... 128/1 C, 1 R, 2.1 B, 128/2.1 R, 419 R, 422 R, 420, 404, 2 R, 2 S, 2.05 R, 2.05 V, 2.05 F, 2.06 R; 340/248 A, 258 A, 258 B, 258 D, 229

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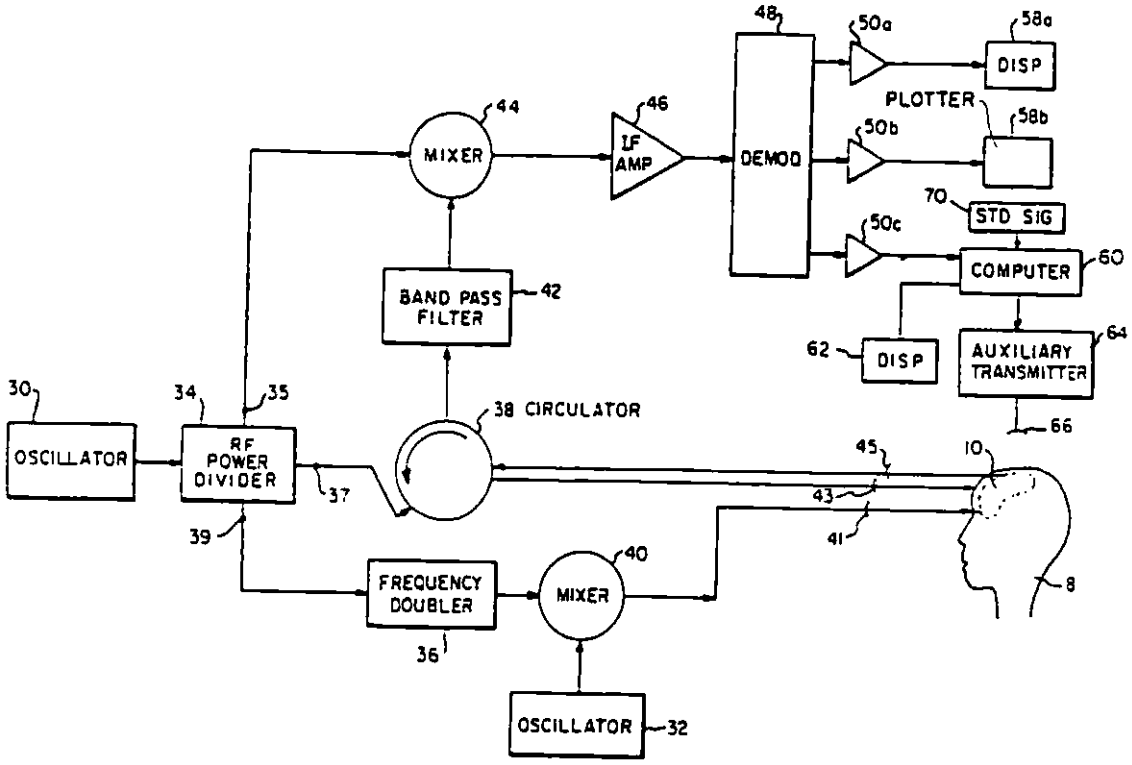
Primary Examiner—William E. Kamm

Attorney, Agent, or Firm—Darby & Darby

[57] **ABSTRACT**

Apparatus for and method of sensing brain waves at a position remote from a subject whereby electromagnetic signals of different frequencies are simultaneously transmitted to the brain of the subject in which the signals interfere with one another to yield a waveform which is modulated by the subject's brain waves. The interference waveform which is representative of the brain wave activity is re-transmitted by the brain to a receiver where it is demodulated and amplified. The demodulated waveform is then displayed for visual viewing and routed to a computer for further processing and analysis. The demodulated waveform also can be used to produce a compensating signal which is transmitted back to the brain to effect a desired change in electrical activity therein.

11 Claims, 2 Drawing Figures



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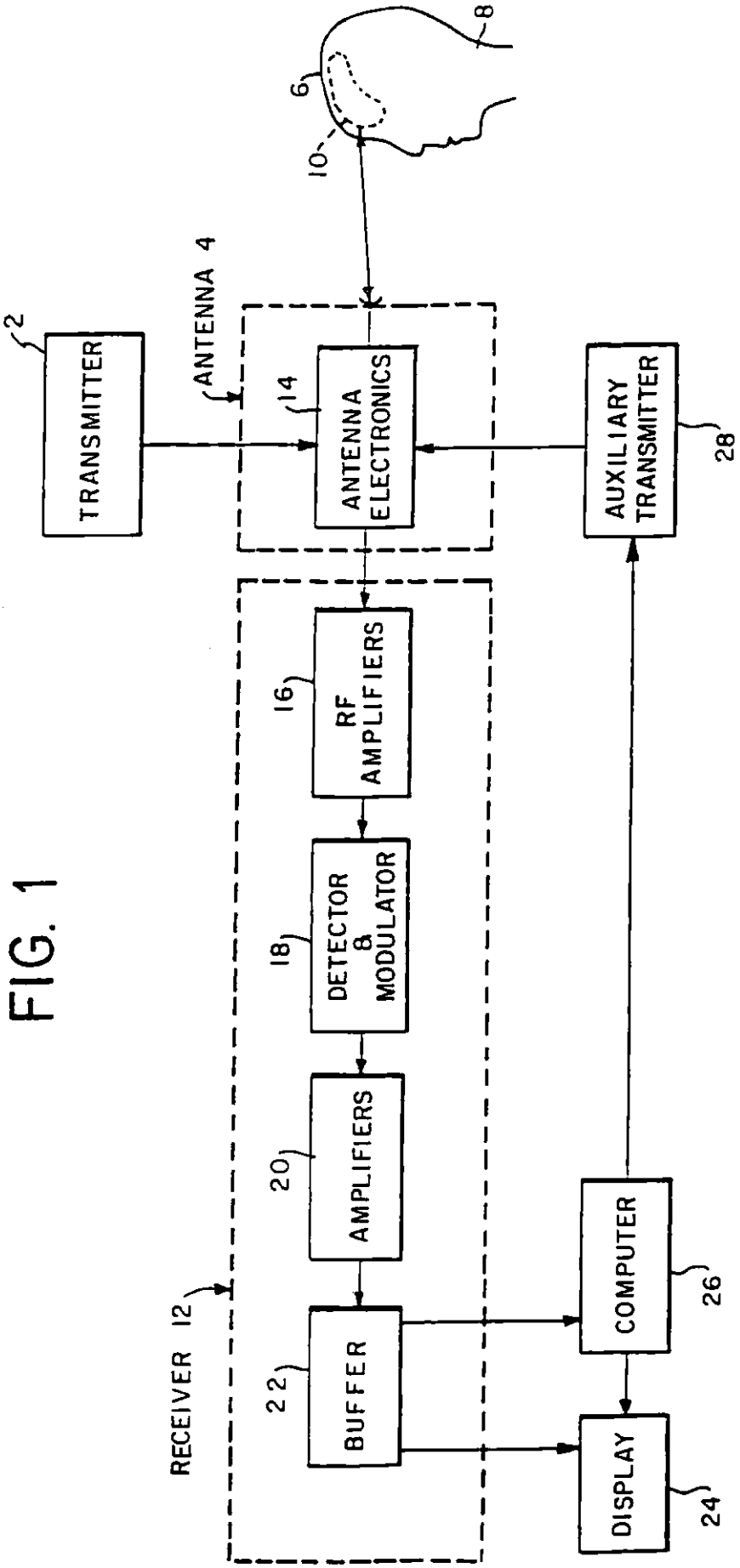
8
6
10
ANTENNA 4
2
TRANSMITTER
14
ANTENNA ELECTRONICS
AUXILIARY TRANSMITTER
28
16
RF AMPLIFIERS
18
DETECTOR & MODULATOR
20
AMPLIFIERS
RECEIVER 12
22
BUFFER
COMPUTER
26
DISPLAY
24

FIG. 1

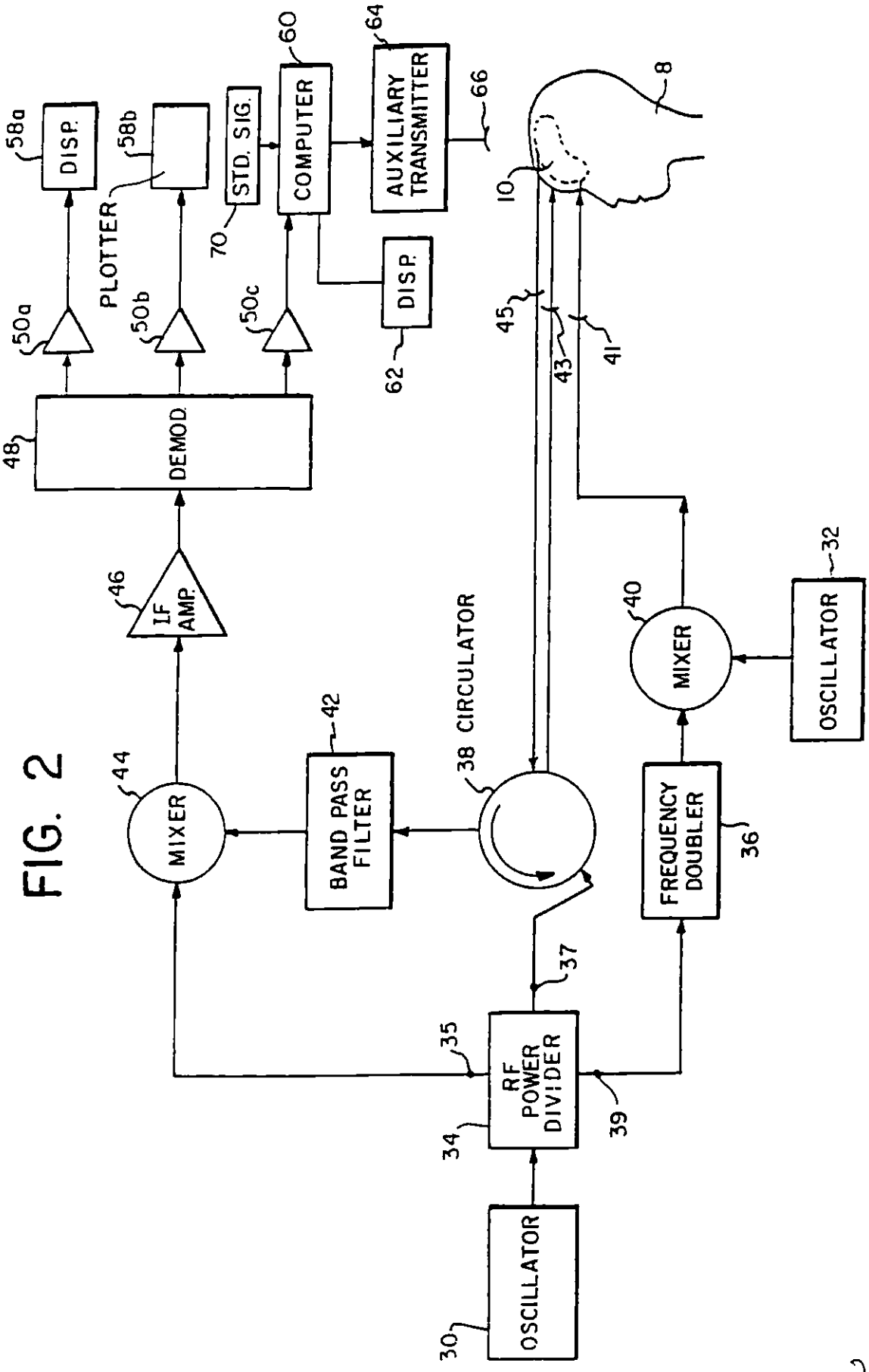
OSCILLATOR
30
RF POWER DIVIDER
34
35
37
39
MIXER
44
BAND PASS FILTER
42
38 CIRCULATOR
FREQUENCY DOUBLER
36
MIXER
40
OSCILLATOR
32
IF AMP.
46
DEMOD
48
50a
50b
50c
PLOTTER
58a
DISP.
58b
STD. SIG.
70
COMPUTER
60
DISP.
62
AUXILIARY TRANSMITTER
64
66
8
10
45
43
41

FIG. 2

21

APPARATUS AND METHOD FOR REMOTELY MONITORING AND ALTERING BRAIN WAVES

BACKGROUND OF THE INVENTION

Medical science has found brain waves to be a useful barometer of organic functions. Measurements of electrical activity in the brain have been instrumental in detecting physical and psychic disorder, measuring stress, determining sleep patterns, and monitoring body metabolism.

The present art for measurement of brain waves employs electroencephalographs including probes with sensors which are attached to the skull of the subject under study at points proximate to the regions of the brain being monitored. Electrical contact between the sensors and apparatus employed to process the detected brain waves is maintained by a plurality of wires extending from the sensors to the apparatus. The necessity for physically attaching the measuring apparatus to the subject imposes several limitations on the measurement process. The subject may experience discomfort, particulary if the measurements are to be made over extended periods of time. His bodily movements are restricted and he is generally confined to the immediate vicinity of the measuring apparatus. Furthermore, measurements cannot be made while the subject is conscious without his awareness. The comprehensiveness of the measurements is also limited since the finite number of probes employed to monitor local regions of brain wave activity do not permit observation of the total brain wave profile in a single test.

SUMMARY OF THE INVENTION

The present invention relates to apparatus and a method for monitoring brain waves wherein all components of the apparatus employed are remote from the test subject. More specifically, high frequency transmitters are operated to radiate electromagnetic energy of different frequencies through antennas which are capable of scanning the entire brain of the test subject or any desired region thereof. The signals of different frequencies penetrate the skull of the subject and impinge upon the brain where they mix to yield an interference wave modulated by radiations from the brain's natural electrical activity. The modulated interference wave is re-transmitted by the brain and received by an antenna at a remote station where it is demodulated, and processed to provide a profile of the suject's brain waves. In addition to passively monitoring his brain waves, the subject's neurological processes may be affected by transmitting to his brain, through a transmitter, compensating signals. The latter signals can be derived from the received and processed brain waves.

OBJECTS OF THE INVENTION

It is therefore an object of the invention to remotely monitor electrical activity in the entire brain or selected local regions thereof with a single measurement.

Another object is the monitoring of a subject's brain wave activity through transmission and reception of electromagnetic waves.

Still another object is to monitor brain wave activity from a position remote from the subject.

A further object is to provide a method and apparatus for affecting brain wave activity by transmitting electromagnetic signals thereto.

DESCRIPTION OF THE DRAWINGS

Other and further objects of the invention will appear from the following description and the accompanying drawings, which form part of the instant specification and which are to be read in conjunction therewith, and in which like reference numerals are used to indicate like parts in the various views;

FIG. 1 is a block diagram showing the interconnection of the components of the apparatus of the invention;

FIG. 2 is a block diagram showing signal flow in one embodiment of the apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, specifically FIG. 1, a high frequency transmitter 2 produces and supplies two electromagnetic wave signals through suitable coupling means 14 to an antenna 4. The signals are directed by the antenna 4 to the skull 6 of the subject 8 being examined. The two signals from the antenna 4, which travel independently, penetrate the skull 6 and impinge upon the tissue of the brain 10.

Within the tissue of the brain 10, the signals combine, much in the manner of a conventional mixing process technique, with each section of the brain having a different modulating action. The resulting waveform of the two signals has its greatest amplitude when the two signals are in phase and thus reinforcing one another. When the signals are exactly 180° out of phase the combination produces a resultant waveform of minimum amplitude. If the amplitudes of the two signals transmitted to the subject are maintained at identical levels, the resultant interference waveform, absent influences of external radiation, may be expected to assume zero intensity when maximum interference occurs, the number of such points being equal to the difference in frequencies of the incident signals. However, interference by radiation from electrical activity within the brain 10 causes the waveform resulting from interference of the two transmitted signals to vary from the expected result, i.e., the interference waveform is modulated by the brain waves. It is believed that this is due to the fact that brain waves produce electric charges each of which has a component of electromagnetic radiation associated with it. The electromagnetic radiation produced by the brain waves in turn reacts with the signals transmitted to the brain from the external source.

The modulated interference waveform is re-transmitted from the brain 10, back through the skull 6. A quantity of energy is re-transmitted sufficient to enable it to be picked up by the antenna 4. This can be controlled, within limits, by adjusting the absolute and relative intensities of the signals, originally transmitted to the brain. Of course, the level of the transmitted energy should be kept below that which may be harmful to the subject.

The antenna passes the received signal to a receiver 12 through the antenna electronics 14. Within the receiver the wave is amplified by conventional RF amplifiers 16 and demodulated by conventional detector and modulator electronics 18. The demodulated wave, representing the intra-brain electrical activity, is amplified by amplifiers 20 and the resulting information in electronic form is stored in buffer circuitry 22. From the buffers 22 the information is fed to a suitable visual

display 24, for example one employing a cathode ray tube, light emitting diodes, liquid crystals, or a mechanical plotter. The information may also be channeled to a computer 26 for further processing and analysis with the output of the computer displayed by heretofore mentioned suitable means.

In addition to channeling its information to display devices 24, the computer 26 can also produce signals to control an auxiliary transmitter 28. Transmitter 28 is used to produce a compensating signal which is transmitted to the brain 10 of the subject 8 by the antenna 4. In a preferred embodiment of the invention, the compensating signal is derived as a function of the received brain wave signals, although it can be produced separately. The compensating signals affect electrical activity within the brain 10.

Various configurations of suitable apparatus and electronic circuitry may be utilized to form the system generally shown in FIG. 1 and one of the many possible configurations is illustrated in FIG. 2. In the example shown therein, two signals, one of 100 MHz and the other of 210 MHz are transmitted simultaneously and combine in the brain 10 to form a resultant wave of frequency equal to the difference in frequencies of the incident signals, i.e., 110 MHz. The sum of the two incident frequencies is also available, but is discarded in subsequent filtering. The 100 MHz signal is obtained at the output 37 of an RF power divider 34 into which a 100 MHz signal generated by an oscillator 30 is injected. The oscillator 30 is of a conventional type employing either crystals for fixed frequency circuits or a tunable circuit set to oscillate at 100 MHz. It can be a pulse generator, square wave generator or sinusoidal wave generator. The RF power divider can be any conventional VHF, UHF or SHF frequency range device constructed to provide, at each of three outputs, a signal identical in frequency to that applied to its input.

The 210 MHz signal is derived from the same 100 MHz oscillator 30 and RF power divider 34 as the 100 MHz signal, operating in concert with a frequency doubler 36 and 10 MHz oscillator 32. The frequency doubler can be any conventional device which provides at its output a signal with frequency equal to twice the frequency of a signal applied at its input. The 10 MHz oscillator can also be of conventional type similar to the 100 MHz oscillator herebefore described. A 100 MHz signal from the output 39 of the RF power divider 34 is fed through the frequency doubler 36 and the resulting 200 MHz signal is applied to a mixer 40. The mixer 40 can be any conventional VHF, UHF or SHF frequency range device capable of accepting two input signals of differing frequencies and providing two output signals with frequencies equal to the sum and difference in frequencies respectively of the input signals. A 10 MHz signal from the oscillator 32 is also applied to the mixer 40. The 200 MHz signal from the doubler 36 and the 10 MHz signal from the oscillator 32 combine in the mixer 40 to form a signal with a frequency of 210 MHz equal to the sum of the frequencies of the 200 MHz and 10 MHz signals.

The 210 MHz signal is one of the signals transmitted to the brain 10 of the subject being monitored. In the arrangement shown in FIG. 2, an antenna 41 is used to transmit the 210 MHz signal and another antenna 43 is used to transmit the 100 MHz signal. Of course, a single antenna capable of operating at 100 MHz and 210 MHz frequencies may be used to transmit both signals. The scan angle, direction and rate may be controlled

mechanically, e.g., by a reversing motor, or electronically, e.g., by energizing elements in the antenna in proper synchronization. Thus, the antenna(s) can be of either fixed or rotary conventional types.

A second 100 MHz signal derived from output terminal 37 of the three-way power divider 34 is applied to a circulator 38 and emerges therefrom with a desired phase shift. The circulator 38 can be of any conventional type wherein a signal applied to an input port emerges from an output port with an appropriate phase shift. The 100 MHz signal is then transmitted to the brain 10 of the subject being monitored via the antenna 43 as the second component of the dual signal transmission. The antenna 43 can be of conventional type similar to antenna 41 herebefore described. As previously noted, these two antennas may be combined in a single unit.

The transmitted 100 and 210 MHz signal components mix within the tissue in the brain 10 and interfere with one another yielding a signal of a frequency of 110 MHz, the difference in frequencies of the two incident components, modulated by electromagnetic emissions from the brain, i.e., the brain wave activity being monitored. This modulated 110 MHz signal is radiated into space.

The 110 MHz signal, modulated by brain wave activity, is picked up by an antenna 45 and channeled back through the circulator 38 where it undergoes an appropriate phase shift. The circulator 38 isolates the transmitted signals from the received signal. Any suitable diplexer or duplexer can be used. The antenna 45 can be of conventional type similar to antennas 41 and 43. It can be combined with them in a single unit or it can be separate. The received modulated 110 MHz signal is then applied to a band pass filter 42, to eliminate undesirable harmonics and extraneous noise, and the filtered 110 MHz signal is inserted into a mixer 44 into which has also been introduced a component of the 100 MHz signal from the source 30 distributed by the RF power divider 34. The filter 42 can be any conventional band pass filter. The mixer 44 may also be of conventional type similar to the mixer 40 herebefore described.

The 100 MHz and 110 MHz signals combine in the mixer 44 to yield a signal of frequency equal to the difference in frequencies of the two component signals, i.e., 10 MHz still modulated by the monitored brain wave activity. The 10 MHz signal is amplified in an IF amplifier 46 and channeled to a demodulator 48. The IF amplifier and demodulator 48 can both be of conventional types. The type of demodulator selected will depend on the characteristics of the signals transmitted to and received from the brain, and the information desired to be obtained. The brain may modulate the amplitude, frequency and/or phase of the interference waveform. Certain of these parameters will be more sensitive to corresponding brain wave characteristics than others. Selection of amplitude, frequency or phase demodulation means is governed by the choice of brain wave characteristic to be monitored. If desired, several different types of demodulators can be provided and used alternately or at the same time.

The demodulated signal which is representative of the monitored brain wave activity is passed through audio amplifiers 50 *a*, *b*, *c* which may be of conventional type where it is amplified and routed to displays 58 *a*, *b*, *c* and a computer 60. The displays 58 *a*, *b*, *c* present the raw brain wave signals from the amplifiers

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50 *a*, *b*, *c*. The computer **60** processes the amplified brain wave signals to derive information suitable for viewing, e.g., by suppressing, compressing, or expanding elements thereof, or combining them with other information-bearing signals and presents that information on a display **62**. The displays can be conventional ones such as the types herebefore mentioned employing electronic visual displays or mechanical plotters 58*b*. The computer can also be of conventional type, either analog or digital, or a hybrid.

A profile of the entire brain wave emission pattern may be monitored or select areas of the brain may be observed in a single measurement simply by altering the scan angle and direction of the antennas. There is no physical contact between the subject and the monitoring apparatus. The computer **60** also can determine a compensating waveform for transmission to the brain **10** to alter the natural brain waves in a desired fashion. The closed loop compensating system permits instantaneous and continuous modification of the brain wave response pattern.

In performing the brain wave pattern modification function, the computer **60** can be furnished with an external standard signal from a source **70** representative of brain wave activity associated with a desired nuerological response. The region of the brain responsible for the response is monitored and the received signal, indicative of the brain wave activity therein, is compared with the standard signal. The computer **60** is programmed to determine a compensating signal, responsive to the difference between the standard signal and received signal. The compensating signal, when transmitted to the monitored region of the brain, modulates the natural brain wave activity therein toward a reproduction of the standard signal, thereby changing the neurological response of the subject.

The computer **60** controls an auxiliary transmitter **64** which transmits the compensating signal to the brain **10** of the subject via an antenna **66**. The transmitter **64** is of the high frequency type commonly used in radar applications. The antenna **66** can be similar to antennas **41**, **43** and **45** and can be combined with them. Through these means, brain wave activity may be altered and deviations from a desired norm may be compensated. Brain waves may be monitored and control signals transmitted to the brain from a remote station.

It is to be noted that the configuration described is one of many possibilities which may be formulated without departing from the spirit of my invention. The transmitters can be monostratic or bistatic. They also can be single, dual, or multiple frequency devices. The transmitted signal can be continuous wave, pulse, FM, or any combination of these as well as other transmission forms. Typical operating frequencies for the transmitters range from 1 MHz to 40 GHz but may be altered to suit the particular function being monitored and the characteristics of the specific subject.

The individual components of the system for monitoring and controlling brain wave activity may be of conventional type commonly employed in radar systems.

Various subassemblies of the brain wave monitoring and control apparatus may be added, substituted or combined. Thus, separate antennas or a single multimode antenna may be used for transmission and reception. Additional displays and computers may be added to present and analyze select components of the monitored brain waves.

Modulation of the interference signal retransmitted by the brain may be of amplitude, frequency and/or phase. Appropriate demodulators may be used to decipher the subject's brain activity and select components of his brain waves may be analyzed by computer to determine his mental state and monitor his thought processes.

As will be appreciated by those familiar with the art, apparatus and method of the subject invention has numerous uses. Persons in critical positions such as drivers and pilots can be continuously monitored with provision for activation of an emergency device in the event of human failure. Seizures, sleepiness and dreaming can be detected. Bodily functions such as pulse rate, heartbeat regularity and others also can be monitored and occurrences of hallucinations can be detected. The system also permits medical diagnoses of patients, inaccessible to physicians, from remote stations.

What is claimed is:

1. Brain wave monitoring apparatus comprising

means for producing a base frequency signal,

means for producing a first signal having a frequency related to that of the base frequency and at a predetermined phase related thereto,

means for transmitting both said base frequency and said first signals to the brain of the subject being monitored,

means for receiving a second signal transmitted by the brain of the subject being monitored in response to both said base frequency and said first signals,

mixing means for producing from said base frequency signal and said received second signal a response signal having a frequency related to that of the base frequency, and

means for interpreting said response signal.

2. Apparatus as in claim **1** where said receiving means comprises

means for isolating the transmitted signals from the received second signals.

3. Apparatus as in claim **2** further comprising a band pass filter with an input connected to said isolating means and an output connected to said mixing means.

4. Apparatus as in claim **1** further comprising means for amplifying said response signal.

5. Apparatus as in claim **4** further comprising means for demodulating said amplified response signal.

6. Apparatus as in claim **5** further comprising interpreting means connected to the output of said demodulator means.

7. Apparatus according to claim **1** further comprising

means for producing an electromagnetic wave control signal dependent on said response signal, and

means for transmitting said control signal to the brain of said subject.

8. Apparatus as in claim **7** wherein said transmitting means comprises means for directing the electromagnetic wave control signal to a predetermined part of the brain.

9. A process for monitoring brain wave activity of a subject comprising the steps of

transmitting at least two electromagnetic energy signals of different frequencies to the brain of the subject being monitored,

receiving an electromagnetic energy signal resulting from the mixing of said two signals in the brain modulated by the brain wave activity and retrans-

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mitted by the brain in response to said transmitted energy signals, and,

interpreting said received signal.

10. A process as in claim 9 further comprising the step of transmitting a further electromagnetic wave signal to the brain to vary the brain wave activity.

11. A process as in claim 10 wherein the step of transmitting the further signals comprises

obtaining a standard signal,

comparing said received electromagnetic energy signals with said standard signal,

producing a compensating signal corresponding to the comparison between said received electrogagnetic energy signals and the standard signal, and

transmitting the compensating signals to the brain of the subject being monitored.

* * * * *

United States Patent [19]
Zanakis et al.

[11] Patent Number: 4,951,674
[45] Date of Patent: Aug. 28, 1990

[54] **BIOMAGNETIC ANALYTICAL SYSTEM USING FIBER-OPTIC MAGNETIC SENSORS**

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[21] Appl. No.: **325,942**

[22] Filed: **Mar. 20, 1989**

[51] **Int. Cl.**[5] **A61B 5/04**
[52] **U.S. Cl.** ..... **128/653 R**; 128/731; 324/244.1
[58] **Field of Search** ..... 324/244 OP; 128/653 R, 128/639, 630, 731, 732

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Primary Examiner—Lee S. Cohen
Assistant Examiner—John C. Hanley
Attorney, Agent, or Firm—Michael Ebert

[57] **ABSTRACT**

A biomagnetic analytical system for sensing and indicating minute magnetic fields emanating from the brain or from any other tissue region of interest in a subject under study. The system includes a magnetic pick-up device constituted by an array of fiber-optic magnetic sensors mounted at positions distributed throughout the inner confines of a magnetic shield configured to conform generally to the head of the subject or whatever other body region is of interest. Each sensor yields a light beam whose phase or other parameter is modulated in accordance with the magnetic field emanating from the related site in the region. The modulated beam from each sensor is compared in an interferometer with a reference light beam to yield an output signal that is a function of the magnetic field being emitted at the related site. The output signals from the interferometer are processed to provide a display or recording exhibiting the pattern or map of magnetic fields resulting from emanations at the multitude of sites encompassed by the region.

8 Claims, 2 Drawing Sheets

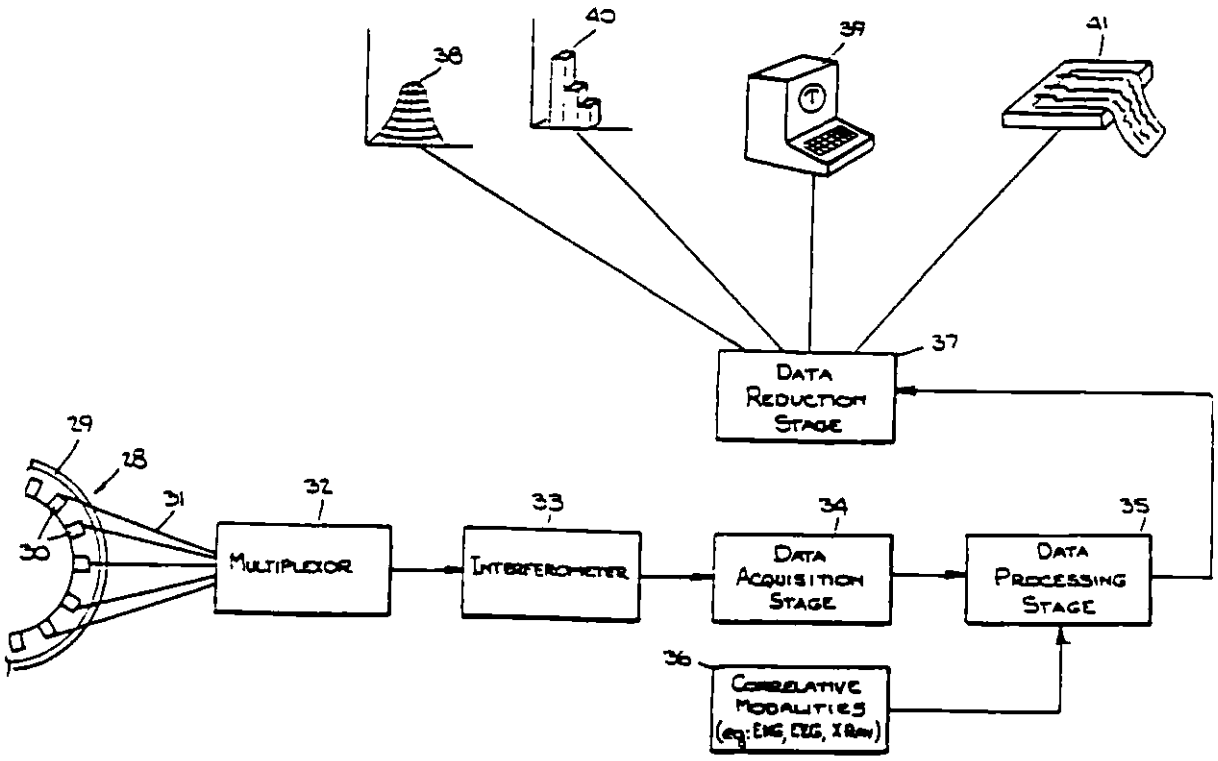


Fig. 1.

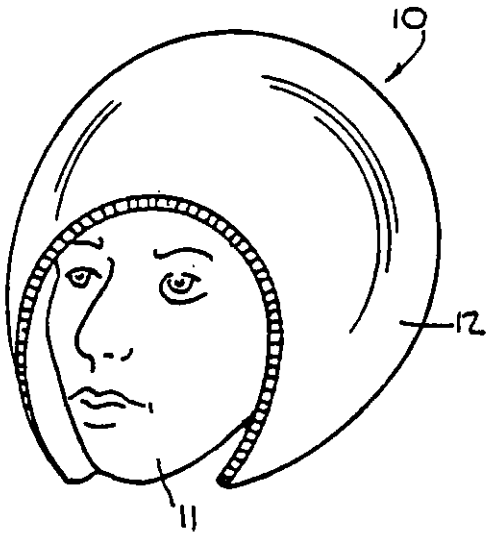
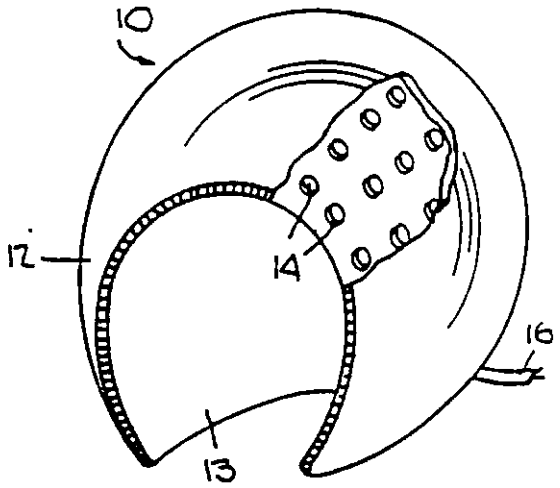


Fig. 2.



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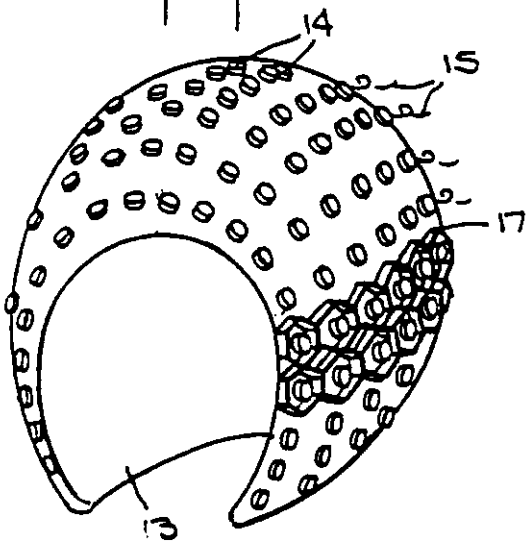

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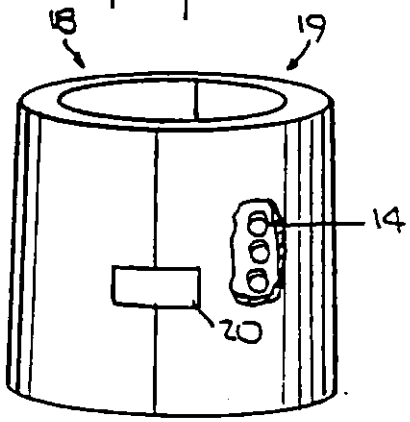

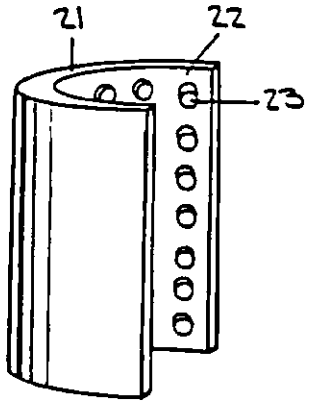

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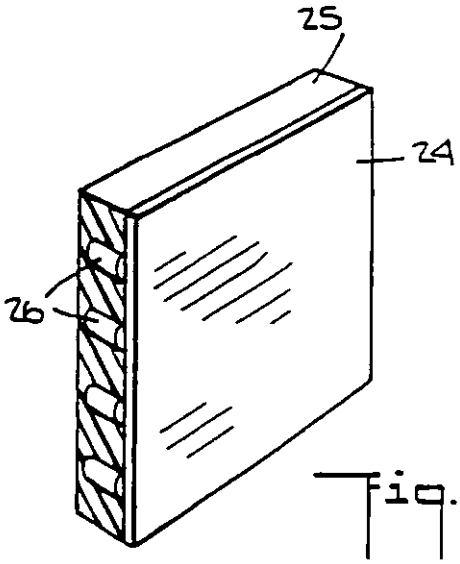

Fig. 6.

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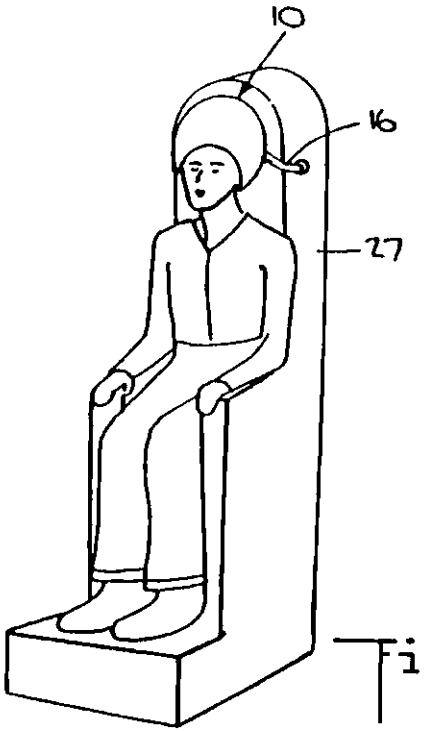
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Fig. 7.

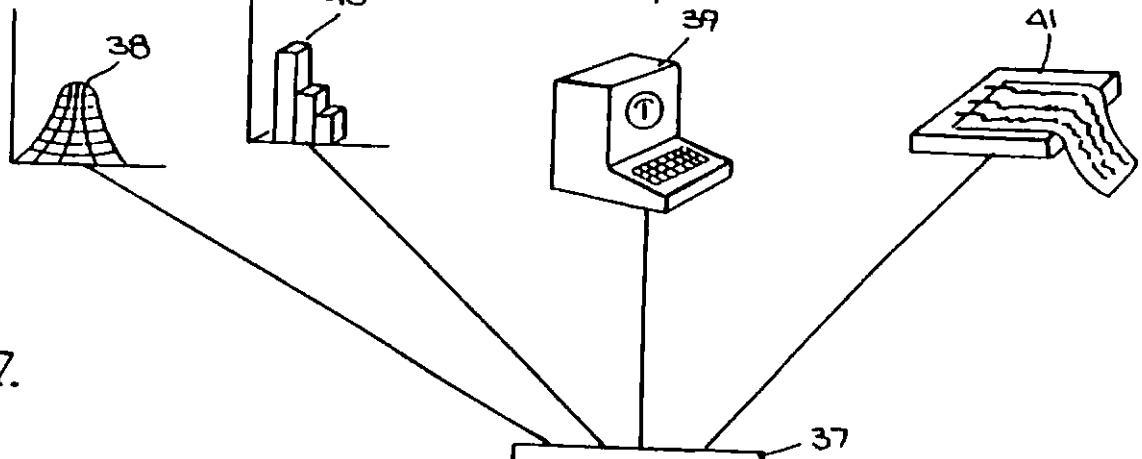
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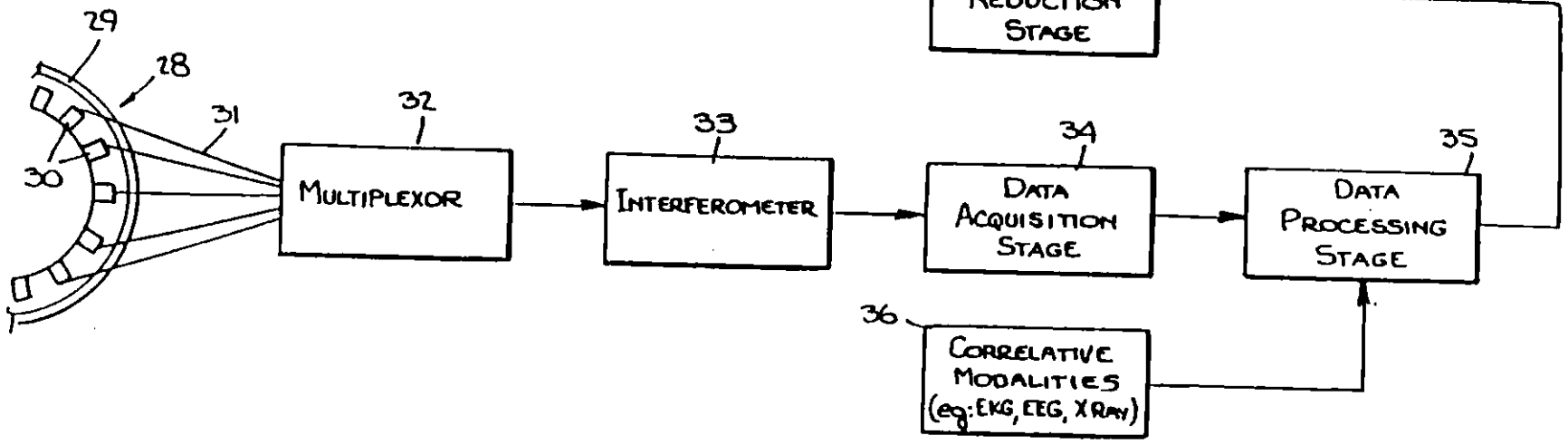
Fig. 8.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MULTIPLEXOR
33
INTERFEROMETER
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DATA ACQUISITION STAGE
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DATA PROCESSING STAGE
37
DATA REDUCTION STAGE
36
CORRELATIVE MODALITIES (eg: EKG, EEG, X RAY)

BIOMAGNETIC ANALYTICAL SYSTEM USING FIBER-OPTIC MAGNETIC SENSORS

BACKGROUND OF INVENTION

1. Field of Invention

This invention relates generally to biomagnetic analytic systems for sensing and indicating minute magnetic fields emanating from the brain and other tissue regions of the human body, and more particularly to a system using fiber-optic magnetic sensor pick-up devices for this purpose.

2. Status of Prior Art

Biomagnetic fields arise from three principal sources, the first being electric currents produced by the movement of ions. The second source is remanent magnetic movement of contaminants, and the third is paramagnetic or diamagnetic constituents of the body.

The first source is of primary significance in human brain activity in which the currents creating the magnetic fields result from signals generated by neurons as they communicate with each other and with sensory organs of the body. The intensity of extracranial magnetic field produced by such currents is extremely minute, having a strength no more than about a billionth of the magnetic field at the earth's surface. It is usually measured in terms of tesla (T) or gauss (G), one T being equal to 10^4 G.

The magnetic field arising from spontaneous brain activity (alpha waves) is about one picotesla ($1pT = 10^{-12}T$), whereas the magnetic field at the earth's surface is about $6 \times 10^{-5}T$. The magnetic field emanating from the brain has a strength much below that emitted by the heart. Hence monitoring of brain magnetic activity presents formidable difficulties.

A major concern of the present invention is magnetoencephalography (also commonly referred to as MEG). This is the recording of magnetic fields emanating from the brain resulting from neuronal electric currents, as distinguished from an electroencephalogram (EEG) in which electric potentials originating in the brain are recorded. With an EEG measurement, it is difficult to extract the three-dimensional distribution of electrically active brain sites from potentials developed at the scalp. While this difficulty can be overcome by inserting electrodes through apertures bored in the skull, this invasive technique is not feasible in the study of normal brain functions or to diagnose functional brain disorders or brain dysfunctions. Thus ionic currents associated with the production of electrically measurable epileptic seizures generate detectable extracranial magnetic fields, and these can be detected externally without invading the skull.

Non-invasive MEG procedures are currently used in epilepsy research to detect the magnetic field distribution over the surface of the head of a patient with a view to localizing the seizure foci and spread patterns. This analysis serves as a guide to surgical intervention for the control of intractable seizures. (See: "Magnetoencephalography and Epilepsy Research"—Rose et al.; Science—16 Oct. 1987—Volume 238, pp. 329-335.)

MEG procedures have been considered as a means to determine the origin of Parkinson's tremor, to differentiate at the earliest possible stage Alzheimer's disease from other dementias, and to localize the responsible cortical lesions in visual defects of neurological origin. MEG procedures are also of value in classifying active drugs in respect to their effects on specific brain structures, and to in this way predict their pharmaceutical efficacy. And with MEG, one can gain a better understanding of the recovery process in head trauma and strokes by observing the restoration of neurological functions at the affected site.

But while MEG holds great promise in the above-noted clinical and pharmaceutical applications, practical considerations, mainly centered on limitations inherent in magnetic sensors presently available for this purpose, have to a large degree inhibited these applications.

The characteristics of biomagnetic activity that are measurable are the strength of the field, the frequency domain and the nature of the field pattern outside of the body. In magnetoencephalography, measurement of all three of these components are important. Ideally, simultaneous measurement of three orthogonal components of the magnetic field provides a complete description of the field as a function of space and time. Coincident measurement of the magnetic field along the surface of the skull can provide a magnetic field map of the cortical and subcortical magnetic activity. With spontaneous activity, the brain emits magnetic fields of about 10^{-8} to 10^{-9} Gauss, compared with approximately 10^{-6} Gauss emitted by the heart. Thus, monitoring of the brain's magnetic activity places heavy demand upon the required hardware.

In brain activity, the current dipole or source is generated by the current flow associated within a neuron or group of neurons. Volume current is analogous to the extracellular component of the current source. In MEG, the net magnetic field measured depends on the magnetic field generated by the current dipole itself. The contribution from volume conduction is small in which approximations to spherical symmetry are made. However, there are tangential magnetic components originating from secondary sources representing perturbations of the pattern by the volume current at boundaries between regions of different conductivity. Contributions from these secondary sources to the tangential component of the field become relatively more pronounced with distance from the current dipole. But there is no interference from these secondary sources when measurement is confined to the magnetic fields perpendicular to the skull.

In biomagnetic analysis, three types of magnetic sensors are known to have adequate sensitivy and discrimination against ambient noise for this purpose. (See: "Magnetoencephalography"—Sato et al.—Journal of Clinical Neurophysiology—Vol. 2, No. 2—1985.) The first is the induction coil. But because of Nyquist noise associated with the resistance of the windings and its loss of sensitivity at frequencies below a few Herz, the induction coil is rarely used in MEG studies.

The second is the Fluxgate magnetometer; and while this has been used in geophysical studies, it has certain drawbacks when used in MEG applications. It is for this reason that the third type, the SQUID system, is presently used almost exclusively in MEG applications.

A SQUID (Superconducting QUantum Interference Device) comprises a superconducting loop incorporating a "weak link" highly sensitive to the magnetic field encompassed within the area of the loop. While the loop itself can act as a magnetic field sensor, use is made of a detection coil tightly coupled to the superconducting loop, the coil acting as a flux transformer. Both the coil and the loop are immersed in a bath of liquid helium contained within a dewar.

With the advent of so-called high-temperature superconductors operating at liquid nitrogen temperatures, a SQUID magnetometer has been developed using such superconductors. (See: "The Impact of High Temperature Superconductivity on SQUID Magnetometers"—Clarke et al.—Science—Vol. 242—14 Oct. 1988.)

In the booklet published by Biomagnetic Technologies, Inc., of San Diego, Calif., entitled "Introduction to Magnetoencephalography—A New Window on The Brain," there is disclosed a SQUID-type sensor for MEG studies. This SQUID is especially suited to measure magnetic fields in the frequency range from DC to 20 kHz, the magnetic field being converted into a signal that is amplified, filtered and displayed for subsequent analysis.

Because the brain's field falls off sharply with distance from the head, the dewar for the cryogenic liquid, which is inherently bulky, is provided with a tail section of reduced diameter to house the pick-up coil and to minimize the distance of the coil from the head of the patient being studied, thereby maximizing the detected field.

As pointed out in the above-identified booklet, in order to produce a contour map of the brain, the magnetic field must be measured simultaneously at a number of points outside the head. While it is possible with SQUIDS to sample the magnetic field emanating from the brain at one to seven points separated laterally from each other by several centimeters, a complete mapping of the field pattern at a given instant requires forty or more pick-up points. It is proposed, therefore, in the booklet to move SQUID sensors from one point to another to accumulate the required field data. But a measurement taken at a point X will not reveal magnetic brain activity taking place concurrently at a point Y if one has to physically shift the sensor from point X to point Y.

The booklet notes that the ultimate goal of MEG measurement is to simultaneously observe all areas of the brain to produce real-time activity maps responding instantaneously to changes as they occur. However, the booklet concedes that this goal has not yet been realized with SQUID sensors.

The present invention attains this goal by means of fiber-optic magnetometers (FOM). In a FOM sensor, a magnetostrictive alloy is interfaced with an optical fiber to produce a magnetometer whose principle of operation is based on the transference of strain from the magnetostrictive material to the core of the optical fiber via mechanical bonding. This results in modulation of the phase or other parameters of the light propagated in the fiber which is subsequently detected by a fiber-optic interferometer. Integrated fiber-optic magnetometers in which all components are fabricated on or around the optical fibers are now known.

FOM sensors of the type currently available are far less expensive to manufacture and maintain than SQUID sensors; they are considerably more compact, and they operate at room temperature. Their sensitivity to weak magnetic fields, which can be greater than that of a SQUID, renders them suitable for MEG and other applications.

The following publications disclose various forms of FOM sensors:

1. "Single-Mode Fiber-Optic Magnetometer with DC Bias Field Stabilization"—Kersey et al.—Journal of Lightwave Technology—Vol. LT-3, [illegible] —August 1985.

2. "Fiber-Optic Polarimetric DC Magnetometer Utilizing a Composite Metallic Glass Resonator"—Mermelstein—Journal of Lightwave Technology, Vol. LT-4, No. 9—September 1986.

3. "Optical Fiber Sensors Using The Method of Polarization-Rotated Reflection"—Enokihara et al.—Journal of Lightwave Technology—Vol. LT-5—No. 11—November 1987.

4. "An Analysis of A Fiber-Optic Magnetometer with Magnetic Feedback"—Koo et al.—Journal of Lightwave Technology—Vol. LT-5—No. 12—December 1987.

The disclosures of these publications are incorporated herein by reference.

SUMMARY OF INVENTION

In view of the foregoing, the main object of this invention is to provide a biomagnetic analytical system which includes a pick-up device employing an array of fiber-optic magnetic (FOM) sensors for measuring and indicating minute magnetic fields emanating from a multitude of sites in the brain or in other tissue regions of interest in a subject being diagnosed.

A significant advantage of a fiber-optic magnetic sensor (FOM) over a SQUID is that the former is a solid-state device that is considerably smaller than the latter and requires no cryogenics, thereby making it possible to distribute a multitude of the sensors (i.e., in excess of forty) around the skull of the patient or about any other tissue region of interest to effect more accurate localization of magnetic activity, as well as a more precise determination of the physiological condition of the region being studied.

More particularly, an object of this invention is to provide a system of the above type for MEG analysis in which the FOM sensors are so distributed in a three-dimensional array as to pick up magnetic fields emanating from a multitude of brain sites simultaneously and to spatially localize the field signals.

Also an object of the invention is to provide a shielded magnetic pick-up device in which the FOM sensors in the array are magnetically shielded from each other to prevent magnetic interaction therebetween, as well as from magnetic fields extraneous to the region of interest, thereby obviating the need for a shielded room to conduct studies on biomagnetic activity.

Yet another object of the invention is to provide a biomagnetic system in which the outputs of the FOM sensors in the array are multiplexed, whereby a common interferometer can be used for the multitude of sensors in the array thereof.

Briefly stated, these objects are attained in a biomagnetic analytical system for sensing and indicating minute magnetic fields emanating from the brain or from any other tissue region of interest in a subject under study. The system includes a magnetic pick-up device constituted by an array of fiber-optic magnetic sensors mounted at positions distributed throughout the inner confines of a magnetic shield configured to conform generally to the head of the subject or whatever other body region is of interest.

Each sensor yields a light beam whose phase or other parameter is modulated in accordance with the magnetic field emanating from the related site in the region. The modulated beam from each sensor is compared in an interferometer with a reference light beam to yield an output signal that is a function of the magnetic field being emitted at the related site. The output signals

from the interferometer are processed to provide a display or recording exhibiting the pattern or map of magnetic fields resulting from emanations at the multitude of sites encompassed by the region.

BRIEF DESCRIPTION OF DRAWINGS

For a better understanding of the invention as well as other objects and further features thereof, reference is made to the following detailed description to be read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a perspective view of a magnetic field pick-up device in the form of a helmet which is fitted over the head of a patient and which incorporates an array of FOM sensors for simultaneously detecting magnetic fields emanating from a multitude of sites in the brain;

FIG. 2 shows the helmet partially cut away to expose an inner insulating liner on which the sensors are mounted;

FIG. 3 is a separate view of the inner liner, illustrating the manner in which the FOM sensors are shielded from each other;

FIG. 4 illustrates, in perspective, a cylindrical magnetic pick-up device;

FIG. 5 shows a semi-cylindrical section of the pick-up device;

FIG. 6 shows a flat pick-up magnetic device;

FIG. 7 illustrates a unit for accommodating a patient undergoing a magnetoencepahlographic examination; and

FIG. 8 illustrates schematically a biomagnetic analytical system in accordance with the invention operating in conjunction with a pick-up device that is appropriate to the region being studied.

DETAILED DESCRIPTION OF INVENTION

FOM Pick-Up Devices

Referring now to FIGS. 1 to 3, there is shown one preferred embodiment of a pick-up device 10 in accordance with the invention, adapted to detect magnetic fields emanating from a multitude of sites on the brain of a patient for purposes of magnetoencelographic (MEG) examination.

Pick-up device 10 includes a generally spherical helmet 12 formed of ferromagnetic or superconductive shielding material, the helmet being configured to generally conform to the head of a patient 11 so that the brain therein lies within the confines of the helmet, and the weak magnetic fields emanating from the brain are confined within the helmet which acts to exclude extraneous magnetic fields, including those emanating from external electronic equipment associated with the pick-up device.

Helmet 12 is provided with a conforming inner liner 13 formed of electrical insulating material, such as in synthetic plastic material or an epoxy compound having good dielectric properties. Embedded in liner 13 or otherwise mounted thereon is a three-dimensional array of identical FOM sensors 14, each provided with a fiber-optic light conducting line 15 to supply light from a suitable laser beam source to the sensor and to conduct the light modulated by the sensor in response to the magnetic field detected thereby to an external interferometer. Lines 15 are bundled to form a cable 16 running from the pick-up device to external signal processing apparatus.

The FOM sensors 14 in the three-dimensional array are distributed uniformly throughout the inner confines

of helmet 12, so that each sensor acts to pick up a unique magnetic field emanating from the head.

As shown in FIG. 3, FOM sensors 14 are internally shielded from each other but not from the magnetic fields emanating from the brain by an open cell ferromagnetic honeycomb 17 so that there is no magnetic interaction between the sensors.

Fiber-optic magnetometers are well known, as evidenced by references (1) to (4), supra. The operation of FOM sensor is based on the transference of strain from the magnetostrictive material in response to a magnetic field to the core of the optical fiber via mechanical bonding, resulting in a phase modification of the propagated light beam. The modulated light from the sensor is subsequently processed in an interferometer which may take the form of a photodetector which compares the phase-modulated light beam with a reference light beam to provide an output signal that is a function of the phase displacement caused by the magnetic field to which the sensor is exposed.

FOM sensors are available in various configurations. In one such configuration, the optical fiber is bonded to a magnetostrictive element to form a waveguide strip that is then coiled into a spool so that the entire sensor is very small. For alternating-current measurements using, for example, metallic glasses as the sensing material, magnetic sensitivities of the order of 10^{-9} G/m of fiber core are obtainable.

Design improvements such as magnetic feedback nulling (Reference 4) can lead to improvements in the linear dynamic range, high suppression of magnetic hysteresis associated with the magnetic material, and improved long-term stability. Methods of improving fluctuations of the transmission characteristics of the fiber (induced by the surrounding environment) exist such as use of phase-sensitive transducers combined with a single polarization-maintaining fiber. Thus polarization-rotated reflection can be used to enhance the performance of the system.

Of the many configurations the magnetometer can take, all detect an externally-induced optical phase shift. The sensitivity of the system is proportional to the length of the fiber, until such time as the length approaches the point where other optical properties of the fiber interfere with the propagation of light. The measurement of the linear strain in length of the fiber which is bonded to (or coated by) the magnetostrictive material forms part of one arm of a fiber interferometer. Several types of interferometer designs have been employed, among which are the Fabra Perot, Mach Zender, Michelson and Sagnac types. Well designed interferometers can detect induced optical phase shifts below $10^{31.6}$ rad over the frequency range of 10–10^{4} Hz. Thus, very weak magnetic fields per meter of fiber can be detected.

The sensor configuration can be a fiber bonded to a magnetostrictive tube or mandrel, a metal film deposited on the fiber, a metallic glass strip bonded to fibers or a metallic glass cylinder. The magnetic materials which are sensitive in the range of DC to 50 kHz are nickel, iron-nickel alloys, cobalt-nickel, and metallic glasses. Piezoelectric activity in the jacket of the fiber can be achieved by the use of various types of polymer films.

Sensing of small AC magnetic fields at optimal DC
[illegible] etic fields for various frequencies can occur.
easuring technique enables the separation of
ic effect (at relatively higher frequencies)

from environmental effects (such as temperature or acoustics at lower frequencies) on the fiber interferometer. Thus, the fiber interferometer can be stabilized without losing sensitivity to magnetic fields.

To extend the AC measuring technique to measure DC bias magnetic fields, one can make use of the effect of DC bias magnetic fields to change the interferometer output due to a fixed AC magnetic field drive at a given frequency. In a sense, this technique utilizes an AC approach to measure DC magnetic fields, thereby overcoming both the environmental perturbation and the 1/f noise problem usually associated with low frequency measurements. It is the nonlinear response of the magnetostrictive material that allows the utilization of an AC technique to measure DC magnetic fields.

In the helmet-type pick-up device shown in FIGS. 1 to 3 which is adapted for MEG studies, each FOM sensor 14 in the three-dimensional array thereof is oriented so that the longitudinal axis of the optical waveguide coil or spool is substantially perpendicular to the surface of the skull of patient 11 wearing the helmet. This orientation makes it possible to dispose a multitude of sensors (forty or more) at positions distributed uniformly about the skull. The density of the coils in the array is limited by factors such as the physical diameter of each spool and induced noise from nearby spools such as eddy currents.

In biomagnetic measurements, sensitivity is limited by fluctuations in the ambient fields and not the intrinsic noise of the sensor. Such ambient fields are produced primarily by the sensor itself, motorized machinery and metallic structural components of buildings which distort the earth's geomagnetic field. The earth's geomagnetic field is uniform and steady. The problem arises when a sensing system vibrates, often in the 1-10 Hz range. Also, the subject may produce noise from normal physiological activity. In MEG, the head proper is the source of a significant amount of noise, produced primarily by the cortex. But because the array of sensors lies within a shield and each sensor occupies a position within a cell in a honeycomb shield, the sensors are isolated from ambient noise and magnetic interaction therebetween is prevented.

Each sensor acts as a gradiometer of predetermined order, any three of which can be used to localize biomagnetic sources at any brain site by the use of the computation techniques described hereinafter.

The pick-up device shown in FIGS. 1 to 3 is adapted to be placed over the head of a patient for MEG analysis. But in practice, the pick-up device can be customized to pick up magnetic field activity arising in other body regions of interest. Thus in measuring magnetic fields generated by the heart, the appropriate pick-up device, as shown in FIGS. 4 and 5, is in a cylindrical form composed of a pair of complementary semi-cylindrical sections 18 and 19 which are joined together by Velcro fasteners 20 or similar means which makes it possible to detach the sections from each other. In practice, for heart analysis, the cylinder is positioned around the thorax.

The cylinder is constituted by an outer shell 21 of shielding material having an inner liner 22 of insulating material in which are embedded a cylindrical array of FOM sensors 23. This cylindrical array of sensors surrounds the thorax, each sensor picking up the magnetic field emanating from a respective site in the heart.

The cylindrical pick-up device can also be configured to go around a limb to measure magnetic fields generated by the muscles therein. For other parts of the body, a flat pick-up device may be appropriate. This flat device, as shown in FIG. 6, is provided with an outer metal plate 24 of shielding material laminated to an inner block 25 of electrical insulating material in which a rectangular array of FOM sensors 26 is embedded.

In practice, the cylindrical pick-up device may be applied to any extremity; and a semi-cylindrical pick-up section can be used separately for measurement purposes. The flat pick-up device is useful for small surface measurements.

In practice, the pick-up device may be contoured to conform to any body region of interest. Thus the pick-up device can be used in a broad range of medical applications by making available to the practitioner a family of pick-up devices, each customized for a particular part of the body. The pick-up device is strapped or otherwise attached to the body part when a biomagnetic study is to be conducted.

For MEG procedures, as shown in FIG. 7, the helmet-type pick-up device 10 may be included as the headpiece of a support unit 27 which also provides a seat, a back rest and a foot platform for the patient whose head is received by the helmet. Housed in the unit is electronic equipment for processing the outputs of the FOM array contained in the helmet.

If one wishes to conduct biomagnetic studies on all portions of the body with a single pick-up device, the pick-up device for this purpose (not shown) may take the form of a sarcophagus-like magnetically shielded enclosure with suitable breathing vents, within which enclosure are disposed arrays of FOM sensors to pick up magnetic fields from different regions of the body. In practice, various standard electronic techniques can be used for noise reduction, either separately or in combination with physical shielding.

The Biomagnetic Analytical System

As shown in FIG. 8, one preferred embodiment of a biomagnetic analytical system in accordance with the invention includes a magnetic field pick-up device 28 in a configuration appropriate to the region under study. Device 28 includes an outer shield 29 within which is an array of FOM sensors 30, each coupled by a fiber-optic line 31 to the input of a multiplexer 32 whose output is applied to an interferometer 33.

Thus instead of having a separate interferometer channel for each FOM sensor which would be very costly, a common interferometer now serves sequentially to compare the modulated light beam derived from each sensor in the array with a reference light beam to produce an output signal. This output signal is a function of the sensed magnetic field emanating from the site related to the sensor.

In practice, multiplex transmission of the signals from the interferometer may be either optical or electrical; that is, by optical waveguides or by conductive wires in the case where the interferometer is of the type which applies the modulated light signal to a photodetector to be compared with the reference light beam.

The output signals from interferometer 33 representing the sensed magnetic fields is applied to a data acquisition stage 34.

The output of interferometer 33 is phase information related to the degree of phase rotation resulting from the detection of the incident vector of the magnetic field transient on the fiber optic sensor. This phase information can evolve over time as the biomagnetic

signal progresses, and it is of an analog nature. Therefore, it can be acquired, recorded, and processed in either the analog or digital form. For purposes of the present embodiment, reducing the data to, and processing the data in digital form will be discussed. However, the specific means of data handling is not important to the invention.

Time-varying phase information can be represented in the form of an evolving analog voltage which is proportional to the phase shift by a predetermined relationship. This signal can be converted to digital form through a conventional high speed sample-and-hold and analog-to-digital converter (ADC) means whereby the resulting bandwidth of the recorded signal can be limited to that which is determined by the sampling rate of this analog signal according to the Nyquist sampling theorem.

Since the signal from each sensor on the sensor array is time-multiplexed before entering data acquisition stage **34**, a single ADC system is sufficient to digitize the signals from the entire sensor array. However, it should be noted that due to the signal bandwidth requirements and the size of the sensor array, it might be possible that the amount of data generated may result in a data rate which is high enough that the conversion rate of a single ADC might be exceeded and thus, a single ADC channel would not suffice. In this case, the multiplexed signal must then be de-multiplexed, the data from each sensor within the array then being directed to a respective ADC channel, there being one ADC channel per sensor, for example.

In practice, several electronic methods may be used to reduce noise, including the use of comb filters, subtracting a reference channel from a signal channel, adaptive filtering of analog or digital format or balancing of detectors. These can quite effectively reduce the ambient noise, even to the point where physical shielding may not be necessary.

The system lends itself to any number of data acquisition and processing means. For example, since the phase information in a magnetoencephalographic signal can be presented in optical form, the data is particularly suited to processing by optical computer technology.

The output of data acquisition stage **34** is applied to a data processing stage **35**. Through the applications of standard spatial localization algorithms, such as are addressed by point source theory, a three-dimensional histogram map can be generated to represent the location and relative magnitude of each magnetic dipole source. The processing of the data will depend upon the configuration of the sensor array, since the proper 3-D mapping of the magnetic dipoles mandates a predetermined geometry of the plane of the array as well as the spacing between each sensor element within the array.

Once the data is acquired in digital form, it can be immediately processed by conventional digital computer means for the purposes of relating the data in various formats including those clinically relevant such as (a) time-varying analog and bandwidth information for each channel, and (b) the spatial localization, through the application of point source theory, of the magnetic dipoles which generated the magnetic field transients that were detected by the sensor array. The data can also be directed to a storage medium for the purpose of recording the digitized biomagnetic data for archiving and later retrieval and processing.

Additionally, other correlative modalities may be employed in conjunction with the biomagnetic data in

order to obtain more complete information about a particular body tissue or system. Thus, modalities such as EEG, EKG, MRI and X-ray from a source **36** can be combined with the biomagnetic data in the data processing stage **35** and represented according to the particular need of the practitioner.

The output of data processing stage **35** is applied to a data reduction stage **37**. The computational techniques necessary for resolution of the image and decoding it into a meaningful "image" for the clinician to interpret requires Fourier analysis of the affected light similar to the analyses utilized by the magnetic resonance imaging (MRI) technology. The FOM-based system in accordance with the invention allows for the detection of a large number of points simultaneously. This feature is most important, since clinicians have long sought a method of actually visualizing the physiological processes of the intact brain (especially deep brain structures) in various states of sleep and consciousness.

Two major problems encountered by the conventional SQUID-based system for MEG is that the resolution is not very good, and that the number of sensors that can be employed is quite limited, thereby limiting the sites in the brain that can be "scanned" for possible pathologies. These two cumbersome problems are overcome with the FOM-based system, making possible many more clinical applications.

With regard to the actual diagnosis of pathologies, the system is targeted toward the same professionals for whom the conventional SQUID-based system is designed. Primarily, these are radiologists, neurologists and surgeons. For example, the practitioner could "see" a functional image of the brain on a CRT, but the image will be a profile of the electromagnetically "active" portions of the brain, as shown by the magnetic pattern **38** derived from data reduction stage **37**. The display plane can represent the location of each magnetic dipole source, and one pixel intensity can represent the magnetic dipole magnitude or phase with respect to a reference signal. What these active areas mean, and how they relate to pathologies is currently an area of intense interest in the basic and clinical neurosciences. Such areas of activity might signify anything from a soft-tissue pathology to abnormal behavioral patterns where no morphological or biochemical anomaly can be detected.

The format of data presentation can take the form of a static or time-varying uni- or multi-dimensional display.

Uni-dimensional display conforms to the current standards of SQUID-based magnetometry and of clinical electrophysiology. In this case, data is represented as linear time-varying representations of single detector elements. Multi-dimensional analysis can provide two- or three-dimensional graphic representations of the data. These multi-dimensional constructs are the result of applying the point source theory algorithms referred to above and can represent the dipole data spatially, or in terms of other dimensionalities, such as k-space in the Fourier domain.

Thus, the three-dimensional histogram map which can be representative of the location and relative magnitude of each magnetic dipole source can be rendered on a standard graphic workstation **39**. Application-specific labelling must be applied to convey orientation and scaling of the 3-D data matrix. The display may take the graphical form **40** in which the level of each sensed field derived from the FOMs is represented by a column. Or

the levels may be separately indicated on a record chart 41.

Advantages

The main advantages of the system are as follows:

I. Each FOM-based sensor is far smaller than a SQUID-based sensor. Thus, a multitude of FCM sensors can be placed over or around the region of interest by the magnetic pick-up device.

II. A system of gradiometers of predetermined order allows for a more accurate localizatior of biomagnetic activity, and a precise determination of the physiological condition.

III. The system affords more freedom to investigate several areas of the tissue region of interest simultaneously, since it provides a means to spatially localize the field signals.

IV. The biomagnetic analyzing system does not use expensive cryogens. The FOM-based pick-up device entails minimal installation time and service requirements.

V. The FOM sensor is relatively easy and inexpensive to construct, since only "solid-state" materials are required.

VI. The magnetic shielding needed for the FOM-based biomagnetic monitoring is limited to the area surrounding the region of interest, thereby eliminating the need for a specially shielded room.

VII. Even if a shielded room or enclosure is preferred for added noise reduction, the enclosure need not be larger than that required to placed the patient in comfortably.

VIII. Multiplexing the output from the sensing array makes it possible for more sensors to be monitored with fewer "decoding" devices at the "back end."

IX. The FOM-based pick-up device produces optical data that lends itself to optical computing available through the field of "photonics" involving optical processing technologies which can drastically decrease data processing times without compromising resolution.

While there has been shown and described a biomagnetic analytical system using various embodiments of FOM pick-up devices in accordance with the invention, it will be appreciated that many changes and modifications may be made therein, without, however, departing from the essential spirit thereof.

We claim:

1. A biomagnetic analytical system for sensing and indicating minute magnetic fields emanating from the brain or any other tissue region of interest in a subject being diagnosed, said system comprising:

(a) a magnetic pick-up device having an outer shell contoured to conform generally to the region of interest, said shell being formed of magnetic shielding material to exclude from its inner confines extraneous magnetic fields, whereby the emitted magnetic fields exist within the confines of the shell, and an array of fiber-optic magnetometer sensors which conforms to the contours of the shell, the sensors being mounted within the shell at positions distributed throughout the inner confines thereof, whereby each sensor is related to a site in the region and yields a light beam modulated in accordance with the magnetic field emanating from this site; and

(b) means including an interferometer to compare the modulated light beam yielded by each sensor in the array with a reference light beam to produce an output signal that is a function of the magnetic field emitted at the related site.

2. A system as set forth in claim 1, wherein said sensors are each disposed within a respective cell of a honeycomb shield supported within the shell to prevent magnetic interaction between the sensors.

3. A system as set forth in claim 1, wherein said sensors in the array are supported on an electrically insulating inner liner conforming to the inner contours of the shell.

4. A system as set forth in claim 1, wherein said shell is configured as a helmet to be worn by the subject for brain magnetic field diagnosis.

5. A system as set forth in claim 1, wherein said shell is configured as a cylinder for heart magnetic field diagnosis.

6. A system as set forth in claim 1, further including means coupled to the output of said interferometer to process the output signals from the interferometer to provide a display exhibiting the pattern of magnetic fields emanating from the sites encompassed by the region.

7. A system as set forth in claim 1, wherein said array has at least forty sensors.

8. A system as set forth in claim 1, wherein the modulated light beams from the sensors are applied sequentially to the interferometer through a multiplexer.

* * * * *

United States Patent [19]

Duffy et al.

[11] **4,408,616**

[45] **Oct. 11, 1983**

[54] **BRAIN ELECTRICAL ACTIVITY MAPPING**

[75] Inventors: **Frank H. Duffy**, Brookline, Mass.; **Norman D. Culver**, Spotswood, N.J.

[73] Assignee: **The Children's Medical Center Corporation**, Boston, Mass.

[21] Appl. No.: **264,043**

[22] Filed: **May 15, 1981**

[51] **Int. Cl.**³ **A61B 5/04**

[52] **U.S. Cl.** **128/731**

[58] **Field of Search** 128/731-733, 128/905

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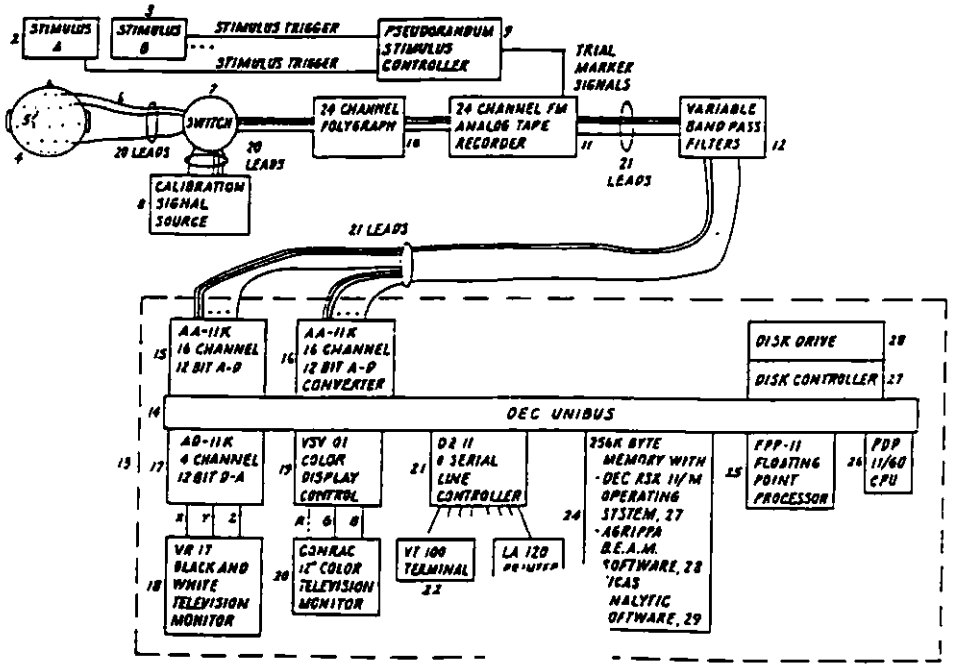
Primary Examiner—Lee S. Cohen

Assistant Examiner—Angela D. Sykes

[57] **ABSTRACT**

Topographic displays of brain electrical activity are produced from matrices of data derived from evoked potential (EP) and steady-state responses of skull transducers. In different aspects, EP responses are displayed at a variable frame rate, the rate of data sampling is sufficient to capture rapid transient events, difference matrices are derived as the difference between matrices corresponding to two different brain conditions, the baseline of the EP responses is zeroed based on the average prestimulus response, and the steady-state response is analyzed by Fourier transforms. In other aspects, statistical comparison matrices representing statistical differences between corresponding elements in two matrices are generated, a coefficient-of-variance matrix is generated, additional display matrices are temporally interpolated, response waveforms are previewed and tagged for elimination from further processing, the topographic maps are displayed on a video monitor with appropriate scaling of the data to the tones of the display, and additional display points are interpolated between the measured data points for display.

82 Claims, 32 Drawing Figures



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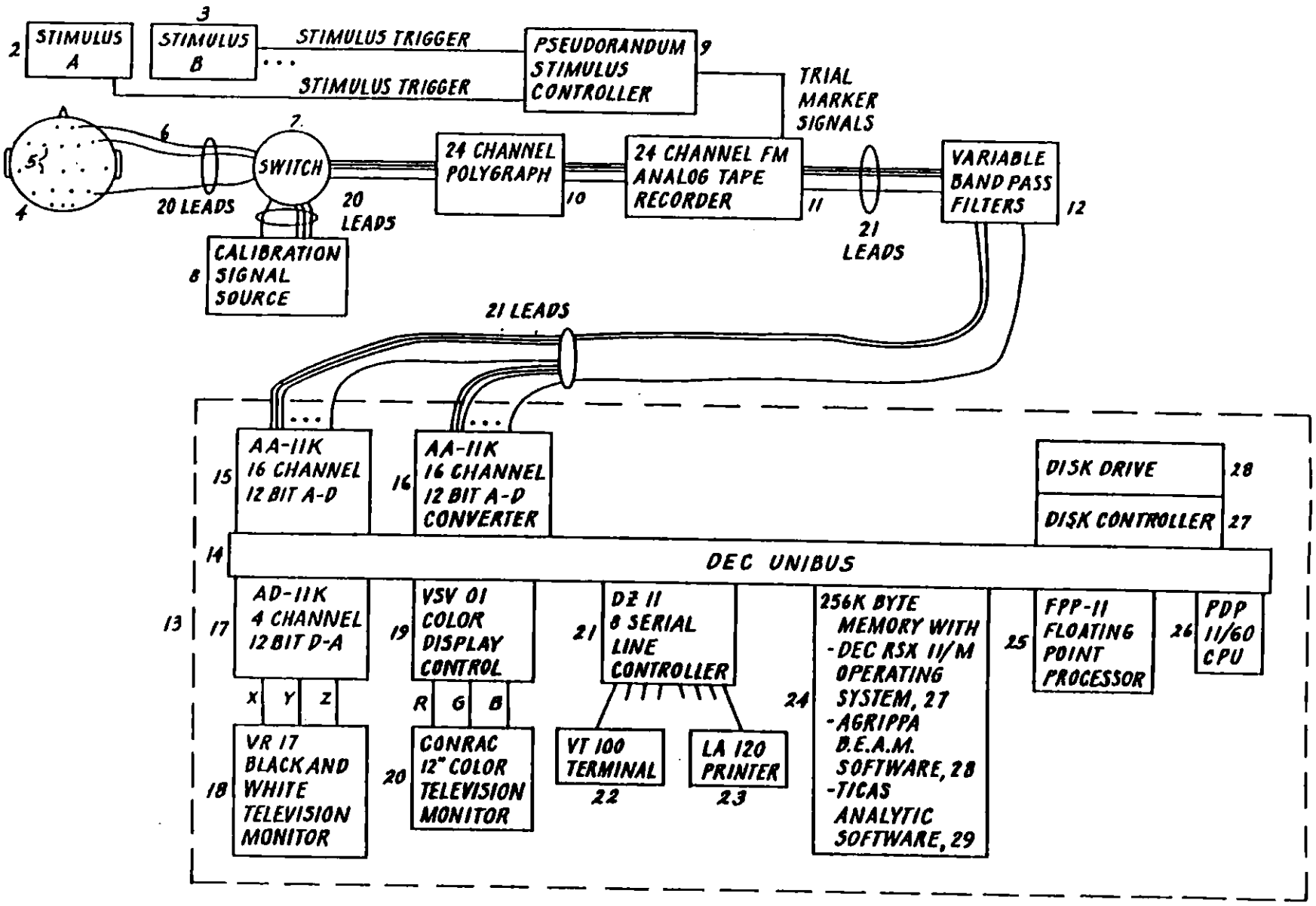
2
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STIMULUS B
STIMULUS TRIGGER
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PSEUDORANDUM STIMULUS CONTROLLER
9
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4
5
6
20 LEADS
7
SWITCH
20 LEADS
24 CHANNEL POLYGRAPH
10
24 CHANNEL FM ANALOG TAPE RECORDER
11
21 LEADS
VARIABLE BAND PASS FILTERS
12
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CALIBRATION SIGNAL SOURCE
21 LEADS
15
AA-11K 16 CHANNEL 12 BIT A-D
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DISK CONTROLLER
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DEC UNIBUS
13
17
AD-11K 4 CHANNEL 12 BIT D-A
X
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Z
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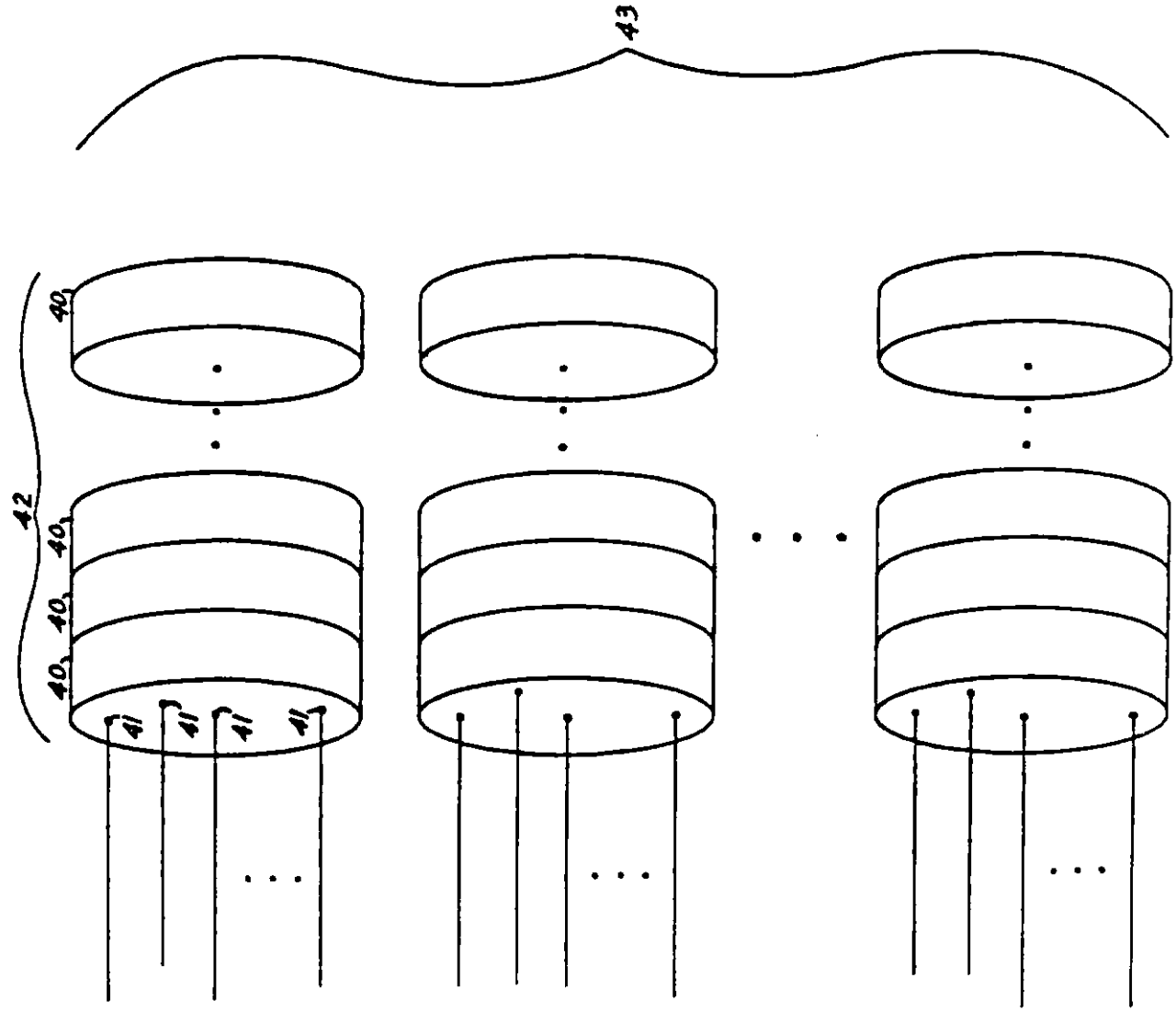
VR 17 BLACK AND WHITE TELEVISION MONITOR
19
VSV 01 COLOR DISPLAY CONTROL
R
G
B
20
CONRAC 12" COLOR TELEVISION MONITOR
21
DZ 11 8 SERIAL LINE CONTROLLER
VT 100 TERMINAL
22
LA 120 PRINTER
23
24
256K BYTE MEMORY WITH -DEC RSX 11/M OPERATING SYSTEM, 27 -AGRIPPA B.E.A.M. SOFTWARE, 28 -TICAS ANALYTIC SOFTWARE, 29
25
FPP-11 FLOATING POINT PROCESSOR
26
PDP 11/60 CPU

Fig 1

Fig 2



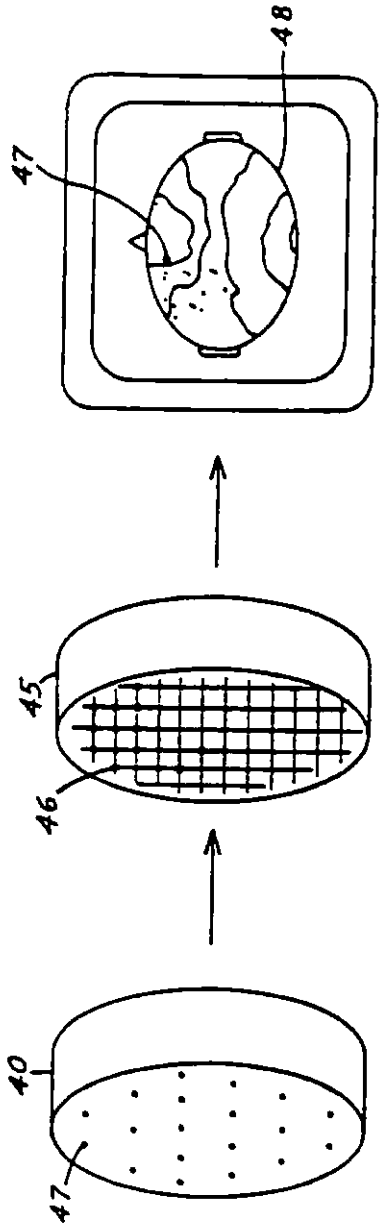


Fig 3

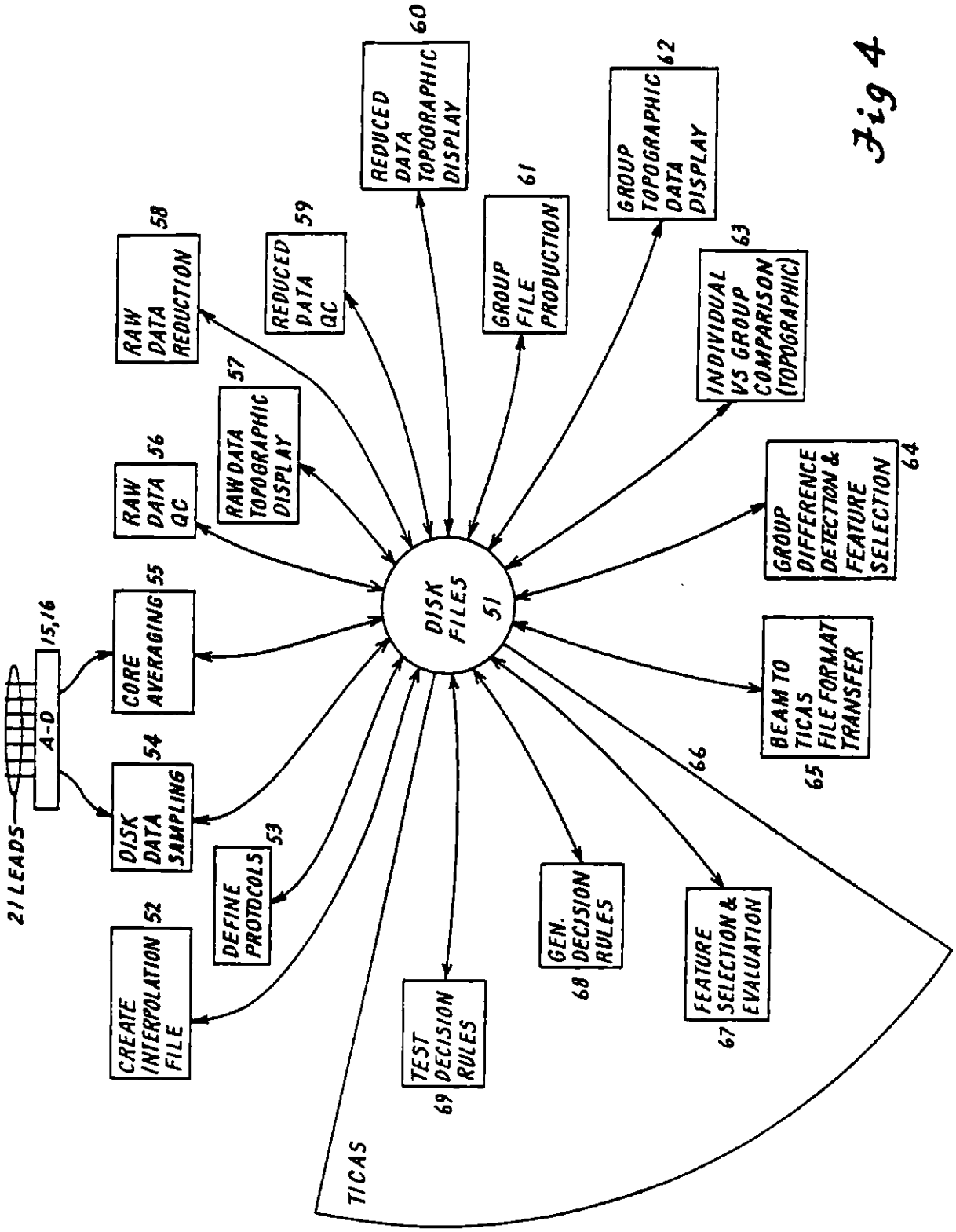
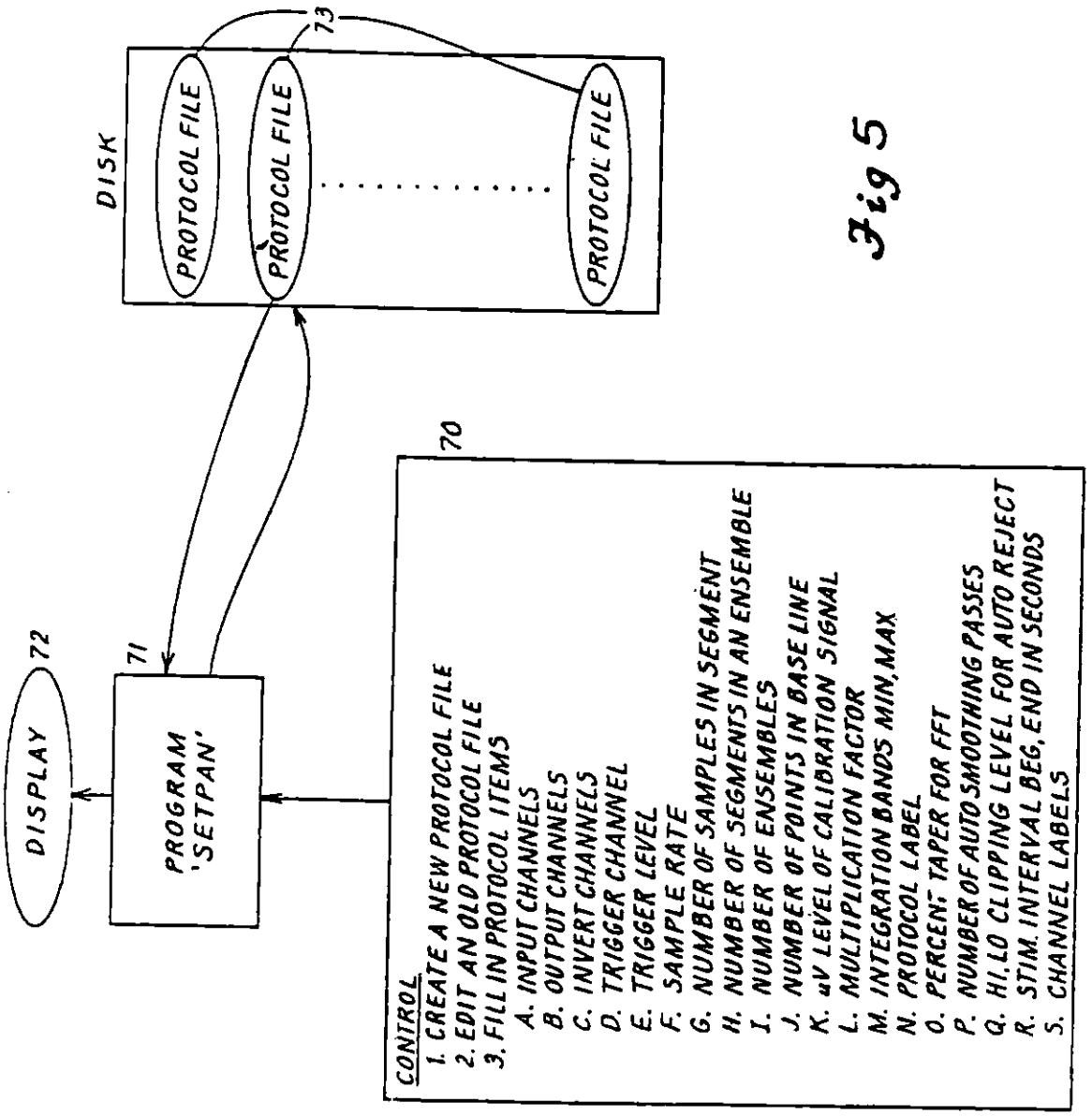

21 LEADS
A-D
15,16
CORE AVERAGING
55
DISK DATA SAMPLING
54
CREATE INTERPOLATION FILE
52
DEFINE PROTOCOLS
53
RAW DATA QC
56
RAW DATA REDUCTION
58
RAW DATA TOPOGRAPHIC DISPLAY
57
REDUCED DATA QC
59
REDUCED DATA TOPOGRAPHIC DISPLAY
60
GROUP FILE PRODUCTION
61
GROUP TOPOGRAPHIC DATA DISPLAY
62
INDIVIDUAL VS GROUP COMPARISON (TOPOGRAPHIC)
63
GROUP DIFFERENCE DETECTION & FEATURE SELECTION
64
BEAM TO TICAS FILE FORMAT TRANSFER
65
66
FEATURE SELECTION & EVALUATION
67
GEN. DECISION RULES
68
TEST DECISION RULES
69
TICAS
DISK FILES
51

Fig 4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PROTOCOL FILE
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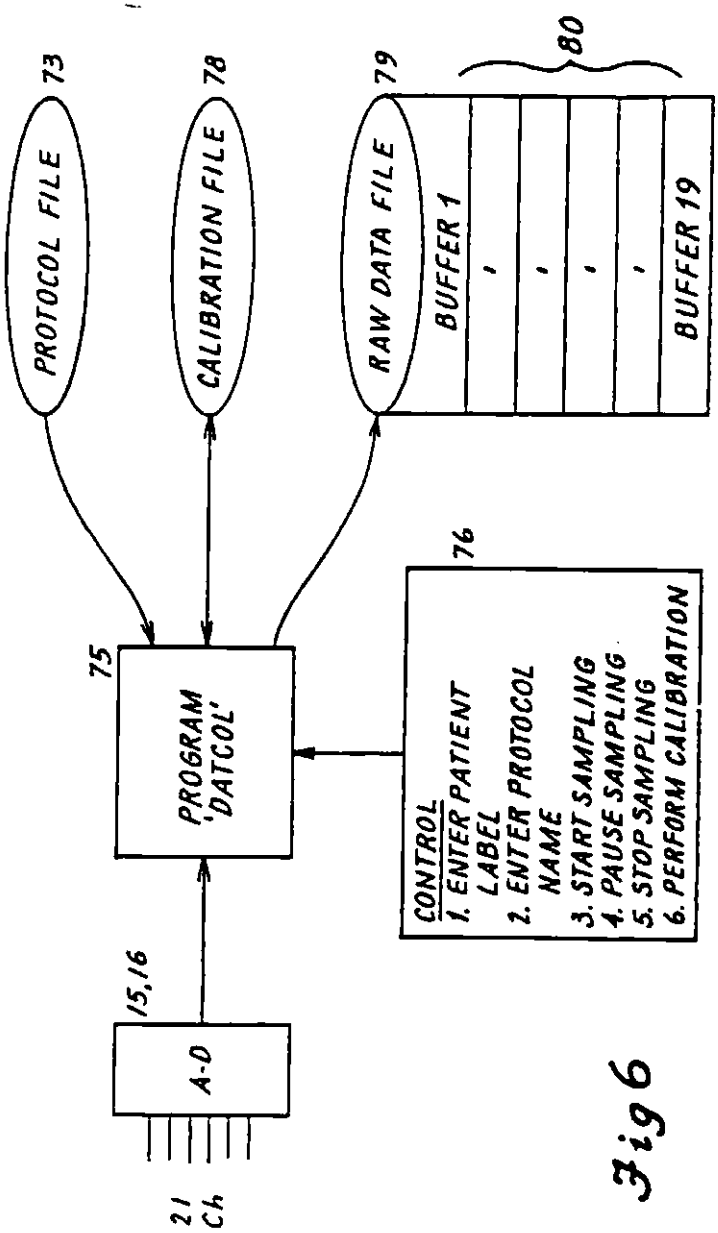
2. EDIT AN OLD PROTOCOL FILE
3. FILL IN PROTOCOL ITEMS
A. INPUT CHANNELS
B. OUTPUT CHANNELS
C. INVERT CHANNELS
D. TRIGGER CHANNEL
E. TRIGGER LEVEL
F. SAMPLE RATE
G. NUMBER OF SAMPLES IN SEGMENT
H. NUMBER OF SEGMENTS IN AN ENSEMBLE
I. NUMBER OF ENSEMBLES
J. NUMBER OF POINTS IN BASE LINE
K. uV LEVEL OF CALIBRATION SIGNAL
L. MULTIPLICATION FACTOR
M. INTEGRATION BANDS MIN, MAX
N. PROTOCOL LABEL
O. PERCENT TAPER FOR FFT
P. NUMBER OF AUTO SMOOTHING PASSES
Q. HI, LO CLIPPING LEVEL FOR AUTO REJECT
R. STIM. INTERVAL BEG, END IN SECONDS
S. CHANNEL LABELS

Fig 5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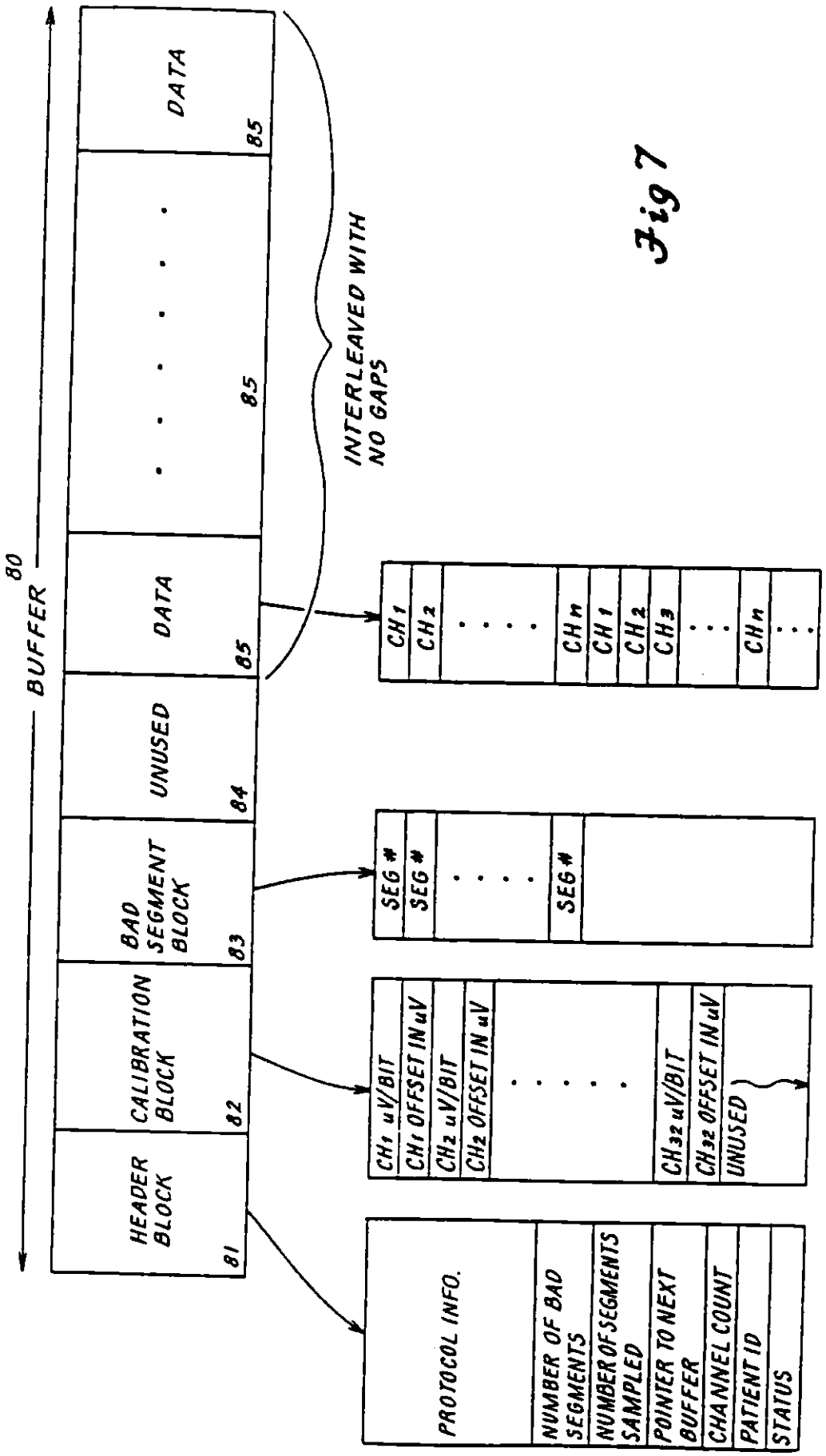
6. PERFORM CALIBRATION
15,16
A-D
21 Ch

Fig 6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CALIBRATION BLOCK
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BAD SEGMENT BLOCK
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UNUSED
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DATA
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DATA
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INTERLEAVED WITH NO GAPS
PROTOCOL INFO.
NUMBER OF BAD SEGMENTS
NUMBER OF SEGMENTS SAMPLED
POINTER TO NEXT BUFFER
CHANNEL COUNT
PATIENT ID
STATUS
CH1 uV/BIT
CH1 OFFSET IN uV
CH2 uV/BIT
CH2 OFFSET IN uV
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CH32 uV/BIT
CH32 OFFSET IN uV
UNUSED
SEG #
SEG #
. . . .
SEG #
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CH2
. . . .
CHn
CH1
CH2
CH3
. . .
CHn
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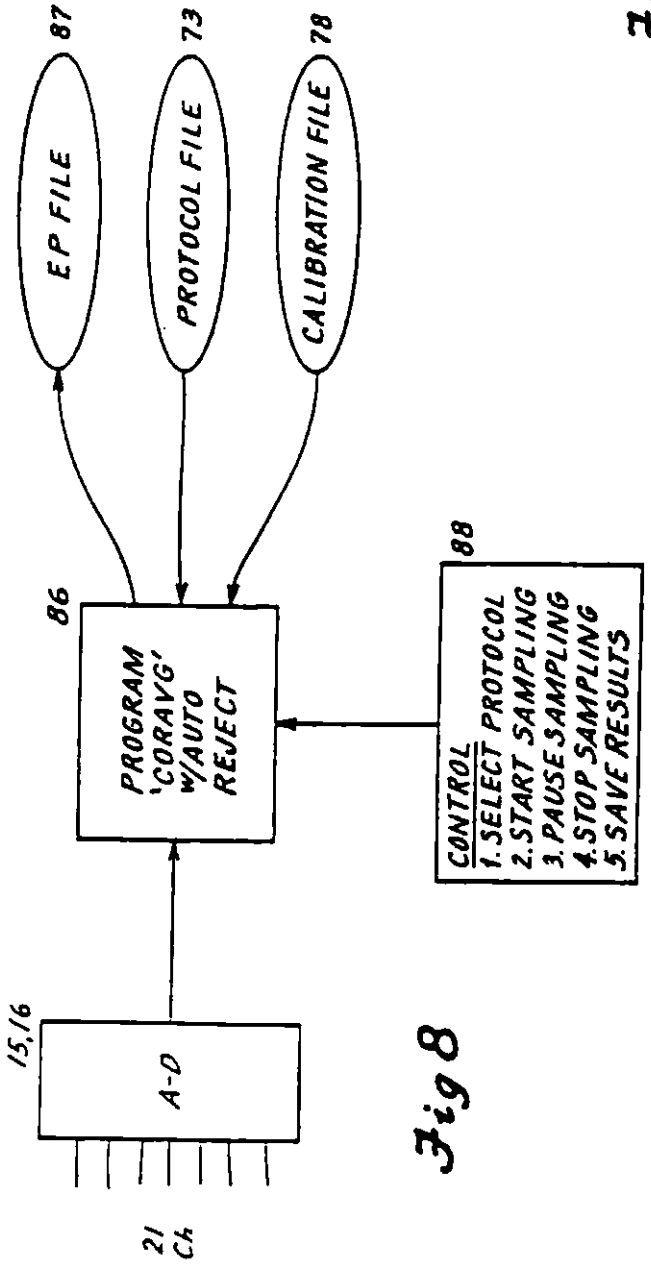
Fig 7

42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CONTROL
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3. PAUSE SAMPLING
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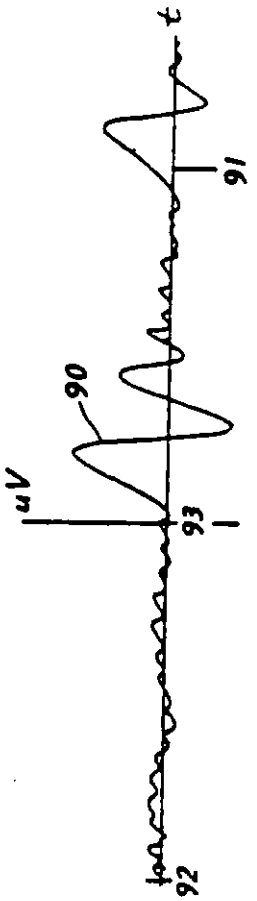
5. SAVE RESULTS
15,16
A-D
21 Ch

Fig 8

Fig 9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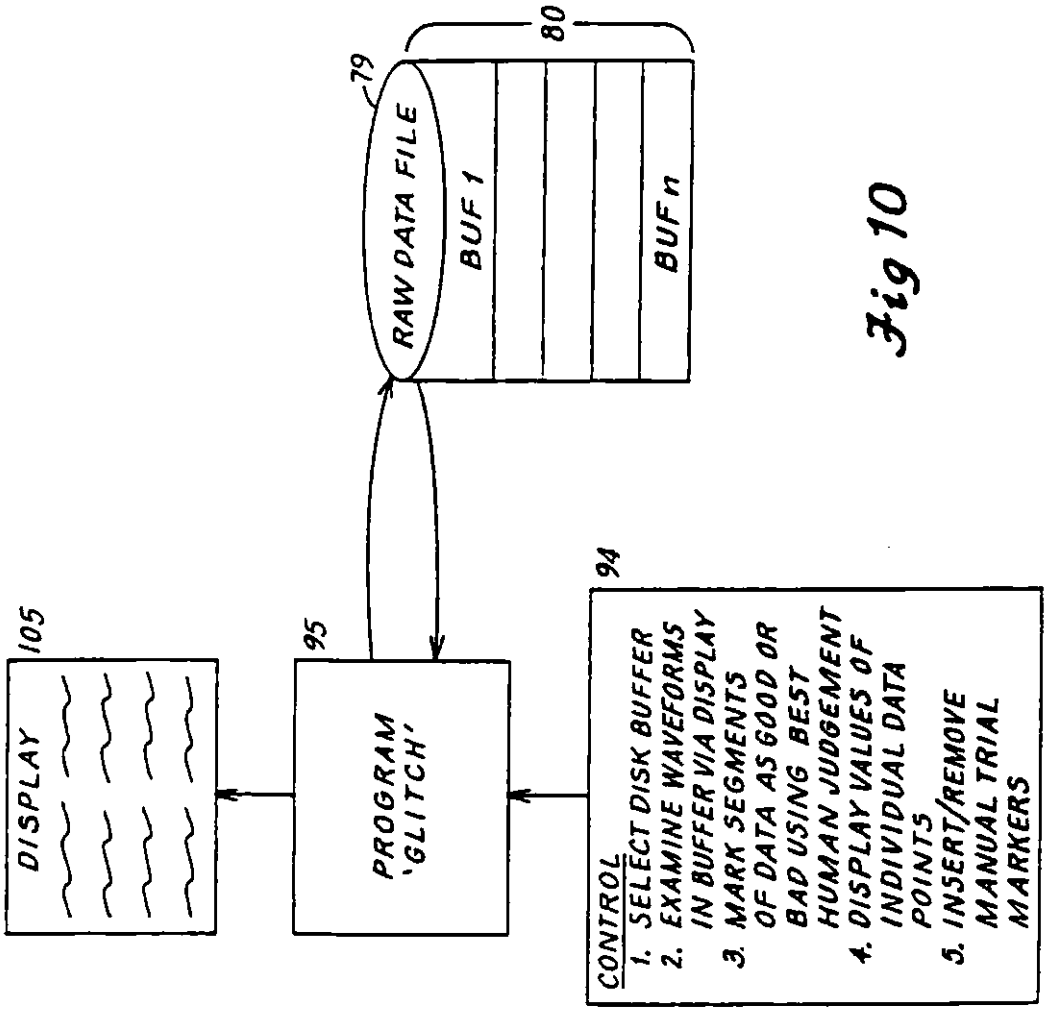
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BUF 1
BUF n
94
105
95
DISPLAY
PROGRAM 'GLITCH'
CONTROL
1. SELECT DISK BUFFER
2. EXAMINE WAVEFORMS IN BUFFER VIA DISPLAY
3. MARK SEGMENTS OF DATA AS GOOD OR BAD USING BEST HUMAN JUDGEMENT
4. DISPLAY VALUES OF INDIVIDUAL DATA POINTS
5. INSERT/REMOVE MANUAL TRIAL MARKERS

Fig 10

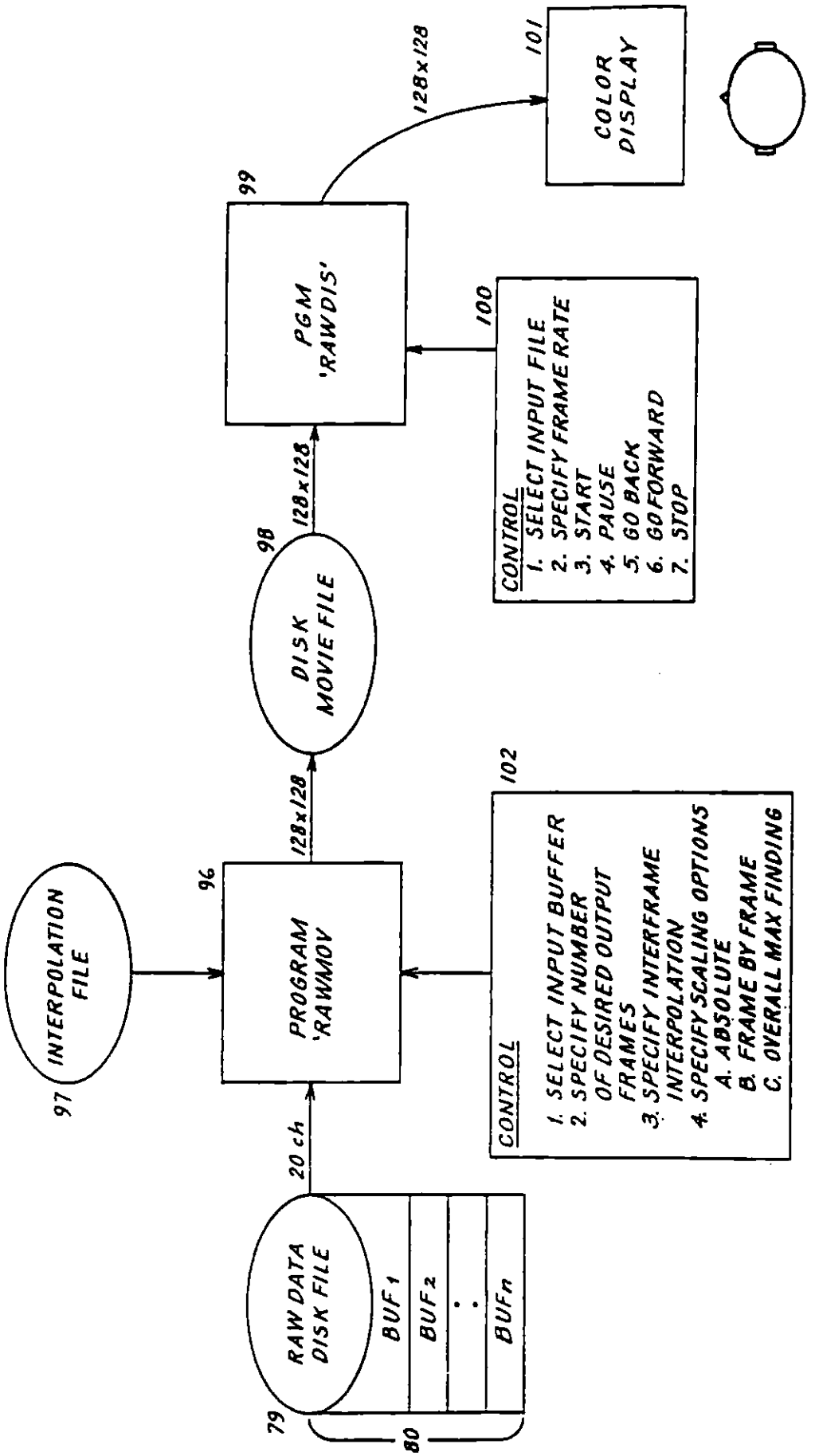

RAW DATA DISK FILE
BUF1
BUF2
BUFn
79
80
20 ch
INTERPOLATION FILE
97
96
PROGRAM 'RAWMOV
128x128
98
DISK MOVIE FILE
128x128
99
PGM 'RAWDIS'
128x128
101
COLOR DISPLAY
100
CONTROL
1. SELECT INPUT FILE
2. SPECIFY FRAME RATE
3. START
4. PAUSE
5. GO BACK
6. GO FORWARD
7. STOP
102
CONTROL
1. SELECT INPUT BUFFER
2. SPECIFY NUMBER OF DESIRED OUTPUT FRAMES
3. SPECIFY INTERFRAME INTERPOLATION
4. SPECIFY SCALING OPTIONS
A. ABSOLUTE
B. FRAME BY FRAME
C. OVERALL MAX FINDING

Fig 11

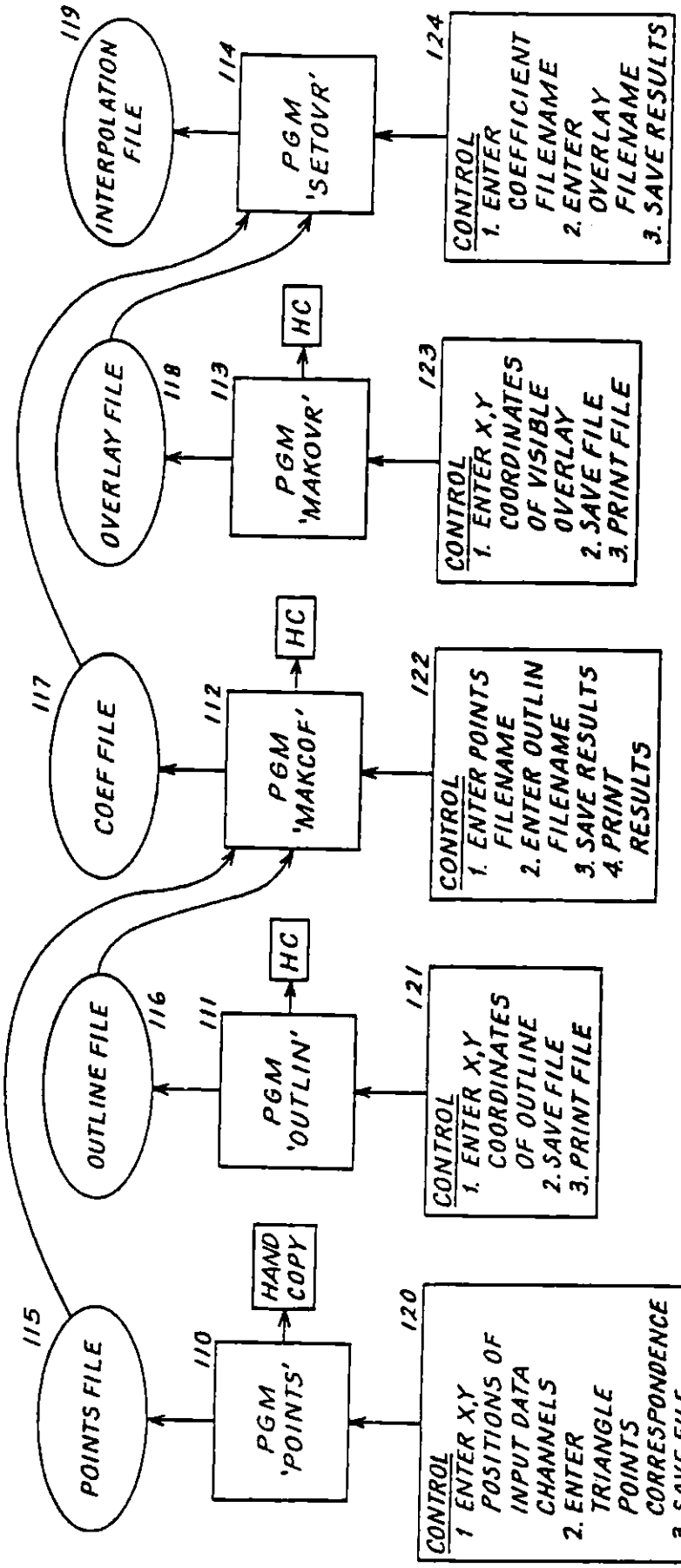

INTERPOLATION FILE
119
PGM 'SETOVR'
114
CONTROL
1. ENTER COEFFICIENT FILENAME
2. ENTER OVERLAY FILENAME
3. SAVE RESULTS
124
OVERLAY FILE
118
PGM 'MAKOVR'
113
HC
CONTROL
1. ENTER X,Y COORDINATES OF VISIBLE OVERLAY
2. SAVE FILE
3. PRINT FILE
123
COEF FILE
117
PGM 'MAKCOF'
112
HC
CONTROL
1. ENTER POINTS FILENAME
2. ENTER OUTLIN FILENAME
3. SAVE RESULTS
4. PRINT RESULTS
122
OUTLINE FILE
116
PGM 'OUTLIN'
111
HC
CONTROL
1. ENTER X,Y COORDINATES OF OUTLINE
2. SAVE FILE
3. PRINT FILE
121
POINTS FILE
115
PGM 'POINTS'
110
HAND COPY
CONTROL
1. ENTER X,Y POSITIONS OF INPUT DATA CHANNELS
2. ENTER TRIANGLE POINTS CORRESPONDENCE
3. SAVE FILE
4. PRINT FILE
120

Fig 12

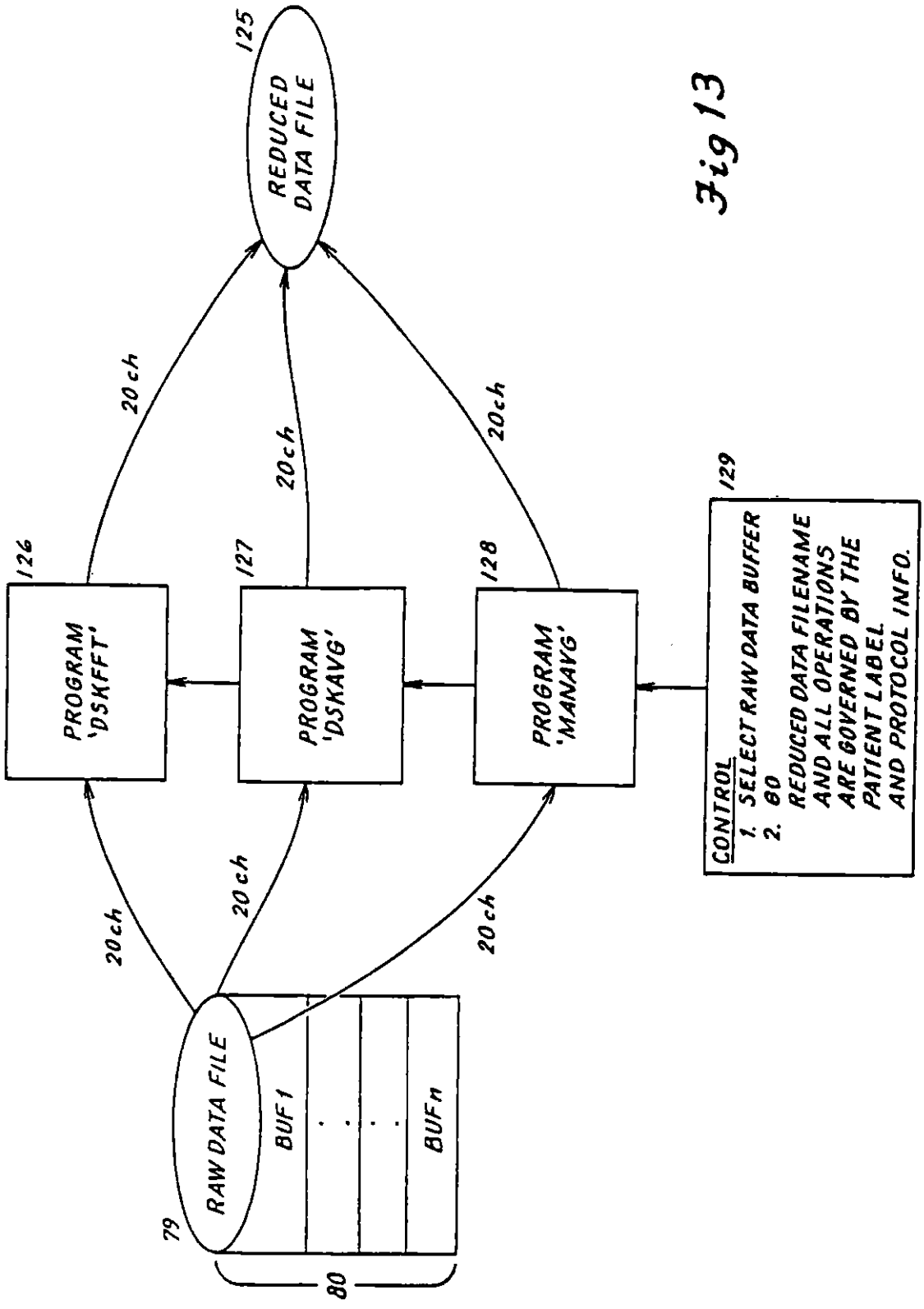
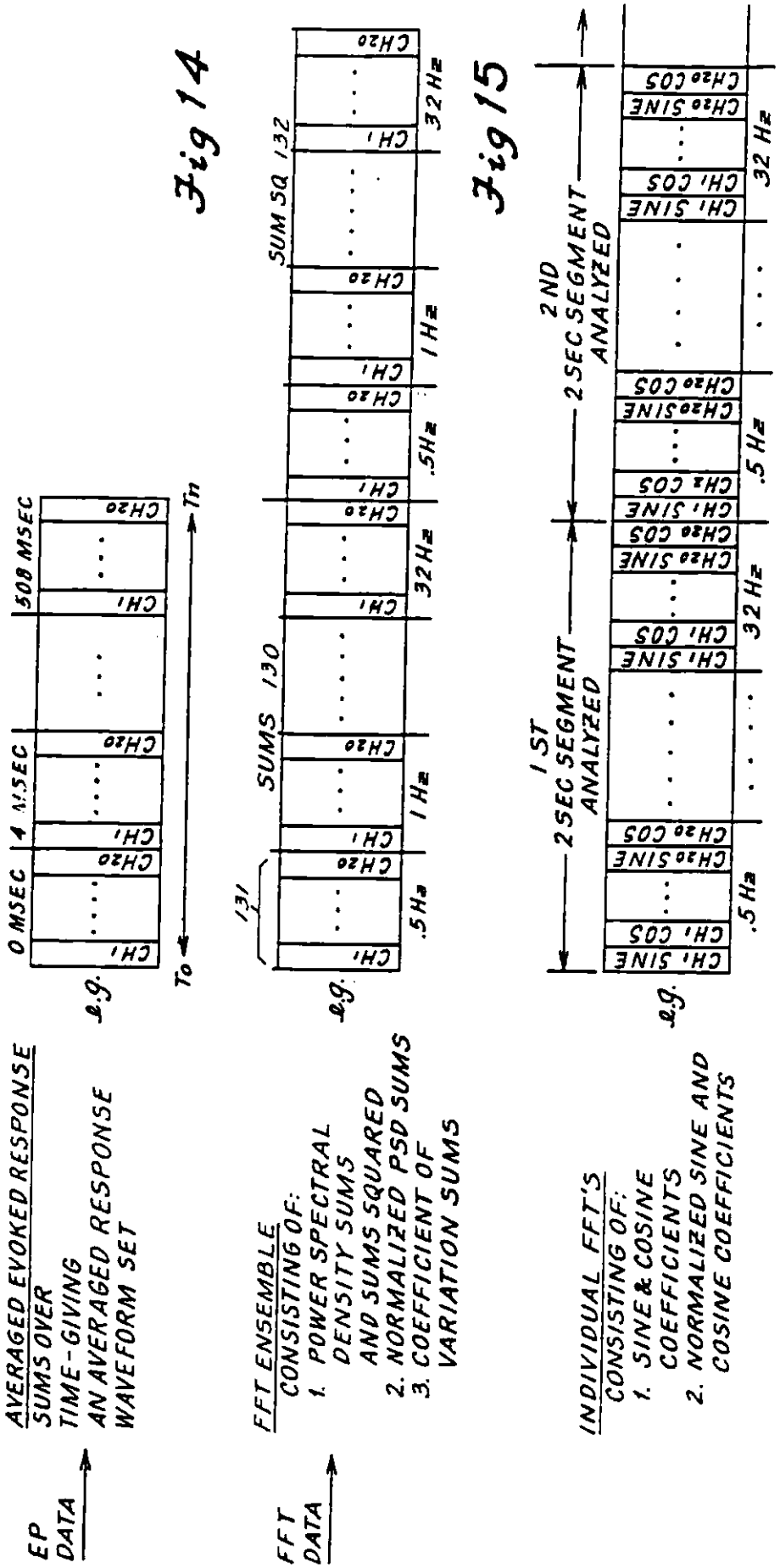

125
REDUCED DATA FILE
20ch
20ch
20ch
126
PROGRAM 'DSKFFT'
127
PROGRAM 'DSKAVG'
128
PROGRAM 'MANAVG'
129
CONTROL
1. SELECT RAW DATA BUFFER
2. 80 REDUCED DATA FILENAME AND ALL OPERATIONS ARE GOVERNED BY THE PATIENT LABEL AND PROTOCOL INFO.
20ch
20ch
20ch
79
RAW DATA FILE
BUF 1
BUF n
80

Fig 13


EP DATA
AVERAGED EVOKED RESPONSE
SUMS OVER
TIME-GIVING
AN AVERAGED RESPONSE
WAVEFORM SET
133
0 MSEC
4 MSEC
508 MSEC
CH1
CH20
e.g.
To
Tn
Fig 14
FFT DATA
FFT ENSEMBLE
CONSISTING OF:
1. POWER SPECTRAL
DENSITY SUMS
AND SUMS SQUARED
2. NORMALIZED PSD SUMS
3. COEFFICIENT OF
VARIATION SUMS
SUMS 130
SUM SQ 132
131
.5 Hz
1 Hz
32 Hz
Fig 15
INDIVIDUAL FFT'S
CONSISTING OF:
1. SINE & COSINE
COEFFICIENTS
2. NORMALIZED SINE AND
COSINE COEFFICIENTS
1 ST
2 SEC SEGMENT
ANALYZED
2 ND
2 SEC SEGMENT
ANALYZED
CH1 SINE
CH1 COS
CH2 COS
CH20 SINE
CH20 COS
Fig 16

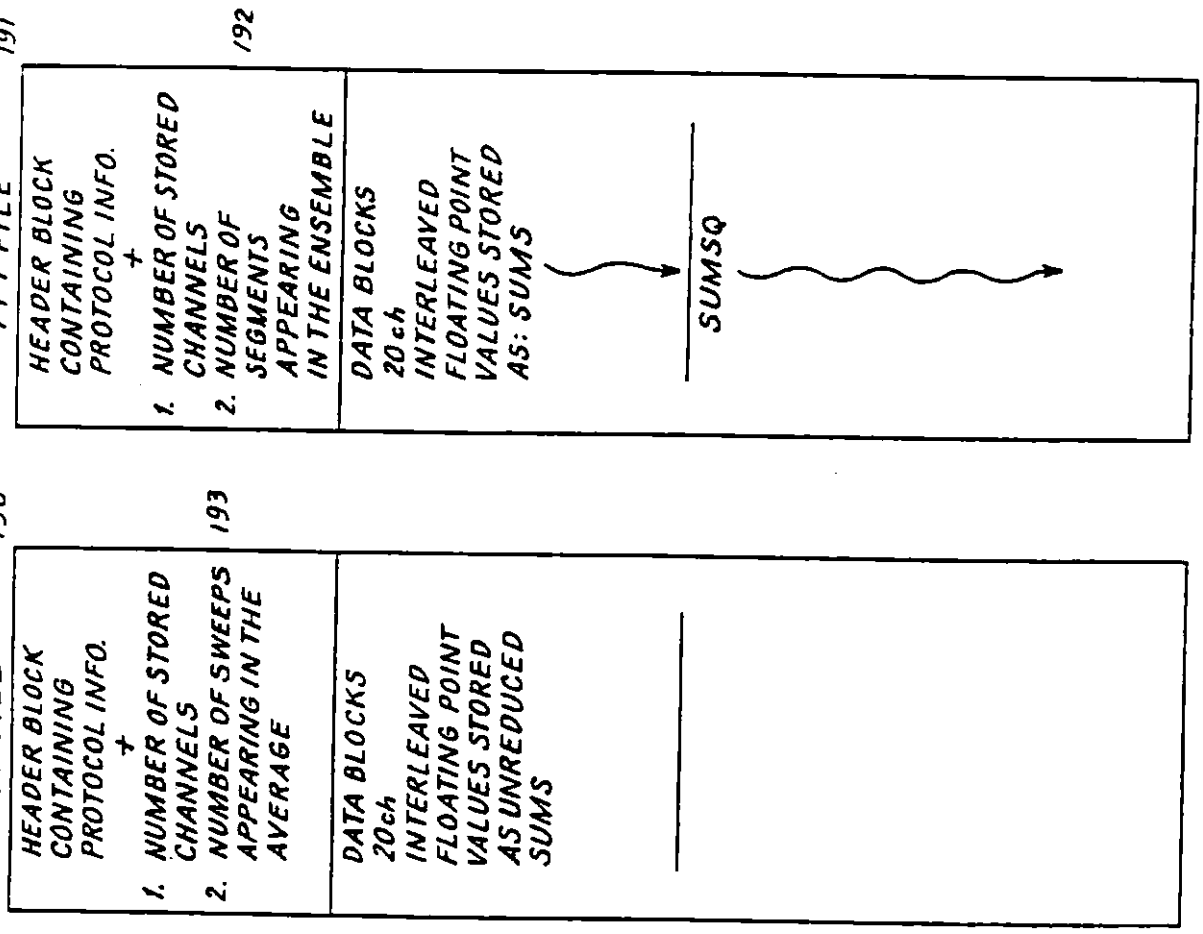


Fig 17

Fig 18

49

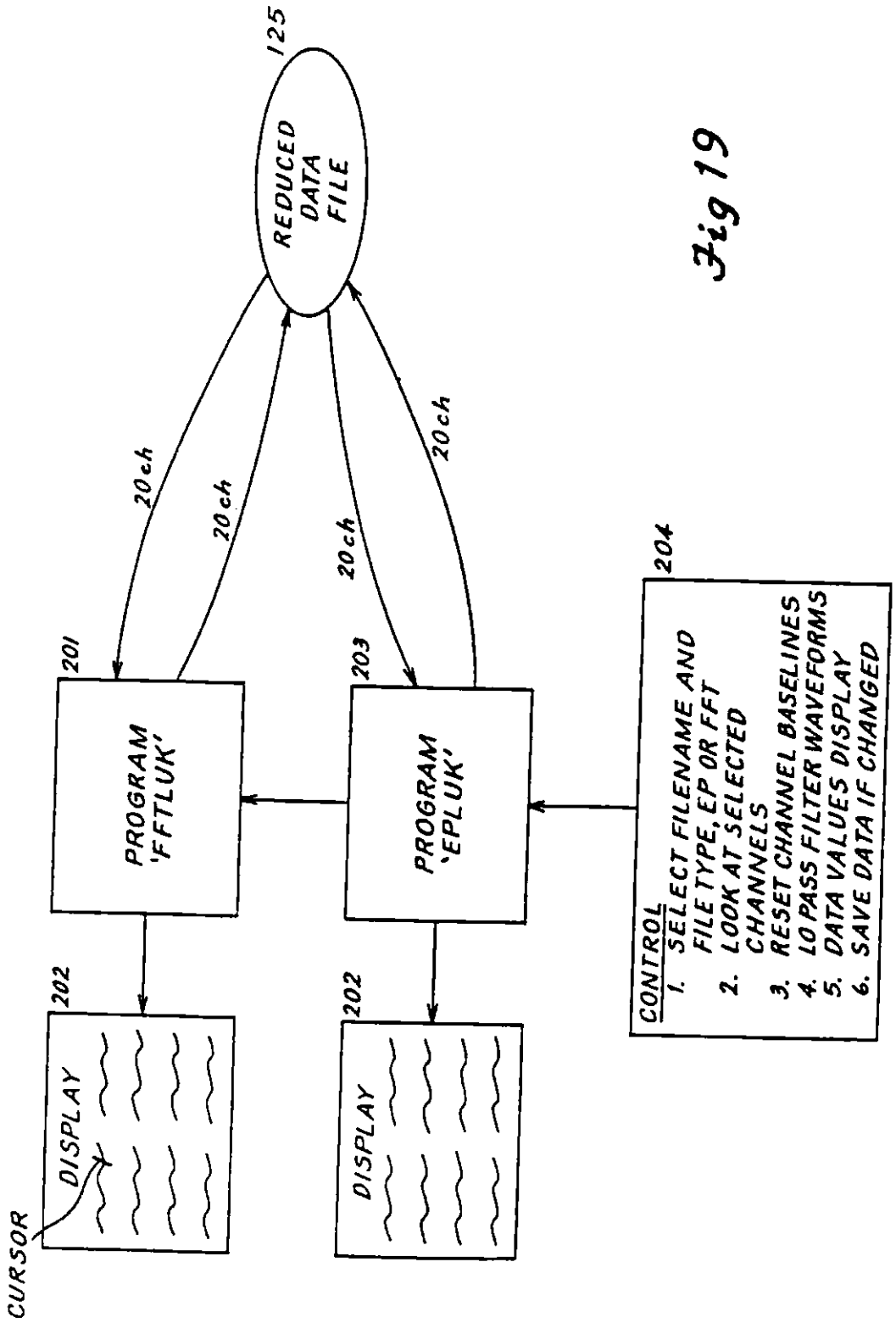

125
REDUCED DATA FILE
20 ch
20 ch
20 ch
20 ch
201
PROGRAM 'FFTLUK'
203
PROGRAM 'EPLUK'
204
CONTROL
1. SELECT FILENAME AND FILE TYPE, EP OR FFT
2. LOOK AT SELECTED CHANNELS
3. RESET CHANNEL BASELINES
4. LO PASS FILTER WAVEFORMS
5. DATA VALUES DISPLAY
6. SAVE DATA IF CHANGED
202
DISPLAY
202
DISPLAY
CURSOR

Fig 19

50

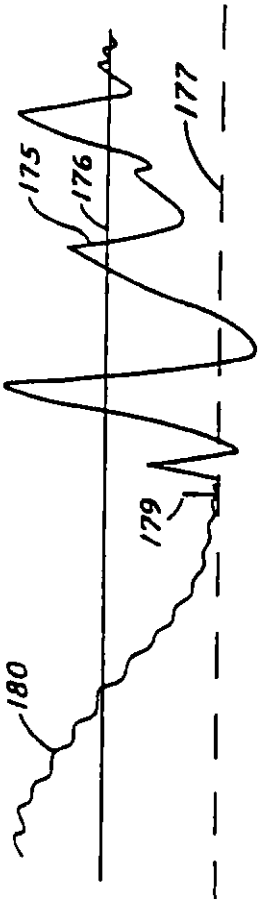


Fig 20

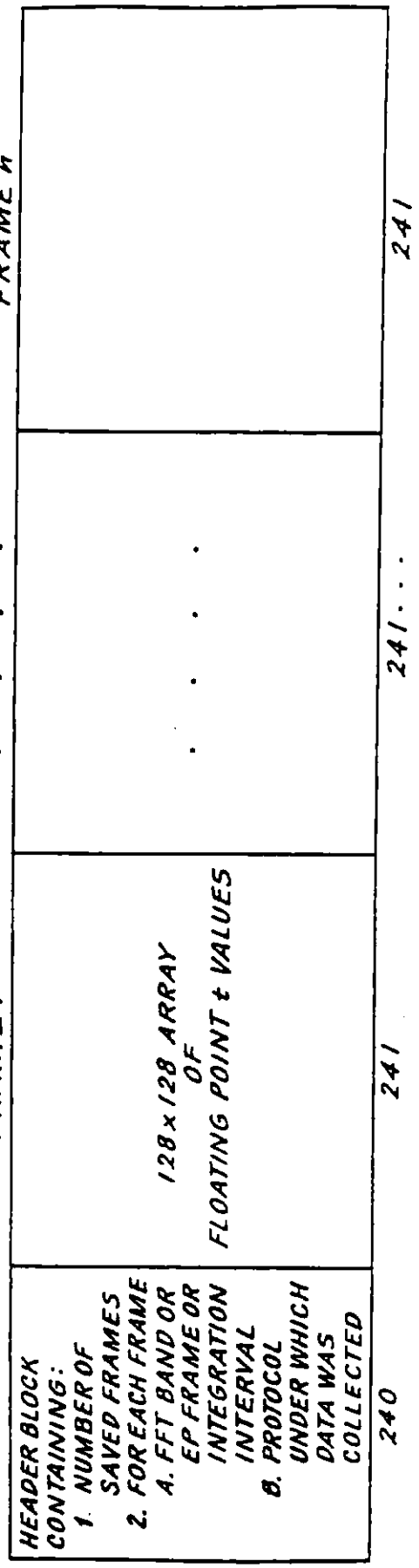


Fig 26

51

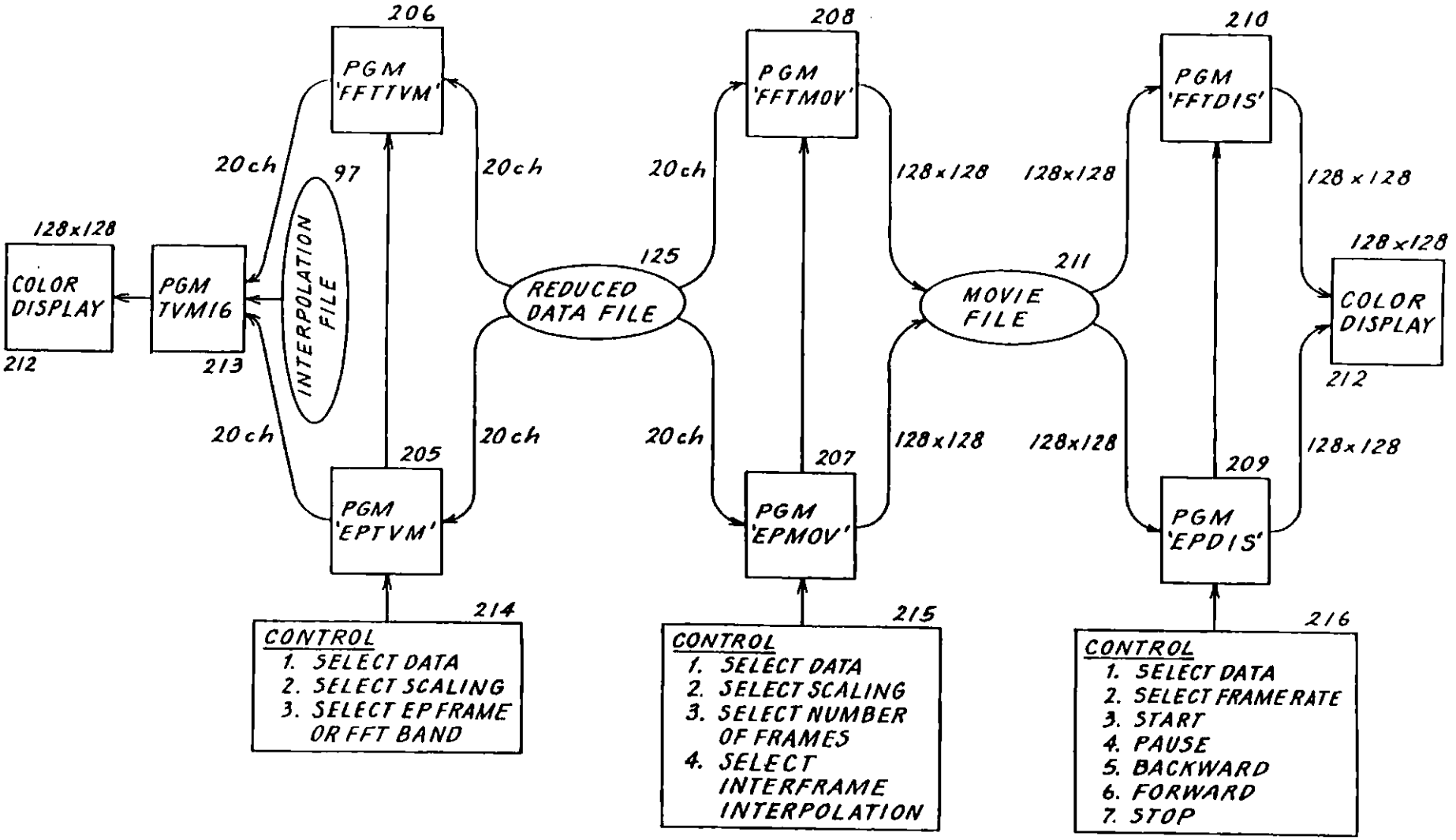

206
PGM 'FFTTVM'
208
PGM 'FFTMOV'
210
PGM 'FFTDIS'
20ch
97
INTERPOLATION FILE
20ch
20ch
128x128
128x128
128 x 128
128x128
COLOR DISPLAY
212
PGM TVM16
213
125
REDUCED DATA FILE
211
MOVIE FILE
COLOR DISPLAY
212
20ch
20ch
20ch
128x128
128x128
128x128
205
PGM 'EPTVM'
207
PGM 'EPMOV'
209
PGM 'EPDIS'
214
CONTROL
1. SELECT DATA
2. SELECT SCALING
3. SELECT EP FRAME OR FFT BAND
215
CONTROL
1. SELECT DATA
2. SELECT SCALING
3. SELECT NUMBER OF FRAMES
4. SELECT INTERFRAME INTERPOLATION
216
CONTROL
1. SELECT DATA
2. SELECT FRAME RATE
3. START
4. PAUSE
5. BACKWARD
6. FORWARD
7. STOP

Fig 21

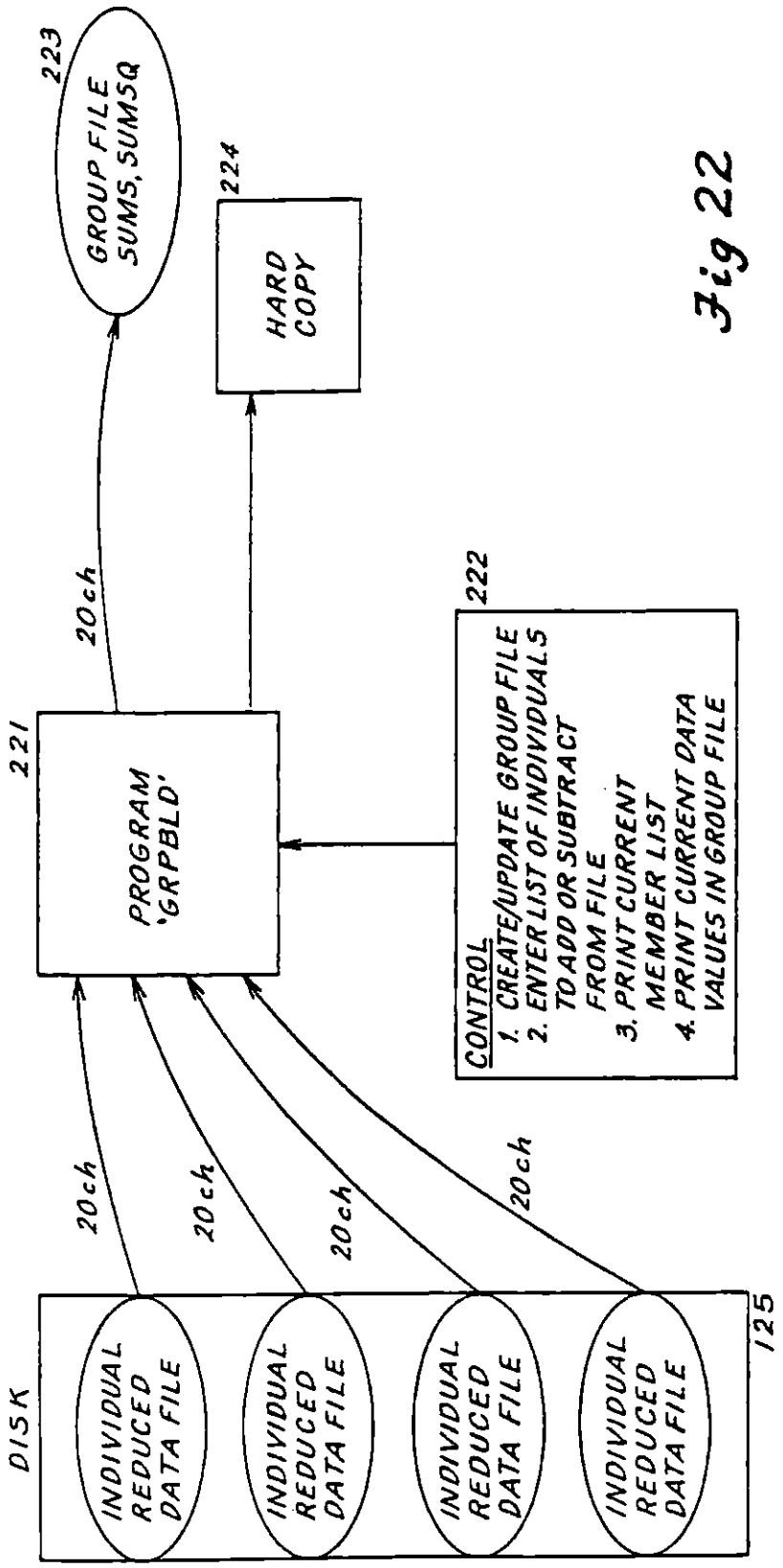

223
GROUP FILE
SUMS, SUMSQ
224
HARD
COPY
20ch
221
PROGRAM
'GRPBLD'
222
CONTROL
1. CREATE/UPDATE GROUP FILE
2. ENTER LIST OF INDIVIDUALS
TO ADD OR SUBTRACT
FROM FILE
3. PRINT CURRENT
MEMBER LIST
4. PRINT CURRENT DATA
VALUES IN GROUP FILE
20ch
20ch
20ch
20ch
DISK
INDIVIDUAL
REDUCED
DATA FILE
INDIVIDUAL
REDUCED
DATA FILE
INDIVIDUAL
REDUCED
DATA FILE
INDIVIDUAL
REDUCED
DATA FILE
125

Fig 22

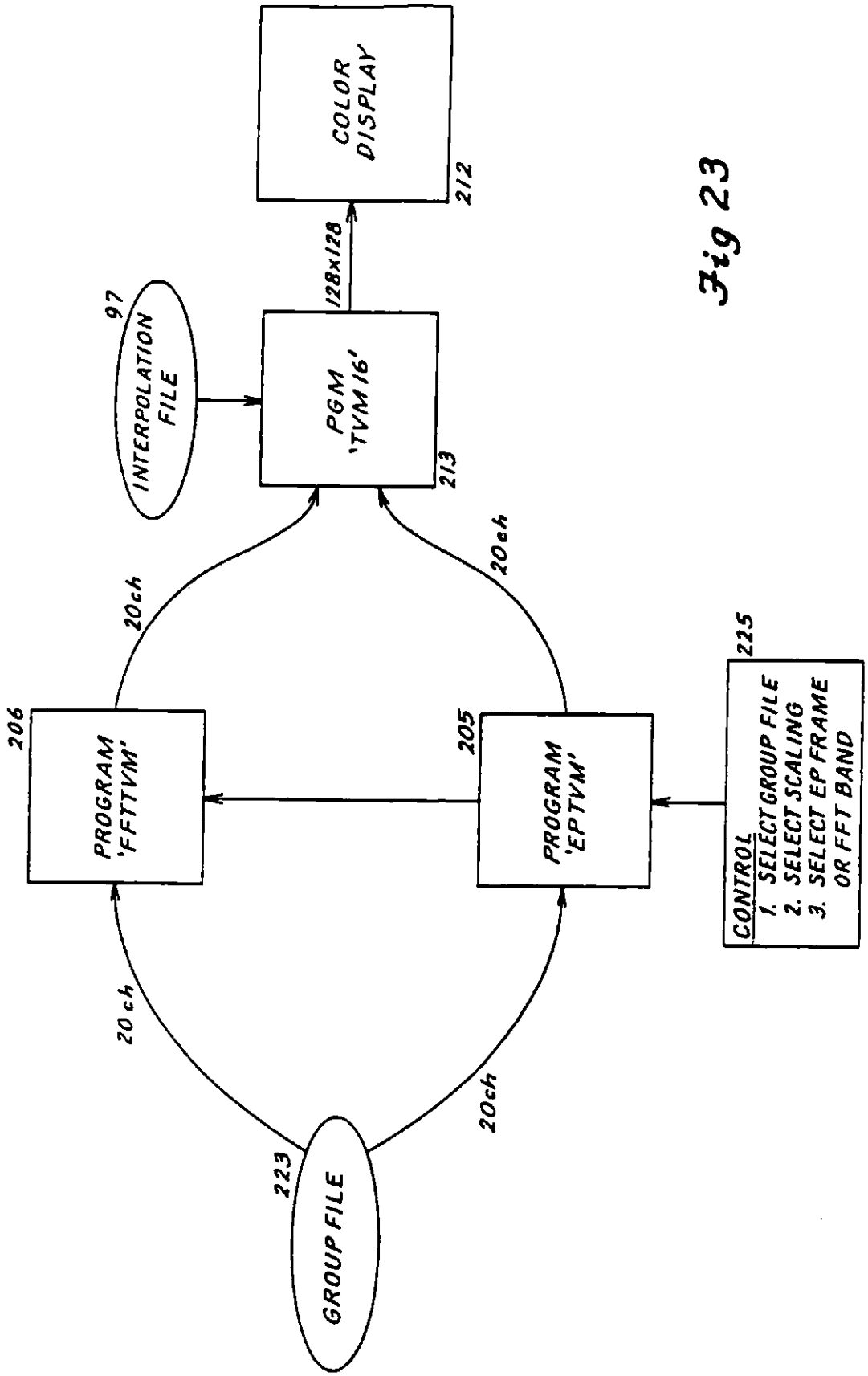

COLOR DISPLAY
212
128x128
PGM 'TVM16'
213
97
INTERPOLATION FILE
20ch
20ch
206
PROGRAM 'FFTTVM'
205
PROGRAM 'EPTVM'
225
CONTROL
1. SELECT GROUP FILE
2. SELECT SCALING
3. SELECT EP FRAME OR FFT BAND
20 ch
20ch
223
GROUP FILE

Fig 23

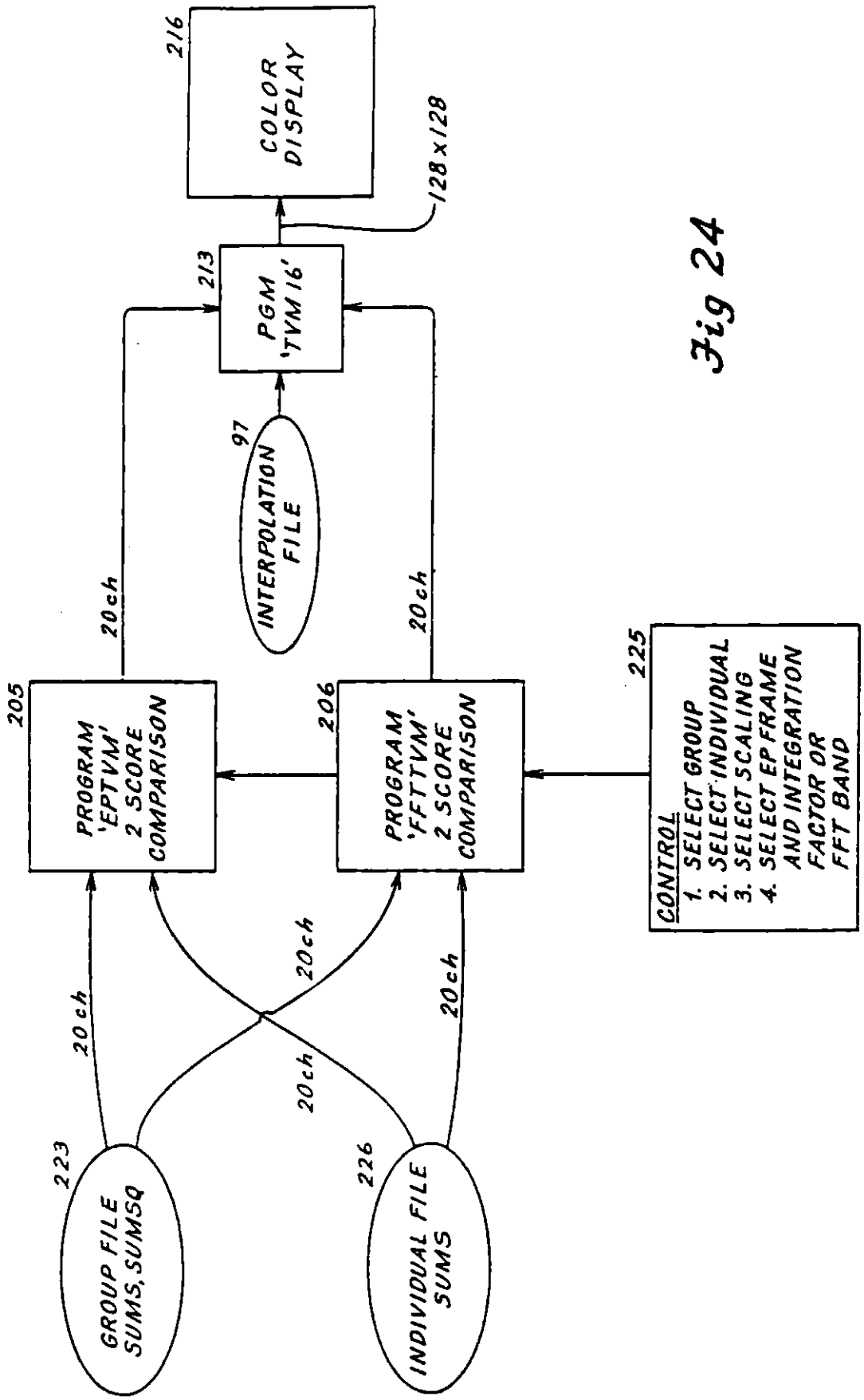

216
COLOR DISPLAY
128 x 128
213
PGM 'TVM16'
97
INTERPOLATION FILE
20ch
20ch
205
PROGRAM 'EPTVM' 2 SCORE COMPARISON
206
PROGRAM 'FFTTVM' 2 SCORE COMPARISON
225
CONTROL
1. SELECT GROUP
2. SELECT INDIVIDUAL
3. SELECT SCALING
4. SELECT EP FRAME AND INTEGRATION FACTOR OR FFT BAND
20ch
20ch
20ch
20ch
223
GROUP FILE SUMS, SUMSQ
226
INDIVIDUAL FILE SUMS

Fig 24

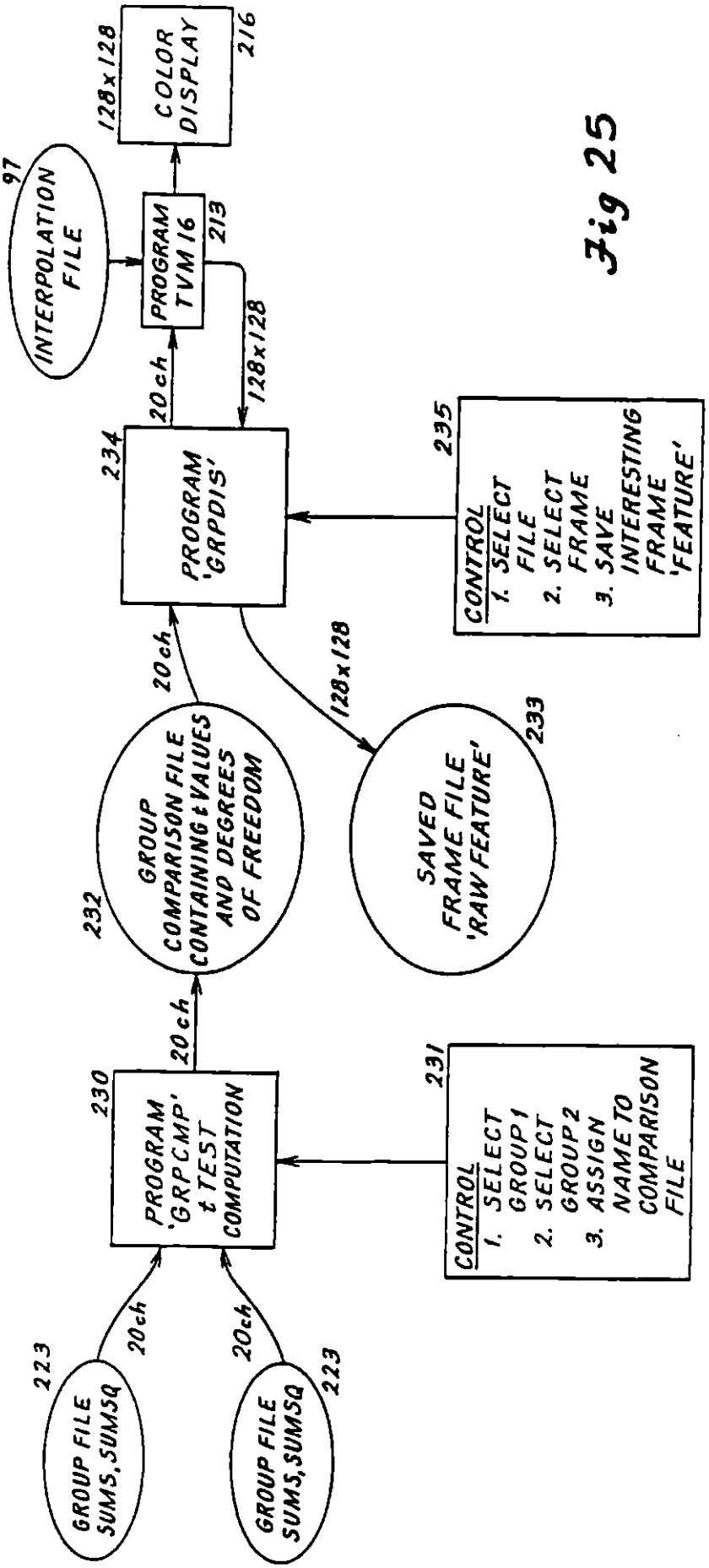

GROUP FILE SUMS, SUMSQ
223
20ch
GROUP FILE SUMS, SUMSQ
223
20ch
PROGRAM 'GRPCMP' t TEST COMPUTATION
230
CONTROL
1. SELECT GROUP 1
2. SELECT GROUP 2
3. ASSIGN NAME TO COMPARISON FILE
231
20ch
GROUP COMPARISON FILE CONTAINING t VALUES AND DEGREES OF FREEDOM
232
SAVED FRAME FILE 'RAW FEATURE'
233
20ch
128x128
PROGRAM 'GRPDIS'
234
CONTROL
1. SELECT FILE
2. SELECT FRAME
3. SAVE INTERESTING FRAME 'FEATURE'
235
20ch
128x128
PROGRAM TVM 16
213
INTERPOLATION FILE
97
128x128
COLOR DISPLAY
216

Fig 25

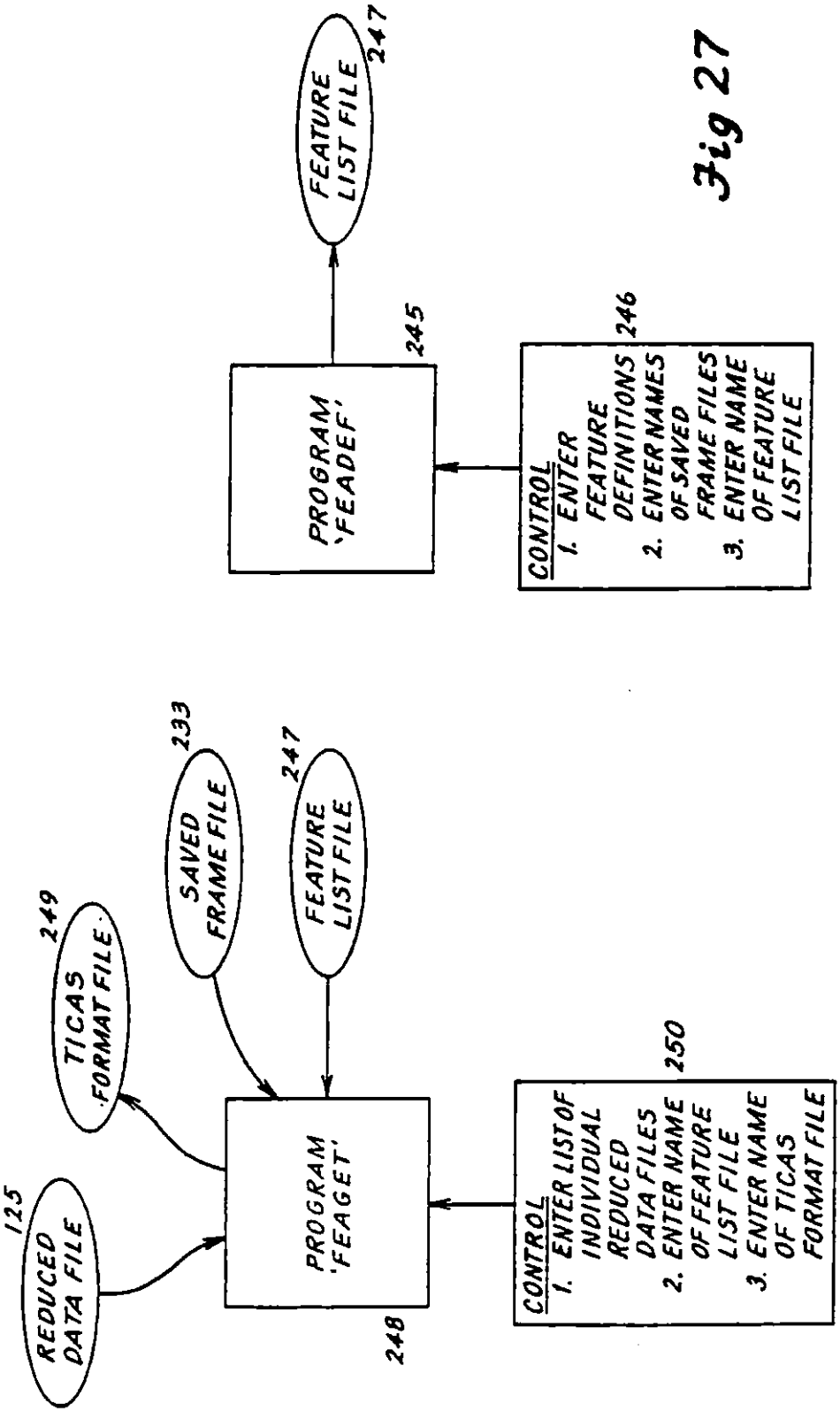

FEATURE LIST FILE
247
PROGRAM 'FEADEF'
245
CONTROL
1. ENTER FEATURE DEFINITIONS
2. ENTER NAMES OF SAVED FRAME FILES
3. ENTER NAME OF FEATURE LIST FILE
246
SAVED FRAME FILE
233
FEATURE LIST FILE
247
TICAS FORMAT FILE
249
REDUCED DATA FILE
125
PROGRAM 'FEAGET'
248
CONTROL
1. ENTER LIST OF INDIVIDUAL REDUCED DATA FILES
2. ENTER NAME OF FEATURE LIST FILE
3. ENTER NAME OF TICAS FORMAT FILE
250

Fig 27

57

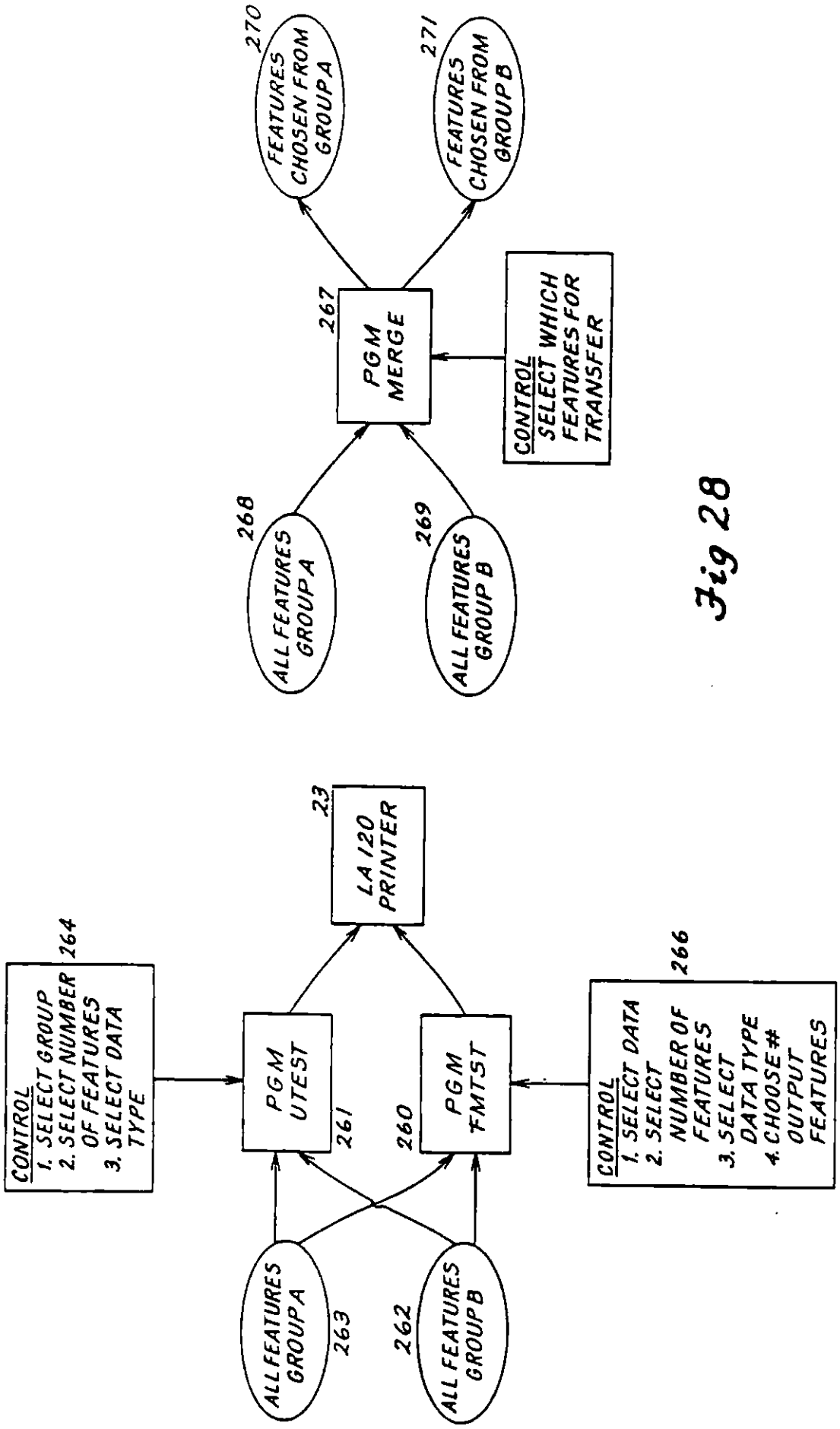

270
FEATURES CHOSEN FROM GROUP A
271
FEATURES CHOSEN FROM GROUP B
267
PGM MERGE
CONTROL
SELECT WHICH FEATURES FOR TRANSFER
268
ALL FEATURES GROUP A
269
ALL FEATURES GROUP B
23
LA 120 PRINTER
264
CONTROL
1. SELECT GROUP
2. SELECT NUMBER OF FEATURES
3. SELECT DATA TYPE
PGM UTEST
261
PGM FMTST
260
266
CONTROL
1. SELECT DATA
2. SELECT NUMBER OF FEATURES
3. SELECT DATA TYPE
4. CHOOSE # OUTPUT FEATURES
263
ALL FEATURES GROUP A
262
ALL FEATURES GROUP B

Fig 28

58

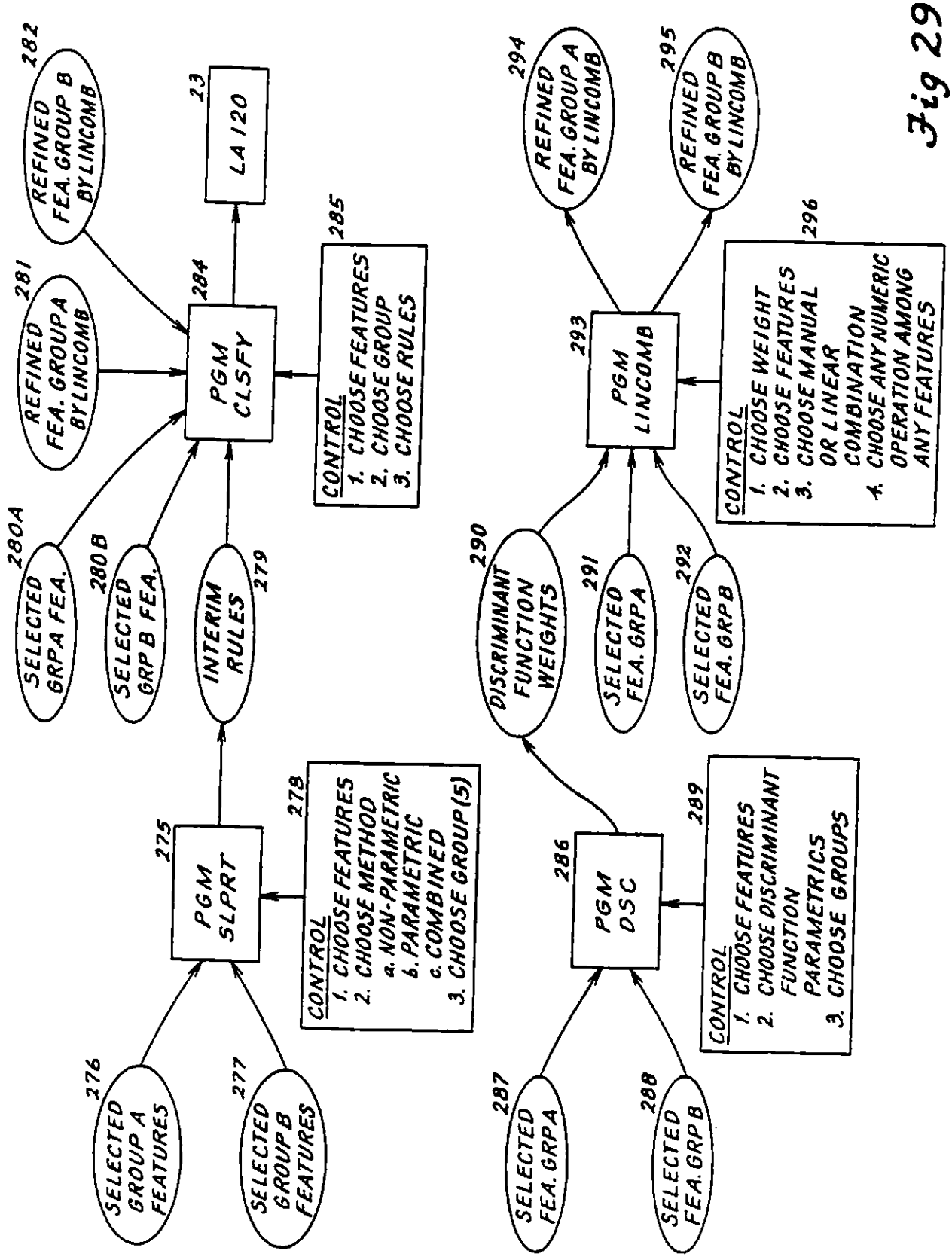

SELECTED GROUP A FEATURES
276
SELECTED GROUP B FEATURES
277
PGM SLPRT
275
CONTROL
1. CHOOSE FEATURES
2. CHOOSE METHOD
a. NON-PARAMETRIC
b. PARAMETRIC
c. COMBINED
3. CHOOSE GROUP (5)
278
INTERIM RULES
279
SELECTED GRP A FEA.
280A
SELECTED GRP B FEA.
280B
REFINED FEA. GROUP A BY LINCOMB
281
REFINED FEA. GROUP B BY LINCOMB
282
PGM CLSFY
284
LA 120
23
CONTROL
1. CHOOSE FEATURES
2. CHOOSE GROUP
3. CHOOSE RULES
285
SELECTED FEA. GRP A
287
SELECTED FEA. GRP B
288
PGM DSC
286
CONTROL
1. CHOOSE FEATURES
2. CHOOSE DISCRIMINANT FUNCTION PARAMETRICS
3. CHOOSE GROUPS
289
DISCRIMINANT FUNCTION WEIGHTS
290
SELECTED FEA. GRP A
291
SELECTED FEA. GRP B
292
PGM LINCOMB
293
CONTROL
1. CHOOSE WEIGHT
2. CHOOSE FEATURES
3. CHOOSE MANUAL OR LINEAR COMBINATION
4. CHOOSE ANY NUMERIC OPERATION AMONG ANY FEATURES
296
REFINED FEA. GROUP A BY LINCOMB
294
REFINED FEA. GROUP B BY LINCOMB
295

Fig 29

59

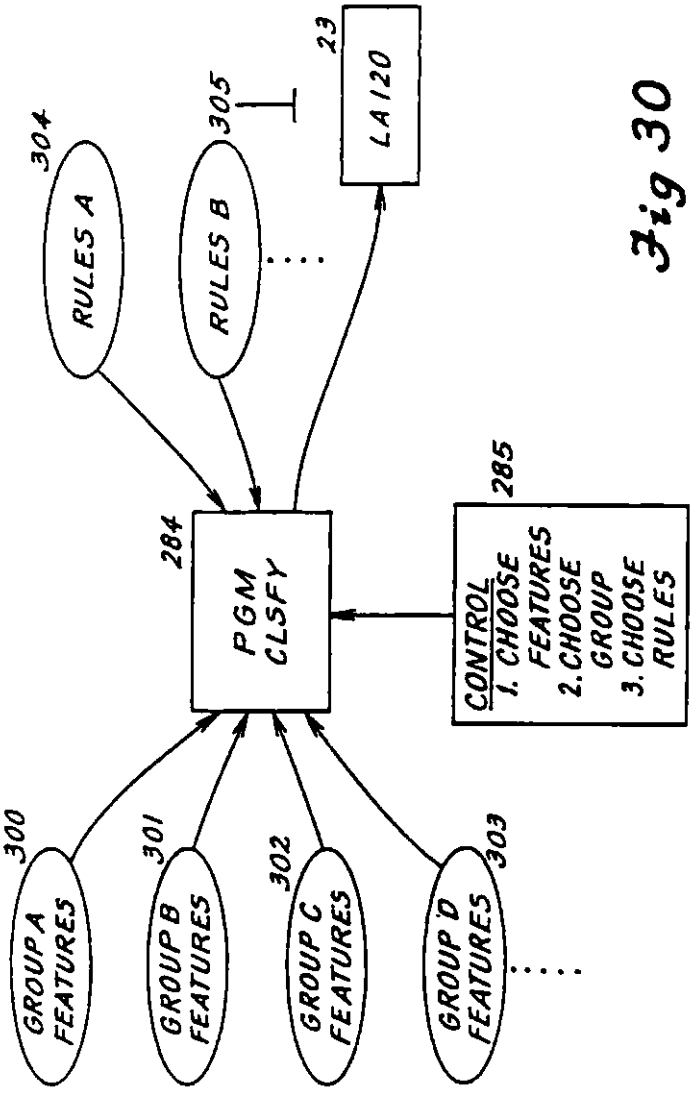

23
LA 120
304
RULES A
305
RULES B
284
PGM CLSFY
285
CONTROL
1. CHOOSE FEATURES
2. CHOOSE GROUP
3. CHOOSE RULES
300
GROUP A FEATURES
301
GROUP B FEATURES
302
GROUP C FEATURES
303
GROUP D FEATURES

Fig 30

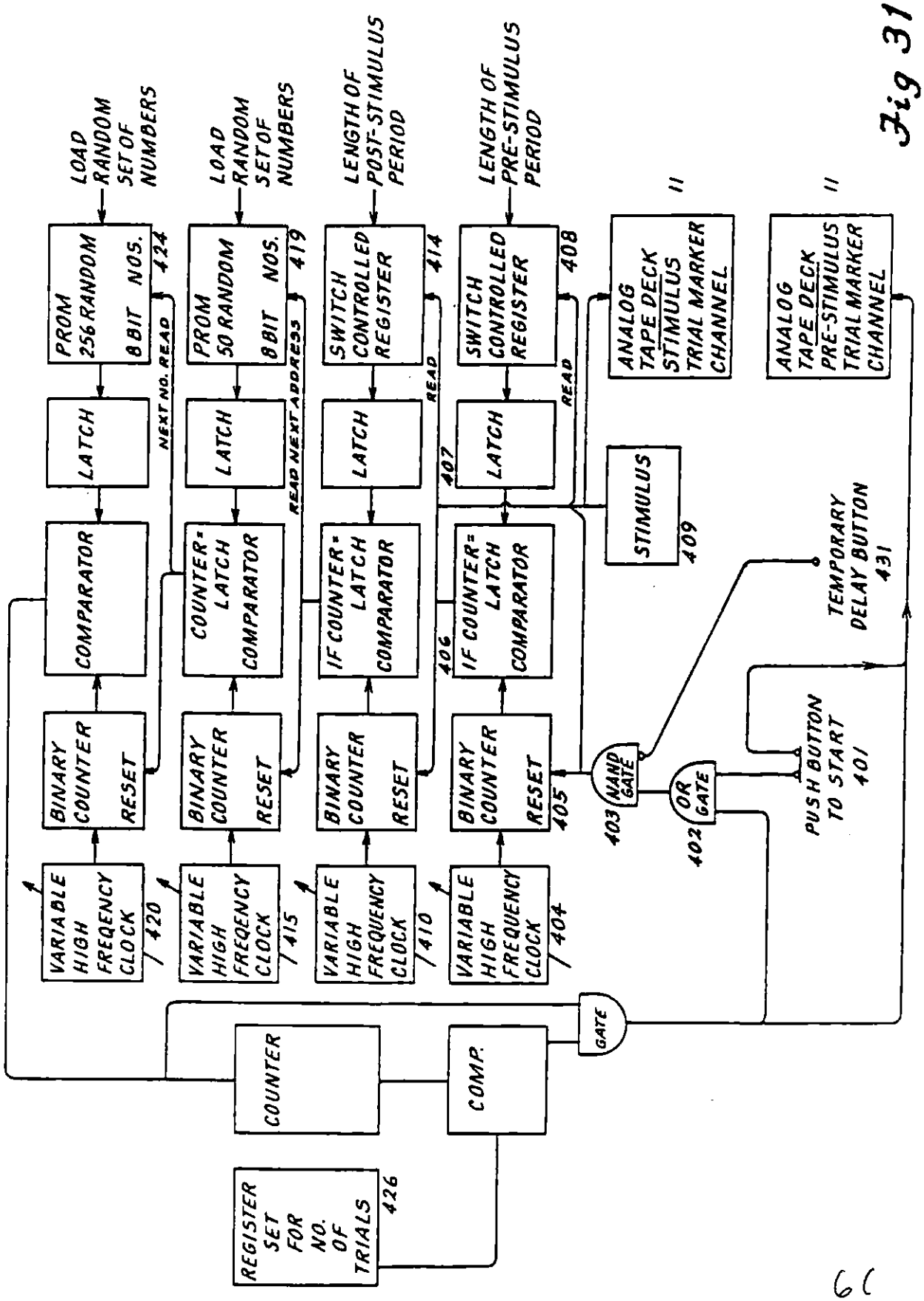

LOAD RANDOM SET OF NUMBERS
PROM 256 RANDOM 8 BIT NOS. 424
LATCH
COMPARATOR
BINARY COUNTER RESET
VARIABLE HIGH FREQENCY CLOCK 420
NEXT NO. READ
LOAD RANDOM SET OF NUMBERS
PROM 50 RANDOM 8 BIT NOS. 419
LATCH
COUNTER= LATCH COMPARATOR
BINARY COUNTER RESET
VARIABLE HIGH FREQENCY CLOCK 415
READ NEXT ADDRESS
LENGTH OF POST-STIMULUS PERIOD
SWITCH CONTROLLED REGISTER 414
LATCH
IF COUNTER= LATCH COMPARATOR
BINARY COUNTER RESET
VARIABLE HIGH FREQUENCY CLOCK 410
READ
LENGTH OF PRE-STIMULUS PERIOD
SWITCH CONTROLLED REGISTER 408
LATCH
IF COUNTER= LATCH COMPARATOR
BINARY COUNTER RESET
VARIABLE HIGH FREQUENCY CLOCK 404
READ
407
406
405
ANALOG TAPE DECK STIMULUS TRIAL MARKER CHANNEL
ANALOG TAPE DECK PRE-STIMULUS TRIAL MARKER CHANNEL
STIMULUS 409
TEMPORARY DELAY BUTTON 431
PUSH BUTTON TO START 401
403 NAND GATE
402 OR GATE
GATE
COUNTER
COMP.
REGISTER SET FOR NO. OF TRIALS 426

Fig 31

6(

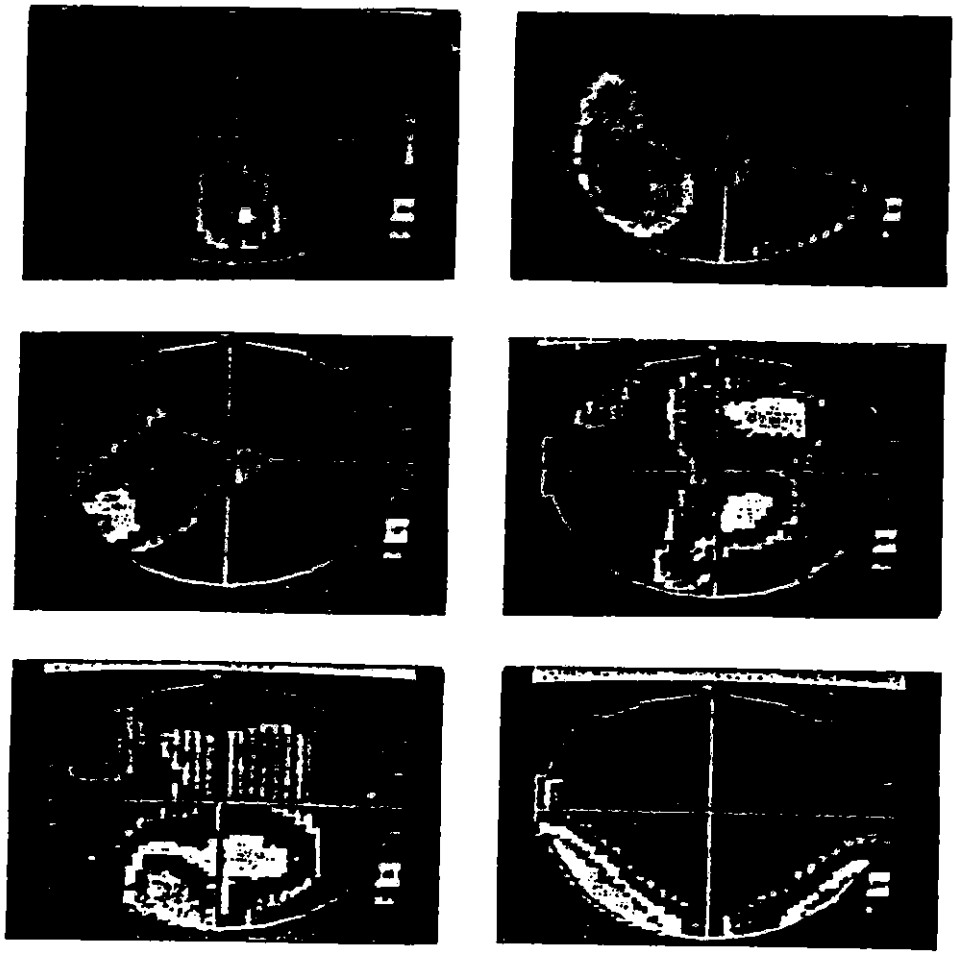


FIG. 32

BRAIN ELECTRICAL ACTIVITY MAPPING

The invention described herein was made in the course of work under a grant or award from the Department of Health and Human Services.

BACKGROUND OF THE INVENTION

This invention relates to analysis of brain electrical activity and diagnosis of brain disorders.

Traditional electro-encephalographic (EEG) techniques of analyzing brain electrical activity to diagnose brain dysfunction require the skilled neurophysiologist to observe and distinguish time and frequency related characteristics of many channels of voltage waveforms derived from an individual's brain and to determine, largely from memory, differences between that individual's waveforms and waveforms characteristic of a normalized population. The process necessarily fails to take account of many subtle but potentially useful pieces of information contained in the analyzed data.

Signal averaged sensory evoked potential (EP) transient responses have also been used as a source for brain electrical activity analysis, but large amounts of useful information contained in such transient response waveforms have traditionally been disregarded because of the difficulty of visualizing the inter-relationship over time of many channels of such information.

SUMMARY OF THE INVENTION

The invention features, in one aspect, displaying time sequences of topographic maps at a variable frame rate. In preferred embodiments, the rate can be selected to display protions of the EP response immediately following the stimulus at a slower rate than later portions; and in preferred embodiments the rate can be varied logarithmically. The variation of display rate permits the operator to give more emphasis to matrices which contain relatively more information, such as the earlier EP response matrices.

In another aspect, the invention features generating topographic displays of information on electrical activity of the brain produced at a plurality of transducers on the skull; generating a time sequence of matrices of electrical activity at successive points in time sufficient in number to capture the onset of a rapid transient event; and displaying the matrices as topographic maps in time sequence at a variable rate. In preferred embodiments, the processor is capable of generating 200 or more matrices for each second of real time. The ability to capture a large number of matrices in a short period of time permits the observation of short-term events such as epileptic spikes.

In another aspect, the invention features generating topographic displays of information on brain electrical activity produced at a plurality of skull transducers; storing the electrical activity of such transducers for two different brain conditions; generating matrices of elements representing electrical activity in the two conditions; forming a difference matrix between corresponding elements of the two matrices; and displaying the difference matrix as a topographic map. In preferred embodiments, the two brain conditions are attained by the use of a patterned light stimulus and a non-patterned light stimulus. The ability to form and display difference matrix enables the operator to identify parts of the brain involved in particular brain states or evoked responses.

In another aspect, the invention features generating topographic displays of information on brain electrical activity produced at a plurality of skull transducers; repeatedly triggering EP responses at the transducers, including pre-stimulus and post-stimulus responses; averaging the responses; setting as a baseline the mean level of the pre-stimulus response; generating matrices from such responses; and displaying topographic maps of the matrices. In preferred embodiments the time of occurrence of each stimulus is stored and the response is divided into pre-stimulus and post-stimulus periods; the matrices generated are a set of time-sequenced frames during the response and are displayed as a sequence of topographic maps; the sequence can be displayed as an endless sequence of maps; the averaging process can be performed using digital words added into summing buffers; and the sampling, storing, response averaging, baseline calculation and subtraction can all be performed digitally; averaging of the pre-stimulus baseline can exclude selected portions of the response; the response can be reviewed to determine the appropriateness of the baseline; there can be calculated the V_{RMS} of the average pre-stimulus and post-stimulus responses and the V_{RMS} can be displayed with the responses, so that the user can determine whether the noise level for any transducer is unacceptably large; the operator can manually adjust the baseline up or down; high-frequency components can be filtered from the post-stimulus response by multipoint interpolation; and the baseline calculation can be repeated until the results are satisfactory. In general, these various features permit the operator to assemble, modify and adjust to an accurate zero level a set of EP responses so that the ultimate topographic display will be accurate and useful. The display of a time-sequence of frames permits the operator to visualize the movement of brain activity in the course of an EP response over the skull. The proper setting at the baseline improves the utility of each response when used in a topographic display, since the relative levels of response at different transducers is more accurately portrayed.

In another aspect, the invention features filtering to remove from the EEG responses frequency components outside the prominent frequency bands of electrical activity; determining, for each transducer, the Fourier transforms and the spectral energy in selected frequency bands, during a period when the brain activity remains in the same state; and processing the results into display matrices for the selected frequency bands. In preferred embodiments, the brain activity can be sampled, stored and Fourier transformed digitally; the filters can remove frequency components below 0.5 Hz and about 50 Hz; the samples can be taken at least 3 times as frequently as the highest frequency in the prominent frequency bands, and particularly at 4 to 5 times that highest frequency; the Fourier analysis can be limited to a period between marked starting and stopping points; the period during which electrical activity is sampled can be limited to avoid interruptions in the subject's brain state, and particularly can be limited to two second sampling periods; the number of samples can be between 20 and 2000; and the frequency bands analyzed can comprise the alpha, beta, delta and theta bands. Removal of irrelevant frequency bands, sampling at high rate, and limiting the sampling period all enable the operator to obtain accurate spectral analyses with minimum interference. The ability to analyze specific frequency bands of interest enables the operator to

review information which effectively corresponds to the electrical activity of the brain in various states.

In another aspect, the invention also features generating a statistical comparison matrix from two matrices, each element of the statistical comparison matrix representing a statistical difference between the corresponding elements in the two matrices; and displaying the statistical comparison matrix as a topographic map. In preferred embodiments, the statistical comparison matrix can be interpolated into a display matrix having additional display points; the statistical comparison can be made between two expanded matrices rather than between two unexpanded matrices; the statistical comparison can be a t-statistic analysis, or a z-statistic analysis; and quantitative features useful for diagnosis can be determined from regions of the maps. The ability to perform and topographically display statistical differences between groups and between an individual and a group offers a versatile and effective tool for visualizing brain areas which are connected to particular brain dysfunctions or to particular brain activities, and for neurophysiological diagnosis and research.

In another aspect, the invention also features generating a coefficient-of-variance matrix, each element of which represents the normalized standard deviation at one skull location; and displaying the coefficient-of-variance as a topographic map.

In another aspect, the invention also features temporally interpolating matrices which represent the response at time instants between other matrices; and displaying said interpolated matrices. The temporal interpolation provides a smoother visual transition between the original frames when a time-sequenced display is presented.

In another aspect, the invention also features previewing waveforms and tagging a waveform to indicate whether it should be used in later processing, eliminating a response from further processing, automatically eliminating a response from further processing if a portion of the response exceeds a predetermined threshhold, smoothing a response by eliminating undesired high-frequency components, for adjusting the zero baseline of a response, eliminating selected portions of a response from further processing, and displaying in numerical form the value of a response at a point in time selected by the operator. These waveform quality control procedures enable the operator to improve the quality and accuracy of the topographic displays.

In another aspect, the invention features generating a topographic display of information on the electrical activity produced at a plurality of skull transducers; sampling and storing the information as a series of matrices; viewing the data as a waveform; adjusting or eliminating portions of the data, processing the matrices into processed matrices; interpolating to expand the matrices for viewing; and displaying the matrices as topographic maps in a grey tone scale. In preferred embodiments, the data matrices, processed matrices and expanded matrices can be tagged and stored for later recall and processing; and the data matrix elements can be calibrated to stored calibration signals by calculating a DC offset and gain component for each transducer. The ability to store display matrices for later use enables the operator to accumulate a series of significant matrices derived from diagnostic or research work. The calibration assures that the topographic displays will be accurate.

In another aspect, the invention features generating a topographic display of electrical activity of the brain produced from a plurality of electrical transducers on the skull; generating matrices of elements representing the electrical activity at different points; using a video monitor to display said matrices, each element of which is represented by a discrete point having a gray tone of color lying within a range of gray tones; and scaling the elements to the tones. In preferred embodiments, scaling can be performed so that all elements are linearly interpolated between the maximum gray tone and the minimum gray tone, or between the maximum gray tone and a "zero" gray tone, or to an operator supplied gray one, or so that certain display elements are excluded from the scaling, or that elements falling outside the available gray tone range are assigned to the closest gray tone; the gray tones can be generated in two colors, which can be complementary colors, representing values on either side of a zero tone, the zero tone being an absence of color; the scaling can be performed either on a matrix by matrix basis, or for all matrices taken together; the data which forms the input to the scaling operation can be previewed to by selected lab for exclusion from the scaling operation. The ability to scale the display data to a range of gray tones in a variety of ways improves the utility and visual effect of the display. The variety of scaling options is suitable for the variety of data which may be displayed. The ability to eliminate very large values from the scaling operation assures the most effective scaling for a given set of data.

In another aspect, the invention features normalizing display matrix elements to a selected value which can be assigned to a selected gray tone for purposes of scaling. In preferred embodiments, the normalization can be to a matrix element representing a particular vertex transducer on the skull, or to the root mean square value of the background activity at the transducer being normalized, or to the average root mean square value of the background activity at all skull locations; normalization can be done in connection with apparatus for topographically displaying a sequence of matrices representing averaged EP responses to repeatedly provided stimuli; normalization can be done in connection with apparatus for displaying spectral band matrices derived by Fourier transform analysis of the electrical activity, the normalization being of each element of each spectral band to the total spectral energy at the corresponding transducer on the average total spectral energy at all transducers. The ability to normalize display elements improves the operator's ability to compare different sets of data by normalizing them to the same value.

In preferred embodiments, the invention features interpolating to form additional matrix elements between the transducer points; the interpolation can be three-point interpolation, particularly three-point linear interpolation to the values of the three closest transducers; the number of transducers can be in the range of 10 to 200; and the number of picture elements is at least 5 times the number of transducers. The expansion of a matrix of a small number of points to a display matrix of a large number of points significantly improves the smoothness, readability and utility of the resulting topographic displays.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of the BEAM system.

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FIG. 2 is a representation of the organization of samples of data in the brain electrical activity mapping system.

FIG. 3 is a representation of the formation of a topographic display from a frame of data in the brain electrical activity mapping system.

FIG. 4 is a block diagram of the functions performed by the BEAM system.

FIG. 5 is block diagram of the define protocols operation.

FIG. 6 is a block diagram of the disk data sampling operation.

FIG. 7 is a data file format diagram of the raw data file.

FIG. 8 is a block diagram of the core averaging operation.

FIG. 9 is a graph of an average EP transient response waveform after automatic baseline zeroing.

FIG. 10 is a block diagram of the raw data quality control operation.

FIG. 11 is a block diagram of the raw data topographic display operation.

FIG. 12 is a block diagram of the create interpolation file operation.

FIG. 13 is a block diagram of the raw data reduction operation.

FIG. 14 is a data file format diagram of signal averaged EP data.

FIG. 15 is a data file format diagram of FFT ensemble data.

FIG. 16 is a data file format diagram of individual FFT data.

FIG. 17 is a data file format diagram of an EP file.

FIG. 18 is a data file format diagram of an FFT file.

FIG. 19 is a block diagram of the reduced data quality control operation.

FIG. 20 is a graph of an average EP transient response waveform after automatic baseline zeroing and after manual baseline readjustment.

FIG. 21 is a block diagram of the reduced data topographic operation

FIG. 22 is a block diagram of the group file production operation.

FIG. 23 is a block diagram of the group topographic display operation.

FIG. 24 is a block diagram of the individual vs. group comparison operation.

FIG. 25 is a block diagram of the group difference detection and feature selection operation.

FIG. 26 is a data file format diagram of a saved frame file.

FIG. 27 is a block diagram of the brain electrical activity mapping to TICAS file transfer operation.

FIG. 28 is a block diagram of the TICAS feature selection and evaluation operation.

FIG. 29 is a block diagram of TICAS generate decision rules operation.

FIG. 30 is a block diagram of TICAs test decision rules operation.

FIG. 31 is a block diagram of pseudorandom stimulus controller.

FIG. 32 is a sample of topographic displays generated by a brain electrical activity mapping system.

DESCRIPTION OF THE PREFERRED EMBODIMENT

We now turn to a description of the preferred embodiment.

System Organization and Software

FIG. 1 illustrates the components of a brain electrical activity mapping system. Twenty electrodes 5 (e.g., Grass gold cup) are attached to subject's skull 4 in a conventional international 10–20 format. Twenty leads 6 from electrodes 5 are connected through switch 7 to conventional 24-channel polygraph 10 (e.g., Grass 8-24D), which contains parallel variable gain differential amplifiers and strip chart recorders. Calibration signal source 8, an A.C. generator, is also connected through switch 7 to polygraph 10. Stimulus A 2 (e.g., Grass Model PS1 strobe light) and stimulus B 3 (e.g., click generator) present stimuli to the subject under the control of pseudorandom stimulus controller 9, which also provides pre-stimulus and stimulus trial marker signals (5 volt spikes) of opposite polarity to one of the input channels to 24-channel FM analog tape recorder 11 (e.g., Honeywell 5600E). In other embodiments, recorder 11 is eliminated and polygraph 10 is connected directly to filter 12 for real-time loading of data. The 21 active outputs of recorder 11 are connected to the inputs of 21 parallel variable band pass filters 12 (e.g., Butterworth filters; EEG Associates Mark 4×24) having variable gain controls. The 21 outputs of filters 12 are connected to 21 of the input terminals of two 16-channel, 12-bit analog-to-digital converters 15, 16 (Digital Equipment Corporation AA-11K), which comprise part of digital computer 13 (Digital Equipment Corporation PDP 11/60). Analog-to-digital converters 15, 16 are attached to data bus 14 (Digital Equipment Corporation Unibus). Also attached to data bus 14 are 4-channel, 12-bit digital-to-analog converter 17 (Digital Equipment Corporation AD-11K) whose three outputs control black and white television monitor 18 (Digital Equipment Corporation VR 17) for waveform displays; color display control 19 (Digital Equipment Corporation VSV 01) whose three outputs control 12" color television monitor 20 (CONRAC) for topographic displays; 8 serial line controller 24 (Digital Equipment Corporation DZ 11) two outputs of which control interactive keyboard and video character display terminal 22 (Digital Equipment Corporation VT 100) and printer 23 (Digital Equipment Corporation LA 120); 256K byte memory 24 containing operating system software 27 (Digital Equipment Corporation RSX 11/M), BEAM software 28 (Agrippa Data Systems), and analytic software 29 (TICAS; University of Arizona); floating point processor 25 (Digital Equipment Corporation FPP-11); central processing unit 26 (Digital Equipment Corporation PDP 11/60); and disk controller 27 controlling at least one disk drive 28.

Software Description

In general, the brain electrical activity mapping system creates color topographic displays reflecting brain electrical activity using, as input, continuous electrical waveforms recorded from a number of points on the skull. The color topographic displays consist of discrete matrices of a large number of display points (also called pixels), each of which has a color or intensity or other visible characteristic which indicates a certain value or values at the location of that point analogous to a point on the skull. In order to generate discrete topographic display matrices having many thousands of display points from continuous analog waveforms at a limited, e.g. 20, number of points on the skull, the brain electrical activity mapping system, as illustrated in FIG. 2,

converts the data to digital form and generates discrete sample frames 40, each sample or frame initially comprising 20 recorded values 41 from 20 channels of information. The system treats related groups of samples 40 as segments 42. In the case of EP data, for example, a segment would consist of a series of frames or samples, each 4 milliseconds in length, the series together representing one transient response sequence from the beginning of a pre-stimulus period to the end of the post-stimulus transient response. In the case of steady-state EEG data, a segment would consist of 2 seconds of data divided into 256 samples. A spectral analysis of the EEG data then produces 256 samples, each of which reflects the energy level in a small, e.g. ½ Hz, energy band and a segment consists of the entire series of 256 spectral samples. For signal averaging purposes, the system considers a set of segments together, e.g., 500 segments each representing a transient response to a given stimulus. The 500 segments taken together are known as an ensemble 43. Frames of data can be raw data or data which has been processed or transformed by the system. In any case, as illustrated in FIG. 3, when a frame 40 is to be displayed it is expanded into a matrix 45 consisting of a large number of display points 46 which are determined by an interpolation process from the original frame data points 47. Each point of the matrix is then converted to a visual display point 47 which forms part of the final topographic display 48.

FIG. 4 illustrates the organization of the operations which comprise brain electrical activity mapping software 28 and TICAS analytic software 29. Raw and processed data is stored in disk files 51. Operations 52–65 and 67–69 use data stored in files 51 to perform data manipulation, data display and data storage functions. Operations 54 and 55 also process data from the outputs of converters 15, 16.

FIG. 5 illustrates the function of define protocols operation 53. Protocol files 73 are generated and edited by program 'SETPAR' 71 based on control information 70 provided by the operator through terminal 22, the results of the operation being displayed (block 72) on terminal 22 to the operator. Each protocol file 73 contains information which governs the manner in which other operations are performed on a particular type of data file (e.g., one protocol might apply to the processing of EP transient response data from strobe light stimuli). The protocol information may include the number and identity of input channels, the labeling of the output channels to correspond to specific points on the final display, the identity of the trial marker channel, the voltage level above which to search for the trial markers, the rate in samples per second of sampling of the data, the number of samples in a segment, the number of segments in an ensemble, the number of ensembles, the number of points in a baseline, the microvolt level of the calibration signal (e.g., 100 microvolts at 10 Hz), a multiplication factor, the number (up to 20) and size (width) of integration bands, the label of the protocol, the percent of taper of samples in a segment of data for fast fourier transform processing, the number of automatic smoothing passes, the high and low values for automatic rejection of data during accumulation, the stimulus interval and location in seconds, and channel labels related to electrode positions on the skull.

FIG. 6 illustrates the function of disk data sampling operation 54. Program 'DATCOL' 75 loads raw data from the output of converters 15, 16 into raw data file 79, which is divided into 19 buffers 80 which hold ensembles of data related to particular brain states or stimuli. The operator provides control information 76 designating the patient to whom the data relates and the name of the applicable protocol file 73. Other control information 76 governs the beginning, end, and pauses in data sampling, and the performance of a calibration of signal levels. Calibration data is initially stored in a buffer 80 of raw data file 79. When the operator requests (block 76) a calibration, and designates which buffer 80 contains the raw calibration data, program 'DATCOL' computes the root mean square value and the mean of at least 30,000 points in each channel of calibration data and divides the root mean square value by 0.707 to establish the assumed peak value of the calibration signal. The peak value, representing the level of the original calibration voltage, and the mean value, representing the D.C. offset of the calibration voltage value for each channel, are stored in calibration file 78.

The format of raw data as stored in raw data file 79 is illustrated in FIG. 7. Each buffer 80 contains header block 81, having protocol and other housekeeping information concerning the data stored in the buffer; calibration block 82 containing for each channel of data the calibration value in microvolts per bit and the number of microvolts by which the calibration signal was offset from zero both of which values were found in calibration file 78 at the time raw data was loaded; bad segment block 83 identifying segments of data which the operator will later decide to exclude from subsequent operations; an unused segment 84; and a series of data segments 85, which hold a series of data samples, each containing values for all 20 channels. The data segments 85 are interleaved with no gaps.

FIG. 8 illustrates the function of core averaging operation 55, usually usef for loading and signal averaging raw EP transient responses. Data from converters 15, 16 is read by program 'CORAVG' 86. User provided control information 88 designates the protocol, obtained from protcol file 73, under which the operation is performed, and determines start, end, and pauses of the operation. Program 'CORAVG' 86 samples data beginning at points labeled by the prerecorded trial markers and forms signal averaged EP transient responses from a series of transient responses resulting from repetition of a stimulus. The series of transient response data are accumulated and held in EP file 87, which is a reduced data file as described below. Calibration file 78 holds calibration information accumulated from the data channels in the manner previously described. Program 'CORAVG' 86 automatically rejects as "bad data" any segment which contains values outside of preset limits. Program 'CORAVG' also automatically adjusts the zero baseline with respect to each electrode's average EP transiet response, by subtracting the mean of the pre-stimulus period values for a channel from each point in that channel's transient response curve.

FIG. 9 illustrates a plot of an average EP transient response 90 of microvoltage against time as it could be displayed on monitor 18 following core averaging operation 55. The stimulus was presented at time 93, the transient response includes pre-stimulus period between time 92 and time 93, and the plot shows calculated zero baseline 91.

FIG. 10 illustrates the function of raw data quality control operation 56, which enables the operator interactively to review and eliminate bad segments of raw data before other operations are performed. By means

of control information 94 the operator can select for review the contents of any buffer 80 in raw data file 79. The buffer data is displayed (block 105) segment by segment by program 'GLITCH' 95 on television monitor 18 to the operator as an analog waveform. The operator can label any segment of bad data, which causes the bad data segment to be identified on bad segment block 83. Control information 94 can also include the insertion of trial markers indicating a point on a waveform at which subsequent operations should begin, and display to the operator the microvolt value of individual points on a displayed curve.

FIG. 11 illustrates raw data topographic display operation 57, which provides topographic time sequenced displays (cartoons) of raw data frames. Program 'RAWMOV' 96 expands the 20 channels of each data frame into a matrix of 128×128 data points by three-point linear interpolation. The operator provides control information 102 designating the disk buffer 80 on raw data file 79 which contains the data to be displayed; the number of display matrices to be produced; the parameters for interframe interpolation; and the parameters and options (described below) for scaling the data points among the available grey color tones of the display. Program 'RAWMOV' 96 calculates each interpolated data point for the display matrix using three-point linear interpolation from the three closest original channels and scales the data to the available grey color tones of the display. The interpolation is performed using preset coefficients stored in interpolation file 97 by an operation described below.

The display matrices produced by program 'RAWMOV' 96 are stored in sequence in disk movie file 98. Program 'RAWDIS' will display (block 101) the frames stored in disk movie file 98 on monitor 20. Control information 100 permits the operator to designate the file to be displayed, the frame rate, and the starting, stopping and reversing of the display sequence. The displays include labels of information taken from the protocol block, e.g., patient identification.

FIG. 12 illustrates the functions of create interpolation file operation 52. Program 'POINTS' 110 creates points file 115 reflecting the X and Y coordinates of each point in the original electrode layout with respect to the 128×128 grid and associating with each point in the 128×128 display matrix the identity of the three original electrode points with respect to which it should be interpolated. Control information 120 provided by the operator includes the X and Y coordinates of each channel and the identity of the three interpolation points for each display point. Program 'OUTLINE' 111 identifies and stores in outline file 116 the X and Y coordinates of the points which outline the plan view of the skull to be included in the display, based on control information 121. Program 'MAKCOF' 112 generates and stores in coefficient file 117 the coefficients needed to perform the three-point linear interpolation for each matrix display point within the skull outline, using points file 115 and outline file 116 as input. Program 'MAKOVR' 113 stores in overlay file 118 the operator provided (block 123) coordinates of the overlay of the skull, nose and ears outline for the display. Program 'SETOVR' 114 generates interpolation file 119 from overlay file 118 and coefficient file 117. Interpolation file 119 then contains the information required to compute interpolated matrix data points and the skull overlay for display.

FIG. 13 illustrates the function of the raw data reduction operation 58. Three alternative programs can operate on data in buffers 80 to produce reduced data files 125. Program 'DSKFFT' 126 accepts segments of EEG data from raw data file 79, performs a fast fourier transform analysis which produces a new segment of data reflecting the spectral energy in each of a sequence of frequency bands. Program 'DSKFFT' 126 also generates, for each group of segments, an ensemble consisting of the sums (used in a later step to form the average values) and sums squared (used in a later step to form the standard deviations) for each channel across all segments in the group, values reflecting each of the sums as a percentage of the total spectral energy in the segment, and values reflecting the coefficient of variation (the standard deviation divided by the mean) for each channel across an ensemble. FIG. 15 illustrates the format of the resulting ensemble of FFT data stored in reduced data file 125. The sums data 130 is filed in sequence by channel for the first frequency band 131, e.g., 0.5 Hz. Similar sums data follows for the other frequency bands. After all sums data is stored, the sums squared data 132, the normalized power spectral density sums, and the coefficient of variation data are stored in similar fashion. In addition to storing the sums and sums squared data for all segments in the ensemble, program 'DSKFFT' can store spectral information for each segment analyzed. As illustrated in FIG. 16, the data is stored as sine and cosine coefficients for each channel for each frequency band, and as normalized sine and cosine coefficients as a percentage of total spectral energy. As illustrated in FIG. 18, the FFt data file 191 stored on reduced data file 125 also includes a header block 192 housekeeping information.

In FIG. 13, program 'DSKAVG' 127 performs a function similar to core averaging operation 55 in signal averaging EP transient response waveforms, but uses as input raw data stored in raw data file 79 and permits the operator to review each waveform and select those to be used in the averaging process, rejecting others. Program 'MANAVG' 128 permits a similar operator-assisted signal averaging process when the raw data does no contain preset stimulus trial markers, requiring the operator to indicate the point at which averaging is to begin for each waveform. FIG. 14 illustrates the format of signal averaged data produced by programs 'CORAVG' 86, 'DSKAVG' 127 and 'MANAVG' 128. The sums of each channel for all trials for the first time frame 133, e.g., 0–4 milliseconds, are loaded in order, followed by similar information with respect to all subsequent time frames for a given segment. As illustrated in FIG. 17, such EP files 190 are preceded by header block 193.

FIG. 19 illustrates the function of reduced data quality control operation 59, which permits the operator interactively to review and modify data in reduced data file 125. By providing control information 204, the operator can select the file to be reviewed and indicate whether it contains FFT spectral information or EP time-sequenced information. For FFT information, program 'FFTLUK' 201 displays (block 202)selected channels of spectral data as frequency-voltage curves on monitor 18 and permits the operator to low-pass filter the waveforms and display the value of particular data points. For EP data, program 'EPLUK' 203 displays (block 202) selected channels as time-voltage curves and permits the operator to reset the zero baseline, to filter high frequency noise from a channel, and

to display the value of any point on a curve. FIG. 20 illustrates the function of manual baseline relocation. Because pre-stimulus period response 180 was not level, automatic baseline 176 set by program 'CORAVG' 86 inaccurately reflects the true zero level for transient response curve 175. The operator can relocate the baseline to a new level 177 by moving cursor 179 to the desired level, causing that voltage value to be subtracted from each point of data along curves 180 and 175.

FIG. 21 illustrates the functions of reduced data topographic display operation 60. For single frame display of FFt data, program 'FFTTVM' 206 reads data from reduced data file 125 as selected by operator control information 214. The data is scaled in accordance with instructions included in control information 214. The selected frame is provided to program 'TVM16' 213 which interpolates a matrix of 128×128 points using the coefficients and other information contained in interpolation file 97, and provides the resulting matrix to color display 212. For single frame EP display, program 'EPTVM' 205 performs an analogous process to that of program 'FFTTVM' 206. Programs 'EPTVM' 205 and 'FFTTVM' 206 also perform compilations of sequences of frames into one display matrix, in accordance with predefined groupings set forth in protocol blocks.

A sequence of FFT matrices or EP matrices can be displayed in rapid time sequence as a cartoon by the use of program 'FFTMOV' 208 and program 'EPMOV' 207, respectively, each of which processes sequences of selected matrices of data from reduced data file 125, using scaling control information 215; interpolates full 128>128 matrices for each frame; interpolates a selected number of additional matrices between the original frames; and stores the resulting matrices in movie file 211. Based on control information 216 specifying data to be displayed, the frame rate of display, start, stop, backward, forward and pause, program 'FFTDIS' 210 and program 'EPDIS' 209 provide cartooned matrices for viewing on color display 212.

FIG. 22 illustrates group file production operation 61. Program 'GRPBLD' 221 creates and updates a composite group file 223 working from selected individual reduced data files 125. Control information 222 provided by the operator indicates the identity of individual reduced data files to be included. The group files 223 consist of the sums and the sums squared for all homologous points in the reduced data files 125 of all individuals in the group. Normalized sums and coefficients of variation may also be produced and stored. Hard copy 224 listing the individuals in each group and the values of group file data are available based on control information 222.

FIG. 23 illustrates the function of group topographic data display operation 62 which is analogous to the operation of the single frame display of reduced data file information, illustrated in FIG. 21, except that the data displayed is from group file 223 instead of reduced data file 125.

FIG. 24 illustrates the function of individual versus group comparison operation 63. Programs 'EPTVM' 205 and 'FFTTVM' 206 are performed respectively on EP and FTT data. In each case, the program generates a frame of points, each of which is the number of standard deviations (z-statistics) by which an individual's point, taken from individual file 226 differs from the average of the group's corresponding points taken from group file 223. The resulting frame is displayed (block 216) by program 'TVM16' 213, which interpolates additional data points to form a 128×128 matrix in the manner previously described.

FIG. 25 illustrates the function of group difference detection and feature selection operation 64, which computes frames of t-statistics reflecting the level of statistical difference between two groups based on the means and standard deviations of homologous data points for the two groups. Program 'GRPCMP' 230 computes t-statistics and degrees of freedom from the sums and sums squared data contained in two different group files 223 designated in control information 231 provided by the operator. The resulting frames are stored in group comparison file 232. Based on file and frame designations set forth by the operator in control information 235, program 'GRPDIS' 234 transmits a selected t-statistic frame for display by program 'TVM16' 213 as previously deascribed. Program 'TVM16' 213 also returns a fully expanded 128×128 matrix back to program 'GRPDIS' 234. Through control information 235, the operator may store such a t-statistic matrix in saved frame file 233. FIG. 26 illustrates the format of saved frame file 233. Header block 240 contains the number of saved frames, and for each frame identifies the time frame length or frequency band and the protocol under which the data was collected. Frames 241 contain 128×128 matrices of floating point t-statistics generated by program 'GRPDIS' 234.

FIG. 27 illustrates the functions of the brain electrical activity mapping to TICAS file transfer operation 65, which converts features of brain electrical activity mapping data to a form usable with TICAS software 29. Program 'FEADEF' 245 generates feature list file 247 from feature definitions and names of saved frame files 234 provided by the operator in control information 246. Program 'FEAGET' 248 then generates TICAS formal file 249 from reduced data files 125, saved frame file 233, and feature list file 247, identified by the operator in control information 250. The feature definitions which may be selected and stored in TICAS format file 249 for subsequent TICAS analysis include nearly all combinations of data found in all individual files, all combinations of integrated bands of frames (e.g., alpha bands) in individual files grouped according to preset protocol specifications, or combinations of individual frame files weighted by the values in a saved t-statistic frame.

FIG. 28 illustrates the functions of TICAS feature selection and evaluation operation 67. In control information 266, 264 the operator designates two groups 262, 263 from TICAS format file 249 whose features are to be analyzed, the type of data to be analyzed, the number of input features to be analyzed, and the number of output features to be produced. Program 'UTEST' 261 peforms a standard two-sample Wilcox-Mann-Whitney U-test and provides a list of U-test scores in rank order which are printed on printer 23 and stored. Program 'FMTST' 260 performs a final merit value (FMV) test and provides and stores a list of values for features in order of final merit values. Program 'FMTST' 260 first determines intermediate merit values as a combination of the standard receiver operating characteristic (ROC) curve or d' value and the results of an ambiguity function analysis. The final merit values for each feature are then determined by correlation of the intermediate merit value with all features ranked higher in intermediate value. Program 'MERGE' 267 selects from Group

A features 268 and group B features 269, based on the FMV values and U values, those features which are most useful, which are then stored in disk files 270 and 271.

FIG. 29 illustrates the functions of TICAS generate discision rules operation 68. Program 'SLPRT' 275 uses an operator controlled (block 278) subset of selected Group A features 276 and selected Group B features 277 to generate disk stored interim rules 279, by a method controlled (block 278) by the operator. The computation method may be a non-parametric d-selection technique, a parametric classification technique, or a combination of the two. Program 'CLSFY' 284 uses operator selected (block 285) interim rules 279 to classify operator selected subjects having operator selected features, from selected group features files 280 or refined group features files 281, 282, printing the results on printer 23, thereby permitting the operator to evaluate the efficacy of each selected interim rule 279. Progran 'DSC' 286 combines operator chosen (289) features from selected Group A features 287 and selected Group B features 288 into new features on the basis of the weighting functions of a standard linear discriminate analysis, subject to the operator's choice (group 289) of discriminant function parameters. Discriminant function weights for the best features are then loaded into a disk file 290. Program 'LINCOM B' 293 uses the original selected Group A features 291 and selected Group B features 292 and the discriminate function weights 29 to create refined Group A features 294 and refined Group B features 295, which are linear or other operator selected (block 296) combinations of the original features. Refined Group A features 294 and refined Group B features 295 can replace the original selected features 276 and 277 as input to program 'SLPRT' 275 to permit an iterative process of decision rule generation.

FIG. 30 illustrates test decision rules operation 69. Program 'CLSFY' 284 uses final sets of decision rules, e.g., rules A 304 and rules B 305, to classify individuals in original Group A 300, original Group B 301 and new unknown groups, e.g., Group C 302 and Group D 303, to determine the efficacy of the final decision rules, the results being provided on printer 23.

Operation

Data Gathering

Accumulation of raw EEG and EP data is accomplished by first attaching 20 electrodes 5 to the scalp of an individual subject in a conventional international 10-20 format. In other embodiments, information from between 10 and 200 electrodes can be gathered and analyzed. Before recording, and if desired during recording, the operator observes the signal levels on the 20 channels of chart recording of polygraph 10 and adjusts the gain on weak signals to produce usable waveforms. A calibration signal of 100 microvolts (10 Hz) from source 8 is recorded on all twenty channels on tape recorder 11 at the beginning of each session and whenever any of the gain levels on polygraph 10 is adjusted.

Data gathering typically begins with a careful administration of a sequence of tests, each of which is intended to establish a particular steady-state electrical condition in the subject's brain. The sequence of tests usually includes instructions to relax and remain still with eyes open, to relax and remain still with eyes closed, to become drowsy, to breathe deeply for hyperventilation, to listen to music and to listen to speech. Other tests rewquire the subject to (1) listen carefully to a story and answer simple questions about its content when completed. (2) remember a set of six abstract figures (often resembling an unknown language alphabet) in black ink on index cards presented by the examiner, (Kimura Figures-Instruction) (3) select the six previously presented figures from a set of 38 figures, verbally indicating yes or no (Kimura Figures-Test), (4) associate each of four abstract figures on index cards with a particular artificial name spoken by the examiner (Paired Associates-Instruction), (5) name each of the four abstract figures when tested by the examiner (Paired Associates-Test), (6) read silently three previously unread paragraphs (e.g., example text from the Gray Oral Reading Test) so as to answer questions subsequently (Reading Test-Instruction), (7) identify whether 34 typed sentences presented by the examiner were previously included in the three paragraphs (Reading Test-Test), and (8) read text upside down: The tests are designed to permit recording of brain electrical signals during simple resting brain activity and during different levels of activation of the left hemisphere, the right hemisphere and both hemispheres of the brain together. This permits the demonstration of pathologies present at rest and those present upon brain activation. The development of specific tests and the choice of tests is determined by the user based in part on the subject being tested and the information eing sought as described in greater detail below. Between twenty seconds and three minutes of steady state brain electrical activity is recorded on all 20 channels during each of the tests. Appropriate records of the tape location of each test are kept. These tests have been used with the brain electrical activity mapping system to demonstrate group differences between normal subjects and those with dyslexia or specific reading disability at the 10-12 year age level and at the six-year age level; to differentiatedemented patients from normals and aged patients from younger patients in clinical settings; to identify patients with an organic basis for sociopathic behavior and other forms of mental illness; to demonstrate epilepsy when the resting background EEG failed to show any abnormalities; to demonstrate abnormalities in EEg and EP data for schizophrenic subjects; and to determine when a brain tumor, previously treated, is about to recur.

With young infants, the brain states tested include sleep, alert and attending to visual and auditory stimuli, alert but not attending to visual and auditory information, and drowsiness. Using these states, it is possible to discriminate among children with poor behavioral scores on a psychological test and those with high psychological scores.

A series of sensory evoked potential (EP) transient responses are then recorded from all electrodes while the subject is repeatedly exposed to a selected stimulus, e.g., a strobe light or a click generator or to a predetermined sequence of two alternate stimuli. Because the EP transient response is weak compared to the background steady-state brain electrical activity, the stimulus must be presented many times (e.g., 500) to the subject for later signal averaging. The total response period of interest is typically 1024 milliseconds, comprising 512 milliseconds before stimulus and 512 milliseconds after stimulus. The process is repeated for different stimuli.

Stimuli presented to the subject can range from simple flash, simple click, simple pattern reversal and simple somatosensory stimulation to those requiring complex decisions. Requiring a subject to discriminate between subtly different auditory stimuli (e.g., the words "tight" and "tyke") is useful in diagnosing dyslexia. This procedure is known as the Tight-Tyke evoked potential phenomic discrimination test. Picking an infrequently different stimulus from among other more frequent stimuli is useful evaluating subjects who have functional brain disorder.

Auditory stimuli generate a set of fast and a set of slow transient responses. The fast responses eminate from the brainstem and have a typical duration of 20 milliseconds. Brainstem responses are normally sampled for a total response period of 40 milliseconds comprising 20 milliseconds before stimulus and 20 milliseconds after stimulus. Filters **12** are adjusted to exclude frequencies below 300 Hz and to include frequencies up to 8000 Hz.

When EP transient responses from such stimuli are averaged to eliminate noise, two types of interference can occur. The first type, known as contingent negative variation (CNV), relates to the connection made by the brain between consecutive equally spaced stimuli when the subject is told to count the stimuli. The D.C. component of the resulting transient response shows a gentle dip and a sharp rise immediately before each stimulus, attributable to the subject's anticipation of the next stimulus. The sharp rise contaminates the evoked potential transient response and makes it difficult to establish a zero baseline. By including as part of the interval between stimuli a first pseudorandom time element which varies from 0 to a period longer than the post-stimulus response and is also a multiple of the wavelength of the interfering frequency described below, the CNV effect is greatly reduced.

The second type of interference results from the existence of background noise at certain characteristic frequencies, e.g., 10 Hz, which reflect prominent bands of steady-state brain wave activity. The major interfering frequency of a given subject may be determined by a spectral analysis of his background EEG signal. The interference problem is especially significant in adults with prominent alpha waves and children with prominent slow brain wave activity. By including in the time interval between stimuli a second pseudorandom time element whose period varies from zero to the wavelength of the major interfering frequency, the background noise can be substantially reduced in the averaging process.

The inclusion of a prestimulus period of recoding for each transient response permits an accurate baseline determination at a later stage of signal processing in order to establish a true zero level for the post-stimulus response and permits a determination of the quality of the signal averaging process.

Pseudorandom stimulus controller **9** measures the interval between stimuli as a combination of the post-stimulus response period, the first pseudorandom period described above, the second pseudorandom period described above, and the pre-stimulus response period.

As illustrated in FIG. **31**, pseudorandom stimulus controller **9** comprises a four-stage timer, each stage of which in turn measures one of the four periods included in the interval between stimuli. The first stage comparator **406** measures the pre-stimulus period p_1/f_{c1} where P_1 is a number preset by the operator in register **408** and f_{c1} is the frequency set on variable frequency clock **404**. When the first stage timing is completed, the second stage times the post-stimulus period as P_2/f_{c2} where P_2 is a number preset in register **414** and f_{c2} is the preset frequency on clock **410**. At the end of the first stage timing period, a stimulus trial marker (5 volt spike) is recorded on the trial marker channel of tape recorder **11** and stimulus **409** is triggered. The selected post-stimulus period is long enough to permit a full decay of the transient response being observed. At the end of the second stage timing period, the third stage measures the first pseudorandom time period P_3/f_{c3}, where P_3 is the next pseudorandom number in programmable read only memory (PROM) **419** and f_{c3} is the preset frequency of variable clock **415**. PROM **419** has been preloaded with a pseudorandom sequence of numbers. At the end of the third stage timing, the fourth stage measures a second pseudorandom period in an analogous manner based on a pseudorandom sequence in PROM **424** and a preset frequency on clock **420**. When the fourth stage timing period is over, a pre-stimulus trial marker (5 volt spike) is recorded on the trial marker channel of recorder **11**. A new timing cycle is then completed and the process is reiterated until the total number of transient responses recorded equals a preset number in register **426** or the process is stopped by the operator. The entire process is begun by pushing button **401**, which causes the recording of a pre-stimulus trial marker. Temporary delay button **431** can be used to temporarily delay the continued operation of the timer at the operator's discretion, as for example when the subject is distracted in a manner which would render the transient response useless. A low order bit in PROM **424** or PROM **419** can be set to 0 or 1 by the operator for each number loaded into PROM **24** or PROM **19** so that two different stimuli (e.g., auditory and visual) can be triggered in a preselected order or pattern, with one stimuli being presented more frequently than the other.

The result of the recording session is an analog tape of raw EEG and EP voltage data and calibration voltages on 20 channels with trial markers on a twenty-first channel. The next step is to load the data into computer **13**.

As previously described, brain electrical activity mapping software **28** performs data collection, data manipulation, and data display functions in accordance with central information provided by the operator. The various operations can be performed in any sequence and the operator can perform a series of functions iteratively. The operator provides control information through the keyboard of terminal **22** and receives information concerning the various operations on printer **23**, waveform monitor **18** and topographic color monitor **20**. The flexibility of operation heightens the system's utility as a diagnostic and analytical tool.

Data Loading

Under operator control,EEg data for each brain state and related calibration signals are loaded directly onto disk storage from recorder **11** after passing through filters **12** set to pass frequency components between 0.5 and 50 Hz or between 0.5 and 1000 Hz and epileptic spike data. Gain controls on the filters are adjusted to fully utilize the signal capacity of converters **15**, **16**. EEG data can be sampled at rates as high as 20,000 samples per second.

Under operator control, EP data is passed through filters **12** set to eliminate frequencies above a selected

frequency of between 40 and 100 Hz, or below 300 Hz for brainstem data, and is signal averaged in core memory using core averaging operation 55, which automatically rejects bad data and sets the zero baseline.

Typically EP data is sampled every 4 milliseconds, or every microseconds for brainstem analysis, and 256 sampled are taken, 128 pre-stimulus and 128 post-stimulus. If the operator determines that the EP transient response data is very noisy, he may alternatively record the data as raw data and use raw data reduction operation 58 to average only selected transient response trials. In cases where the transient response data may not contain the necessary stimulus trial markers, such as in recordings of rapid eye movement (REM) sleep, the data can similarly be recorded as raw data and trial markers can be added manually by the operator, using raw data operation 58, before signal averaging is done.

Raw Data Quality Control and Display

To assure the maximum accuracy and utility of raw data, the operator can, using raw data quality control operations 56, display recorded waveforms, accept or reject each waveform for later processing, have mathematical smoothing operations performed, reset baselines or eliminate certain points of data.

The operator views the EP transient responses for the 20 channels for the purpose of evaluating the utility of each curve and specifying modifications which will improve their utility when displayed. The operator may direct a further adjustment of the baseline, which has already been set automatically, by having a constant number added to or subtracted from the value in each frame, or can determine to have the automatic baseline determination redone using a smaller number of the later pre-stimulus frames as the baseline. This procedure is particularly useful when the early pre-stimulus frames are found to contain the tail end of the transient response of the prior stimulus. By reviewing the relative levels of V_{RMS} (pre-stimulus) and V_{RMS} (post-stimulus) for a given channel, the operator can determine whether the background noise level is unacceptably large with respect to the transient response, necessitating another recording session with the subject. The operator may also filter any high frequency noise in the post-stimulus period by three-point interpolation.

As part of the raw data quality control process, if a channel contains spurious values (e.g., voltage spikes) in particular frames, the operator can eliminate those values and substitute values interpolated from the next prior and next later frames. If the voltage levels on one channel are substantially higher than for the other channels, the operator can flag that channel to indicate that the channel should be excluded from the subsequent display scaling procedure (described below). Based on the operator's instructions, the automatic baseline determination may be redone and the results are viewed again until the operator is satisfied that the set of transient responses contain satisfactorily low noise levels and are properly zeroed.

Raw data topographic display operation 57 enables the operator to display a cartoon series of topographic maps of raw data, which has been expanded by interpolation into a matrix of 128×128 points. The cartoon can be started or stopped and run forward or reversed at will. When raw EEG data is to be cartooned, the operator can sample the data at a high rate, e.g., 400 frames per second, and then display the information at slower speed or in a series of matrices, each of which is an average of a sequence of frames. The averaging can be done on a running basis, so that the first N frames are averaged and displayed, then the N frames beginning with the second frame are averaged and displayed, and so on.

EEG Data Reduction

Raw EEG data is converted to spectral data using the fast Fourier transform process of raw data operation 58, as previously described. The segments of raw EEG curves whose spectral data is averaged are generally about 2 seconds in length each, which is shorter than the average period between spurious artifact signals. Typically from 15 to 90 segments are spectrally analyzed and the spectra averaged. The spectra usually consist of 128 frequency bands of $\frac{1}{2}$ Hz in width covering the spectrum from 0 to 64 Hz. The ends of each segment can be tapered in accordance with the operator's discretion in connection with the Fourier transform process.

Reduced Data Quality Control and Topographic Display

Working with reduced EP and EEG data, that is sequences of time frames of transient response data and groups of spectral band data, the operator can use reduced data quality control operation 59 to view the waveforms, discard bad data reflecting movement artifact, eye blink, or muscle activity and eliminate high frequency noise. The reduced data can then be topographically displayed on a frame by frame or cartooned basis using the reduced data topographic display operation 60. In either case, the operator can form frames which represent combinations of underlying frames. For example, groups of $\frac{1}{2}$ Hz bandwidth frames can be combined into larger bandwidth frames corresponding with typical spectra of clinical interest, e.g., alpha, beta, delta and theta. Bands of any desired width can be formed. In addition to displaying raw spectral energy information from EEG data, it is possible to display normalized spectral energy in which the points on each display are normalized to the overall spectral energy of each electrode or to the average overall spectral energy at all electrodes. In the case of EP data, it is similarly possible to display each point as a normalized value to the value at one specific electrode, e.g., the vertex electrode designated "C_z", or to a standardized value, or to a selected value, or to the V_{RMS} of the background activity at each electrode, or to the V_{RMS} of all electrodes. Similarly, the 128 frames of an EP transient response can be grouped into frames of greater time duration for display.

Group Data Analysis

By accumulating a number of stored data frames, it is possible for the operator to assemble and display group data files using group file production operation 61 and group topographic data display operation 62.

Significance Probability Mapping (SPM)

Using stored data for various groups and individuals, the operator can perform and display topographically t-statistic comparisons between groups of frames and z-statistic comparisions between an individual frame and a group of frames. Any other statistical group comparison can also be used to form a display matrix to illustrate group differences. This type of analysis, significance probability mapping (SPM), enables the operator

to identify significant brain activity features related to various neurophysiological illnesses and conditions.

Grid Sector Analysis

Frames produced by the SPM procedure may be further analyzed by a Grid Sector Analysis (GSA). While the frames produced by the SPM procedure reflect regional abnormalities, the GSA procedure produces numerical measures of the degree of global or focal deviations from normal, which can assist in automatic determination of the existence of regional abnormalities in unknown subjects.

The first step of the GSA process conceptually requires the division of a frame into a number of different grids, each divided into sectors of a uniform size. Within each grid sector, the mean of all values of the data points lying within the sector is determined as the value of that sector. The process is repeated for grids of different fineness. Preferably three grids, of 4000 sectors, 64 sectors, and 16 sectors respectively, are used. Histograms of sector values are then prepared for each grid reflecting sector t-statistic or z-statistic values on the horizontal axis and numbers of sectors having that value on the vertical axis for each grid. Various analyses of the histrograms, which differ for focal and global abnormalities, will indicate whether an abnormality is focal, i.e., localized in one area, or global, i.e., diffused over a large part of the brain. One such analysis would simply be the observation that the peak number of sectors for the coarser grids will be at lower z or t values in the case of a global abnormality than in the case of a focal abnormality.

In the case of focal abnormalities, there is a marked difference in the histograms for the three grids, while in the case of global abnormalities, there is little or no difference for the three grids. A variety of features can be developed from the histograms to serve as possible diagnostic rules. The maximum z-value for each grid, the maximum amount of asymmetry between homologous grid regions, the mean asymmetry between homologous grid regions, and the difference between the absolute values of the sum of all left hemisphere and all right hemisphere values. Also, one can calculate the number of regions above certain criterion levels for each histogram.

A group of spectral maps or a series of EP responses can be analyzed as an ensemble by forming at each matrix point the mean of the values of each map in the ensemble. The grid region on each individual map showing the largest value is given a score of 4, the next largest a score of 2, the third largest a score of 1, and the rest a score of 0. The scores are then summed by region across all maps in the ensemble, and the regions having the three largest scores and their sum are stored as indications of focal features. The same process is repeated for the three regions having the greatest asymmetries in each image between corresponding grid sectors. The resulting information can serve as features which can be processed using TICAS to develop diagnostic rules to classify unknown subjects between a group of normals and a group having a particular dysfunction. The numerical descriptors generated by GSA, when used for statistical analysis are approximately as successful in the identification of patients with brain tumors as visual inspection of EEG data by expert clinicians.

Coefficient of Variation Analysis

Given an ensemble of segments of data, the operator can determine the mean and the standard deviation of each point across the segments. By displaying the standard deviations as percentages of mean at each point, the coefficient of variation (C/V) across the skull can be observed topographically. The normal expect range of C/V values is 40–60% and deviations from that range are immediately evident from the displays. The C/V display is useful in demonstrating head regions where there are wide variations in activity, e.g., epileptogenic regions.

Difference Maps

A display matrix can be formed to represent at each point, the difference in value of corresponding points on two underlying frames. This permits, for example, displays which suggest the regions of the brain activated by patterned light, by comparing the frames corresponding to plain light stimulation and to patterned light stimulation.

Automatic Diagnostic Rules

Working from significant brain activity features and using TICAS-related operations 65, 67, 68 and 69, the operator can develop and test diagnostic rules for accurately classifying unknown subjects between normal and abnormal groups.

Scaling

Several of the available BEAM system operations produce color topographic displays. Video monitor displays typically involve assigning to each point on the display a grey tone of color which represents the value of the point. Sixteen tones of color represent 16 different graduated values. For example, red can be used for positive values and blue can be used for negative values with the grey tone of blue or red indicating the level of positive or negative value. An absence of color represents zero. In order to maximize the visual effectiveness of the display, it is desirable to scale the values of the data points to the available color tone levels in such a way that the useful variations in value are spread among the maximum range of color tones. The scaling can be done according to a variety of options. The data points can be scaled so that the maximum absolute value of the data points over a set of matrices will be equivalent to the maximum positive and negative color tones and all other points will be scaled linearly to the intermediate color tones. Scaling can be done from zero to the maximum absolute value. The same scaling technique can be accomplished with one or more channels excluded by the operator from the scaling process so that unusually high value data points will not skew the scaling process. Scaling can be done on a matrix by matrix basis rather than across a group of matrices. Scaling can be done to a maximum value chosen by the operator. In the scaling process, any data value which is larger than the brightest available grey color will be truncated and displayed as that brightest color.

Three-Point Linear Interpolation

Since the data frames to be presented for display originally contain a relatively small number of points, e.g., 20 points, and the display is preferably of a continuous matrix of 128 × 128 points, expansion of the data by some form of interpolation is required. The expansion is

accomplished by three-point linear interpolation, in which each display point is determined as a sum of the values of the three nearest data points on the original data frame, each multiplied by a predetermined coefficient which reflects the precise location of the display point. As an alternative to the software previously described, the calculation of the display point can be done on hardware having an extremely short processing time, making possible "real-time" displays, that is, each display matrix is calculated in a time shorter than the display time for each display matrix. A detailed description of the three-point interpolation technique is contained in U.S. patent application Ser. No. 221,830 (hereby incorporated by reference).

Display Features; Multidimensional Display

As illustrated in FIG. 32, the each topographic display comprises an outline of the skull with an indication of its orientation with respect to the ears and nose. All display points outside the outline are suppressed. Within the skull outline are displayed the grid of data points, each of which reflects a value or values for that point on the skull. The number of dimensions of information which may be represented by a given point varies with the display method. Frequently only one dimension of information is presented at any point in the form of a grey-tone of color on a predetermined grey-tone scale. Alternatively additional dimensions may be reflected at a point as a unique combination of three colors. Three dimensions can be represented by the quantity of each of the original colors which is mixed into the combination and a fourth dimension could be the lightness or darkness of the three. In this manner, for example, spectral EEG data for four frequency bands of brain activity could be displayed simultaneously. A detailed description of this four-dimensional display is contained in U.S. patent application Ser. No. 221,830.

Whenever displays are cartooned, the operator may select the frame rate of display from stationary to ten frames per second minimum. The cartoon can also be displayed legarithmically with time, so that the later matrices are displayed in faster sequence then the earlier ones, which visually compensates for the fact that more EP response information is available just after the stimulus than toward the end of the response period.

Examples of System Use

The brain electrical activity mapping system offers a powerful brain diagnostic and research tool by permitting immediate video display of information about steady-state brain waves, EP transient responses, spectral analyses of EEG signals, and statistical information based on these types of data, and the ability to develop diagnostic rules from selected features of data. The following examples illustrate the versatility and utility of the system.

Suspected Epilepsy

Although the "spike and wave" as seen on routine EEG graphs is virtually diagnostic of epilepsy, over 10% of all true epileptics fail to demonstrate this abnormality. Use of special electrodes, sleep studies, and activating drugs often fails to produce spikes in true epileptics. This means that although an epileptic may have brain cortex that is capable of demonstrating sufficient irritability at times to produce a seizure, that at other times it fails to be sufficiently irritative to produce a spike on the EEG and thus eludes diagnosis. Topographic display is of great assistance in such situations. Such suspected epileptic patients should have eyes open (EO) and eyes closed (EC) topographic studies performed. Irritative cortex presents itself as focal increases of activity over all frequency bands, especially the high frequency beta bands. The visual evoked EP response (VER) topographic study should also be performed. Irritative cortex leads to focal increases of both positive and negative waves. If the epilepsy is associated with an atrophic lesion, a region of reduced EEG and EP activity may be found in close association with the focal irritability.

When spikes are found, displays of their topographic extent are extremely useful in determining their point of origin. In this case, raw EEG data is displayed in cartoon form thus delineating the epileptic dipole.

Suspected Supratentorial Brain Lesion

Patients are often referred for EEG tests in order to rule in or out a lesion of one or both cerebral hemispheres. This includes tumor, stroke, abscess, atrophy, arterio-venous malformation, congenital malformation, hemorrhage, regional encephalitis. These subjects should be subjected to topographic studies in the eyes open and eyes closed brain states, and for the VER and bilateral somotosensory evoked response (BSER) EP situations. In general these lesions may be recognized by the pattern of hypo- or hyperactive cortex that become visible on the brain electrical activity mapping images. For example, tumors show decrease in activity early, excessive activities later, and reduced activity at the vertex. Brain electrical activity mapping greatly adds to the information obtained by radiographic scanning as it is sensitive to the functional disturbances produced by these lesions which usually extend beyond the anatomical limits of the lesion.

To pinpoint abnormalities the technique of significance probability mapping (SPM) should be used. Furthermore, quantification of a lesion by grid sector analysis (GSA) is often useful.

Brain electrical activity mapping is most useful when tests must be applied to a large population for screening purposes or repeatedly to a single person. Such uses would include screening for tumor and stroke, determining whether a lesion is increasing or decreasing, and assessing the effects of treatment on a lesion. Brain electrical activity mapping is completely non-invasive, and not dangerous as radiographic techniques would be in such circumstances. There is also evidence that many lesions produce electrical (functional) disturbances before they can be detected by radiographic means.

Suspected Learning Disabilities

Brain electrical activity mapping studies are most useful in the elucidation of regional abnormalities of brain activity found in dyslexia, hyperactivity, dyscalculia, and combinations of the above. For example, dyslexia reveals abnormalities not just in the classic left temporal lobe speech areas but in the medial frontal lobe bilaterally. To demonstrate these abnormalities, one needs to perform the full test battery which includes: right hemispheric activating tests (the Kimura Figures task and listening to music as described elsewhere); left hemispheric activating (listening to speech and reading Grey Oral passages as described elsewhere); and bi-hemispheral tests (Paired Associates test and the Tight-Tyke evoked potential phenomic discrimination test as described elsewhere).

Automated classification tests to discriminate among these clinical entities can be developed.

Emotional Dysfunction

Many forms of emotional disorder can be caused by the lesions mentioned above. Brain electrical activity mapping can be more useful in the recognition of covert pathology in this patient population than radiographic techniques. In addition, certain forms of psychopathology have recognizable brain electrical activity mapping signatures. For example sociopathic behavior is associated with lack of synchrony between the frontal lobes; e.g., the VER may show different electrical polarity between the right and left frontal lobes. Schizophrenia shows markedly increased EEG slow activity overlying the frontal regions. In this group of subjects, the eyes open and eyes closed EEG and VER studies are most useful.

Infant Competence

Discrimination between babies at risk for future learning and emotional problems is a frequent clinical request. Brain electrical activity mapping has proven useful in accomplishing such discrimination. In addition to studying the EEG and VER in stages 1 and 2 sleep, the EEG should be studied while the babies are brought into the alert state and maintained there as discussed elsewhere. Less competent babies, for example, show paradoxical increases in frontal delta slowing as they are alerted.

Suspected Dementia

Senile and pre-senile dementia represent a major problem for gerontologists and neurologists. Radiograpic evidence of brain abnormality may not be found until the clinical symptom complex is well established. On the other hand, brain electrical activity mapping studies demonstrate early abnormalities in a non-invasive manner. The best battery of tests is similar to those described above for suspected learning disabilities, but generally the tight-tyke EP is replaced by another EP where the subject must discriminate between frequently and infrequently heard tone pips of differing frequency. A difference EP between the response to the two different tone pips is produced. The topographic display of the difference EP shows a marked reduction in dementia and may be used to follow the course of dementia and the response of dementia to pharmacotherapies.

Headache

Headache may be caused by many factors. Brain electrical activity mapping is very useful to screen out serious lesions of the types described as supratentorial lesions above. The specific syndrome of migraine headache has a frequently seen pattern on brain electrical activity mapping of excessive 8–11 Hz occipital oscillations and excessive occipital activity. It is best to use the EO and EC EEG and VER for headache. Occasionally the BSEP is useful.

Comparison of Individual to Group

As described above, the brain electrical activity mapping system is generally able to compare an individual statistically to a group and display the result topographically. In a clinical setting, the individual in question, who may have displayed a normal CT scan, is compared to an age matched/sex matched group of normals, and abnormalities are then displayed in color-

mapped form, wherein bright colors show high abnormality and dull colors show insignificant abnormality. This technique provides an effective diagnostic tool.

Comparisons of Groups; Automatic Diagnosis Rules

The result of a group comparision under the system is a topographic display of statistical difference expressed as t-statistics, which when coupled with the number of degrees of freedom available in the calculation, produce a probability level of significant difference between two groups at a particular brain state. For instance, a group of normals could be compared to a group of schizophrenics by the creation of t-statistic displays with respect to a variety of brain states and stimuli. The user looks for displays which exhibit high degrees of coherence and statistical difference. This is normally shown on a screen in color. The larger statistical differences appear as brighter colors. The degree to which the differences are focused at particular points or diffused over the skull is also apparent. Smoothness in the lines dividing areas of different brightness suggests focused differences, while diffuse differences are suggested by ragged edges between dim and bright areas. It is possible for the researcher, upon selection of a particular map that shows something interesting, to save the matrix for later analysis. Such a saved matrix of t-statistics can be used to non-linearly weight the underlying data frames to create features which can be analyzed using TICAS. Once a set of saved frames representing group difference information is accumulated, he then converts all of the saved information, representing features which tend to distinguish the two groups into a file format which is suitable for analysis by TICAS, which is a multi-variate classification system, publicly available from the University of Arizona, courtesy of Dr. Peter H. Bartell.

TICAS is designed to sift through all of the features saved in the course of the inter-group analysis and pick those which prove to be the most discerning mathematically to produce a set of features which succinctly allows automatic diagnosis of a patient.

This procedure has been used to successfully discriminate between normal subjects and those with dyslexia, to discriminate between normal subjects and those with supertentorial brain tumor, and to discriminate between subjects with exposure to organophosphate compounds and nonexposed controls.

Dyslexia Analysis

An article, *Dyslexia Regional Differences in Brain Electrical Activity by Topographic Mapping*, Duffy et al. (Annals of Neurology, Vol. 7, No. 5, May, 1980), hereby incorporated by reference, describes the use of the brain electrical activity mapping system to identify the parts of the brain whose electrical activity differs for individuals suffering from reading disability (dyslexia) as compared with normal individuals, and to establish objective standards for diagnosing dyslexia. The previously described battery of brain state tests were administered to a dyslexic group and a control group. Visual and auditory stimuli were repeatedly presented to both groups and recorded with the appropriate trial markers. The stimuli were offered in pseudorandom fashion. Using the brain electrical activity mapping system, topographic displays of the alpha (8 to 11.75 Hz) and theta (4 to 7.75 Hz) activity at each electrode for each tested brain state for each subject were produced. Similar cartoons of 128 frames (4 milliseconds

each) were prepared for each type of EP response for each subject. The resulting brain state frames and EP response frames for the dyslexic group and the control group were then averaged to form mean frames of each group for each state and stimulus. The two groups of mean images were then compared using the t-statistic function. A further transformation produced a matrix of percentile index values (PI) whose value is related inversely to t-values. The PI values permit a graphic localization of regions of maximum difference between the dyslexic group and the control group. By topographically displaying the PI matrices for alpha and theta for each brain state and for each EP stimulus, it was possible to identify the brain regions which differed between the dyslexics and the controls. As a final step, a new display matrix was formed which summarized the differences reflected in all of the PI matrices as indicated by the occurrence of a certain PI level on at least one of the underlying PI matrices. The map of PI differences having a value of at least 2 identified four brain areas related to dyslexia: (1) bilateral medical frontal, (2) left anteriolateral frontal, (3) left mid-temporal and (4) left posterolateral quadrant. Classic concepts of dyslexia had not suggested the involvement of all of these brain areas in dyslexics. The study also indicated that alpha brain activity was involved in dyslexia as well as the theta activity which has previously been viewed as of primary importance.

In *Dyslexia: Automated Diagnosis by Computerized Classification of Brain Electrical Activity,* Duffy et al. (Annals of Neurology, Vol. 7, No. 5, May, 1980) hereby incorporated by reference, specific highly effective diagnostic rules for identifying dyslexics were developed by a rule selection process applying TICAS software to the brain wave data derived in the study described immediately above. Working from displays of brain electrical activity, 183 features were identified for particular regions and brain states in which the strongest differences between the dyslexic group and the normal group occurred. Two of the 183 features were identified as capable of classifying unknown subjects as dyslexic or normal with a success of 80–90%.

Localization of Tumor

In *Brain Electrical Activity Mapping (B.E.A.M.); A Method for Extending the Clinical Utility of EEG and Evoked Potential Data,* Duffy, et al (Annals of Neurology, Vol. 5, No. 4, April, 1979), hereby incorporated by reference, the use of brain electrical activity mapping system topographic displays to identify the location of a brain tumor was discussed. Spectral EEG data in the four classic bands (delta, theta, alpha, and beta) was recorded for various tested brain states. Average EP response data for strobe light stimuli comprising 128 time frames of 4 milliseconds each was also recorded. After three-point linear interpolation to expand the matrix, displays of spectral EEG data, and cartooned EP data were obtained. FIG. 5 of the article illustrates the spectral EEG displays in the four classic bands of brain activity for a patient with a known tumor, which had been located by CT scanning. The assymmetries in the spectral displays also identify the area of the tumor, although the suggested lesion size was larger than indicated by CT scanning. Analysis of 7 tumor patients, whose classic EEG's were normal or non-localizing, showed that brain electrical activity mapping studies were able to define the lesions almost as effectively as CT scan.

Use of Significance Probability Mapping with B.E.A.M. to Compare Groups and Compare Individuals to Groups

In *Significant Probability Mapping: An Aid in the Topographic Analysis of Brain Electrical Activity,* Duffy et al., accepted for publication the authors describe the use of topographical displays of statistical transformations of data. In one application, EP response data was obtained from a group of subjects with brain tumors and a second control group of subjects. The data was broken into sequential frames of 4 milliseconds each. For the control group, new matrices of mean and variance of each electrode over all members of the group were prepared. A z-statistic matrix was formed for each tumor subject to illustrate his deviation from the normal population. Using the z-statistic display a clinical neurophysiologist was able to identify 11 of 12 tumor subjects.

In a second application, discussed in the same article, EEG steady-state signals were recorded for three different brain states (resting but alert with no external stimulation, listening to a tape recording of speech, and listening to a tape recording of music) for individuals in a group of dyslexics and individuals in a group of normal readers. Matrices of alpha band activity were produced for each individual, and mean and variance matrices for each state were prepared for each of the two groups. For each group t-statistic matrices were formed to compare the resting and listening to speech states and the resting and listening to music states. By examining the t-statistic displays for the two groups it was possible to infer the differences in speech-induced and music-induced brain activity between the dyslexics and the normal readers. Those determinations could not have been made from an analysis of the underlying EEG alpha matrices.

Use of Grid Sector Analysis of B.E.A.M. SPM Data to Determine Degree of Focal or Global Deviation From Normal

In an unpublished article, "Quantification of Focal Abnormalities in BEAM Data by Grid Sector Analysis: Automated discrimination Between Normal Subjects and Patients with Supratentorial Brain Tumor", Duffy, et al., describes uses of grid sector analysis as part of the brain electrical activity mapping system for the purpose of automated neurophysiological diagnosis of brain tumor. In this application, EEG and visual EP data were recorded from a group of patients with confirmed supratentarial brain tumor and from a control group. SPM matrices were prepared comparing the tumor subjects to a normal group and comparing the control group to the tumor group. Four 96 millisecond time periods of EP data were analyzed. Grid sector analyses on the data resulted in a set of 1096 combined global and focal features from the combined EEG and EP data. By a process of features selection and rule development and testing, two features were identified as most useful in distinguishing the tumor subjects from the control subjects. When classification rules developed on the initial group of 30 subjects were applied to a new group of 10 subjects, containing 5 normals and 5 subjects with brain tumor, all ten were correctly classified.

Other Embodiments

Other embodiments of the invention are within the following claims. For example, the input data may be

obtained from any type of transducer capable of measuring brain electrical activity, and

topographic displays can be prepared from the signals taken from the skull, without interpolation of additional points to form a display matrix.

Related Applications

This application is related to the following applications, each of which is hereby incorporated by reference:

(1) Frank H. Duffy, Brain Electrical Activity Mapping (BEAM)

(2) Norman David Culver, Brain Electrical Activity Mapping (BEAM)

(3) Norman David Culver, Analysis of Brain Electrical Activity

(4) Norman David Culver, Apparatus and Method for Topographic Display of Multichannel EEG Data, U.S. Ser. No. 221,830.

What is claimed is:

1. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient,

stimulus means for repeatedly providing a sensory stimulus for activating the brain to produce EP responses to said transducers,

response averaging means connected to be responsive to said transducers, to produce average responses for each transducer,

processing means connected to be responsive to said averaging means for processing said average responses to generate a time sequence of matrices,

display means connected to be responsive to said processing means, for displaying said matrices as a time sequence of topographic maps of the skull, said matrice having elements defining discrete points of said maps,

said display means including means for displaying said topographic maps at a variable frame rate, said maps corresponding to different portions of said average responses being displayed respectively at different selected frame rates.

2. The apparatus of claim 1 wherein said display means includes means for displaying maps corresponding to initial portions of said average responses at a slower rate than maps corresponding to later portions of said average responses.

3. The apparatus of claim 1 wherein said display means includes means to display said topographic maps at a frame rate that varies logarithmically.

4. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus including

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull,

processing means connected to be responsive to said transducers, for processing responses of said transducers to generate a time sequence of matrices, each of said matrices having elements representing the instantaneous amplitudes of said responses at various locations on the skull and there being a sufficient number of said matrices for a selected time period of actual brain activity for capturing

onset of a transient event that occurs with a rapidity on the order of that of an epileptic spike,

said processing means including means to generate from said time sequence of matrices a running-average matrix which at any given time represents the current matrix averaged with a selected number of the matrices preceding it in time,

display means connected to be responsive to said processing means, for displaying said matrices as a time sequence of topographic maps of the skull, said elements defining discrete points of said matrice having maps,

said display means including means for displaying said topographic maps at a variable frame rate and for selectably slowing said frame rate to permit observation of said transient event.

5. The apparatus of claim 4 wherein said processing means includes means for generating 200 or more matrices for each second of real time.

6. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient,

storage means connected to be responsive to said transducers for storing responses of said transducers during first and second time periods,

processing means connected to be responsive to said transducers, for processing said responses to generate first and second matrices each having elements representing brain activity at different skull locations, said first matrix representing information on brain activity during said first period, and said second matrix representing information on brain activity during said second period,

different means connected to be responsive to said processing means, for forming a difference matrix having elements each corresponding to the difference between corresponding elements of said first and second matrices,

display means connected to be responsive to said different means, for displaying said different matrix as a topographic map of the skull, said matrix elements each forming a discrete point of said topographic map.

7. The apparatus of claim 6 further comprising stimulus means for providing a sensory stimulus to generate an EP response and wherein at least one of said first and second periods of time are during said EP response.

8. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient,

stimulus means for repeatedly generating a sensory stimulus for the brain, to produce at said transducers repeated segments of data, each said segment having a pre-stimulus response and a post-stimulus response,

response averaging means connected to be responsive to said transducers, for averaging said segments to produce average pre-stimulus and average post-stimulus responses for each transducer,

baseline means connected to be responsive to said responsive averaging means, for determining a zero baseline for said average segments from the mean

level of at least a portion of the respective average pre-stimulus response, and

subtraction means connected to be responsive to said baseline means, for generating zeroed average segments by subtracting from each average segment the zero baseline determined by said baseline means,

processing means connected to be responsive to said subtraction means, for processing said zeroed average segments to generate one or more matrices, each said matrix having element representing information on the electrical activity of the brain at one location on the skull,

display means connected to be responsive to said processing means, for displaying said one or more matrices as topographic maps of the skull, said matrix elements forming discrete points of said maps.

9. The apparatus of claim 8 further comprising

means connected to be responsive to said stimulus means, for storing the time of occurrence of each said stimulus and

means connected to be responsive to said means for storing, for dividing each said segment into a predetermined pre-stimulus subinterval during which the pre-stimulus response occurs and a predetermined post-stimulus subinterval during which the post-stimulus response occurs, by using said stored times of stimuli occurrence as an indication of the boundary between said subintervals.

10. The apparatus of claim 8 wherein said processing means includes means to generate from said zeroed average segments a time sequence of said matrices, the display elements of each matrix representing the instantaneous amplitude of an EP response at various locations on said skull, and

said display means includes means for displaying said matrices in sequence, to thereby display said EP response as a time-varying topographic map.

11. The apparatus of claim 10 wherein said processing means includes means to generate said sequence of matrices in an endless loop, to thereby produce a cyclical display of said EP response.

12. The apparatus of claim 8 further comprising sampling means connected to be responsive to said transducers, for sampling and storing as a sequence of digital words said segments, and wherein said response averaging, baseline, and subtraction means all include means for performing the respective functions digitally.

13. The apparatus of claim 12 wherein said response averaging means includes

a summing buffer connected to be responsive to said sampling means, and having locations for storing each said sampled digital word for each transducer and

means connected to be responsive to said sampling means, for adding to said buffer locations new digital words corresponding to each new segment, to thereby generate said average pre- and post-stimulus responses.

14. The apparatus of claim 13 wherein said sampling means includes means for taking from 20 to 2000 equally-spaced-in-time samples of said pre-stimulus response and for taking 20 to 2000 equally-spaced-in time samples of said post-stimulus response.

15. The apparatus of claim 13 further comprising means connected to be responsive to said sampling means, for comparing said new digital words to predetermined limits and rejecting digital words falling outside said limits, thereby not adding said words to said buffer locations.

16. The apparatus of claim 12 further comprising means connected to be responsive to said transducers, for filtering high-frequency components from the post-stimulus response for any selected transducer by multipoint interpolation of the digital words for the selected response.

17. The apparatus of claim 8 wherein said baseline means includes means for selectively eliminating from the mean level computation portions of an average pre-stimulus response for a selected transducer, to thereby provide a more accurate baseline for the response of the selected transducer.

18. The apparatus of claim 8 further comprising means connected to be responsive to said baseline means, for displaying said pre-stimulus and post-stimulus responses and said baseline for a selected transducer, to permit an operator to evaluate the appropriateness of said baseline.

19. The apparatus of claim 8 wherein

said baseline means includes means for calculating the root mean square average value of the average pre-stimulus response and of the average post-stimulus response and

said display means includes means for displaying said root mean square average values along with said responses,

whereby such root mean square value can be used in connection with said displayed responses to evaluate whether the noise level in the responses for any particular transducer is unacceptably large and for thereby determining whether new data should be taken.

20. The apparatus of claim 8 or 19 further comprising means connected to be responsive to said baseline means, for an operator to adjust the baseline value up or down for any selected transducer average response.

21. The apparatus of claim 8, 18, or 20 further comprising means connected to be responsive to said baseline means, for repeating the steps of calculating said baseline and viewing said responses for selected transducers, whereby adjustments can be made to said baseline until said responses are satisfactory.

22. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient or measure the EEG response at said locations,

sampling means connected to be responsive to said transducers, for sampling said EEG responses during time intervals shorter than the anticipated interval between interruptions in the state of brain activity,

spectral processing means connected to be responsive to said sampling means, for computing, for each of said transducers, the Fourier transforms of the sampled EEG responses and for computing from said Fourier transforms, for each of said transducers, the spectral energy contained in selected frequency bands,

processing means connected to be responsive to said spectral processing means, for processing the output of said spectral processing means to generate a plurality of matrices, one said matrix for each se-

lected frequency band, each said matrix having elements each of which represents the spectral energy within the respective frequency band at one location on the skull,

display means connected to be responsive to said processing means, for displaying said matrices as topographic maps of the skull, said matrix elements forming discrete points of said maps.

23. The apparatus of claim 22 wherein said sampling means is arranged for sampling and storing as a sequence of digital words selected portions of said EEG responses, and wherein said spectral processing means includes means for digitally performing said Fourier transform determination.

24. The apparatus of claim 23 wherein said sampling means includes means to sample said EEG responses at at least 3 times the highest frequency in said selected frequency bands.

25. The apparatus of claim 24 wherein said sampling means includes means to sample said EEG responses at from 4 to 5 times said highest frequency.

26. The apparatus of claim 22 wherein said sampling means includes marking means for storing the start and stop times of a particular brain activity.

27. The apparatus of claim 22 wherein a time maximum interval for sampling said EEG responses is on the order of two seconds.

28. The apparatus of claim 22 wherein said sampling time interval of said EEG responses is from 0.1 to 4.0 seconds long.

29. The apparatus of claim 22 further comprising averaging means connected to be responsive to said spectral processing means, for averaging said Fourier transforms to generate, for each transducer, the average spectral energy contained within said frequency bands.

30. The apparatus of claim 22 wherein said frequency bands comprise the alpha, beta, delta, and theta bands.

31. The apparatus of claim 22 further comprising filtering means connected to be responsive to said transducers, for removing from said EEG responses frequency components outside the prominent frequency bands of brain electrical activity.

32. The apparatus of claim 31 wherein said filtering means includes means for removing from said EEG responses at least frequency components below 0.5 Hz and above 50 Hz.

33. The apparatus of claim 31 wherein said filtering means includes means for removing from said EEG responses at least frequency components below 0.5 Hz and above 1000 Hz.

34. The apparatus of claim 31 wherein said filtering means includes means for removing from said EEG responses at least frequency components below 300 Hz and above 5000 Hz.

35. The apparatus of claim 22 wherein said spectral processing means includes means for tapering the beginning and end portions of said responses prior to determination of the Fourier transform to reduce high frequency artifacts.

36. Apparatus for generating a topographic display of information of the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patien:

processing means connected to be responsive to said transducers, for processing electrical responses measured at said transducers, said processing means including means for generating one or more matrices, each matrix containing a plurality of elements, said elements representing information on the electrical activity of the brain at particular skull locations,

statistical processing means connected to be responsive to said processing means, for processing at least two said matrices to generate a statistical comparison matrix having elements, each element being representative of a statistical difference between the corresponding elements in said two matrices,

display means connected to be responsive to said statistical processing means, for displaying said statistical comparison matrix as a topographic map of the skull, said matrix element forming discrete points of said map.

37. The apparatus of claim 36 further comprising interpolation means connected to be responsive to said statistical processing means, for expanding said statistical comparison matrix to a larger matrix prior to display, and larger matrix having additional statistical comparison elements for skull locations intermediate said transducer locations, said additional elements being generated by interpolation from the elements of said statistical comparison matrix.

38. The apparatus of claim 36 further comprising interpolation means connected to be responsive to said processing means, for expanding said matrices to larger matrices prior to said statistical processing, said larger matrices having additional elements for skull locations intermediate said transducer locations, said additional elements being generated by interpolation from the elements of said matrices.

39. The apparatus of claim 36 wherein said statistical processing means includes means to generate as said statistical comparison matrix a matrix of t values representing the statistical difference between a first and a second group of matrices, each group having matrices having a plurality of elements.

40. The apparatus of claim 39 wherein said statistical processing means includes

means connected to be responsive to said means to generate a matrix of t values, for generating a first mean-value matrix having elements which are representative of the mean values of the respective elements the matrices said first group,

means connected to be responsive to said means to generate a matrix of t values, for generating a first standard-deviation matrix having elements which are representative of the standard deviations of the respective elements of the matrices of said first group,

means connected to be responsive to said means to generate a matrix of t values, for generating a second mean-value matrix having elements which are representative of the mean values of the respective elements of the matrices of said second group,

means connected to be responsive to said means to generate a matrix of t values, for generating a second standard-deviation matrix having elements which are representative of the standard deviations of the respective elements of the matrices of said second group,

means connected to be responsive to said means to generate a matrix of t values, for generating said matrix of t values from said first and second mean-

value matrices and said first and second standard-deviation matrices.

41. The apparatus of claim 36 wherein said statistical processing means includes means to generate as said statistical comparison matrix a matrix of z values representing the statistical difference between one matrix and a group of matrices.

42. The apparatus of claim 41 wherein said statistical processing means includes

means connected said means to generate a matrix of z values, for generating a first matrix representative of the mean of said group of matrices,

means connected said means to generate a matrix of z values, for generating a second matrix representative of the standard deviation of said group of matrices,

said matrix of z values being generating from said one matrix and said first and second matrices, each of said matrices having a plurality of elements.

43. The apparatus of claim 42 wherein said first matrix is representative of the mean of a normalized reference population, said second matrix is representative of the standard deviation of said population, and the elements of said matrix of z values are thereby representative of the number of standard deviations by which the elements of said one matrix differ from the mean of said population.

44. The apparatus of claim 36 further comprising

means connected to be responsive to said statistical processing means, for producing from said statistical comparison matrix one or more quantitative features which are each determined by processing the elements within selected regions of said statistical matrix,

means connected to be responsive to said means for producing features, for determining a statistical merit value for selected features,

means for determining how to combine said features to form decision rules, and

means connected to be responsive to said means for determining, for classifying individuals using said decision rules.

45. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient,

statistical processing means connected to be responsive to said transducers, for processing responses at said electrical-activity transducers to generate a coefficient-of-variance matrix, said matri having element each of which represents the normalized standard deviation of the responses at one skull location, the normalized standard deviation being the standard deviation divided by the mean,

display means connected to be responsive to said statistical processing means, for displaying said coefficient-of-variance matrix as a topographic map of the skull, thereby providing a map of the level of variation in brain activity.

46. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient,

processing means connected to be responsive to said transducers, for generating from responses measured at said transducers a time sequence of first matrices, each said first matrices having display elements representing the instantaneous response at various locations on said skull,

temporal interpolation means connected to be responsive to said processing means, for generating by interpolation second matrices interspersed in said sequence of first matrices, said second matrices having elements representing the approximate response at instants of time intermediate the instants of time associated with said first matrices,

display means connected to be responsive to said processing means, for displaying said first matrices and said interspersed second matrices as a time sequence of topographic maps of the skull, said matrix elements forming discrete points of said maps, said second matrices enhancing the visual smoothness of the transitions over time between said first matrices.

47. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient,

processing means connected to be responsive to said transducers, for generating one or more matrices from the responses measured at said transducers, each matrix having elements representing information on electrical activity of the brain at one location on the skull,

display means connected to be responsive to said processing means, for displaying said matrices as topographic maps of the skull, said matrix elements forming discrete points of said maps,

waveform quality control means for previewing said transducer responses or processed versions thereof, said quality control means including at least two of the following means

means for tagging a response with information on its waveform quality, including an indication of whether the response should be used in later processing,

means at the discretion of the operator for eliminating a response from further processing,

means for automatically eliminating a response from further processing if a portion thereof exceeds a predetermined threshold,

means for smoothing a response to eliminate undesired high frequency components,

means for adjusting a zero baseline of a response, said zero baseline having been previously set automatically,

means for eliminating selected portions of a response from further processing, and

means for displaying in numerical form the value of a response at a point in time selected by the operator.

48. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient,

means connected to be responsive to said transducers, for sampling responses measured at said transduc-

ers and storing the sampled responses as a series of data matrices, one matrix for each sampling time,

means connected to be responsive to said means for sampling, for selectively viewing the sampled responses corresponding to a single transducer as a plot of transducer output versus time,

quality control means for adjusting portions of said selectively viewed responses or eliminating said responses from further processing,

processing means connected to be responsive to said means for sampling, for processing said data matrices to generate one or more processed matrices, said processed matrices having elements each corresponding to one transducer location,

interpolation means connected to be responsive to said processing means, for generating expanded matrices by expanding the number of elements in said processed matrices to provide elements corresponding to skull locations intermediate said transducer locations,

display means connected to be responsive to said interpolation means, including a video monitor capable of generating a matrix of grey tones for displaying said expanded matrices as topographic maps of the skull, said expanded matrices having elements defining the grey tones of discrete points on said maps.

49. The apparatus of claim 48 further comprising matrix storage means connected to be responsive to said means for sampling, processing means, and interpolation means, for tagging selected data, processed, or expanded matrices and storing them for later recall and processing.

50. The apparatus of claim 48 further comprising means connected to be responsive to said transducers, for storing calibration responses from said transducers and means for calibrating said responses matrices by determining from said stored calibration responses a DC offset and gain for each said transducer.

51. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient,

processing means connected to be responsive to said transducers, for processing responses measured at said transducers to generate one or more matrices, each matrix having elements representing information on brain activity at different skull locations,

display means connected to be responsive to said processing means, for displaying said one or more matrices as topographic maps of the skull, said matrix elements forming discrete points of said maps, said display means including a video monitor which generates a visible grey tone at each said discrete point, said tone being variable from a maximum tone to a minimum tone, and

scaling means connected to be responsive to said processing means, for scaling said matrix elements to the available tones.

52. The apparatus of claim 51 wherein

said video monitor generates a zero tone intermediate said maximum and minimum tone and

said scaling means comprises at least two of the following means

means connected to be responsive to said processing means, for scaling the maximum matrix element to the maximum tone and the minimum matrix element to the minimum tone and linearly interpolating inbetween,

means connected to be responsive to said processing means, for scaling the maximum matrix element to the maximum tone and the minimum matrix element to the zero tone and linearly interpolating inbetween,

means connected to be responsive to said processing means, for scaling the maximum matrix element to an operator supplied tone,

means connected to be responsive to said processing means, for scaling the minimum matrix element to an operator supplied tone,

means connected to be responsive to said processing means, for excluding from the scaling operation selected unusually high or low valued matrix elements and for assigning to matrix elements that fall outside the available tone range the closer of the maximum or minimum tone.

53. The apparatus of claim 51 wherein said video monitor generates colored grey tones of a first and a second color, with grey tones of said first color forming said grey tones between said maximum tone and said zero tone, with grey tones of said second color forming said grey tones between said minimum tone and said zero tone, and with the absence of a color tone forming said zero tone.

54. The apparatus of claim 53 wherein said two colors are complementary colors.

55. The apparatus of claim 53 wherein there are at least 6 grey tones of each of said two colors.

56. The apparatus of claim 51 wherein there are a plurality of said matrices to be displayed and said scaling means includes means for independently performing said tone scaling for each matrix displayed.

57. The apparatus of claim 51 wherein there are a plurality of said matrices to be displayed and said scaling means includes means for scaling with respect to the display elements in all said matrices so that the scaling remains the same for each matrix displayed.

58. The apparatus of claim 51 further comprising preview means connected to be responsive to said transducers, for viewing selected segments of the transducer responses and for tagging selected segments for exclusion from the scaling operation and wherein said scaling means includes means for identifying the presence of said tagging and for excluding data so tagged from said scaling operation.

59. Apparatus for generating a topographic display of information on the electrical activity of the brain, said apparatus comprising

a plurality of electrical-activity transducers adapted to be placed at spaced apart locations on the skull of a patient,

processing means connected to be responsive to said transducers, for processing responses measured at said transducers to generate one or more matrices, each matrix having elements representing information on brain activity at different skull locations,

display means connected to be responsive to said processing means, for displaying said one or more matrices as a topographic map of the skull, said matrix elements forming discrete points of said map, said display means including a video monitor which generates a tone at each said discrete point, said tone varying from a maximum tone to a minimum tone,

normalizing means connected to be responsive to said processing means, for normalizing said matrix elements to a selected value, and

scaling means connected to be responsive to said processing means, for scaling said matrix elements to the available tones, said scaling means including means for assigning a selected tone to said selected normalization value.

60. The apparatus of claim 59 wherein said normalizing means includes means for normalizing said matrix elements to the matrix element representing brain electrical activity at the vertex.

61. The apparatus of claim 59 wherein said normalizing means includes means for normalizing each individual matrix element to the root mean square value of the background electrical activity at the skull location represented by the individual matrix element.

62. The apparatus of claim 59 wherein said normalizing means includes means for normalizing said matrix elements to the average root mean square value of the background electrical activity over all skull locations.

63. The apparatus of claim 59, 60, 61 or 62 further comprising

stimulus means for repeatedly providing a sensory stimulus for the brain, to produce repeated EP responses at said transducers,

response averaging means connected to be responsive to said transducers, for averaging said repeated responses for each transducer to produce an average response for each transducer, and

wherein said processing means includes means for generating from said average responses a time sequence of said matrices, and

said display means includes means for displaying said matrices in sequence.

64. The apparatus of claim 59 wherein

there is further provided spectral processing means connected to be responsive to said transducers, for computing the Fourier transforms of the responses measured by said electrical-activity transducers and for computing from said Fourier transforms the spectral energy contained in selected frequency bands,

said processing means includes means for processing the output of said spectral processing means to generate a plurality of matrices, one said matrix for each selected frequency band, each matrix having elements representing the spectral energy within the selected frequency band at various locations on the skull, and

said normalizing means includes means to normalize said matrix elements either to the total spectral energy for all said frequency bands at the skull location corresponding to said matrix element or to the average total spectral energy for all said frequency bands for all matrix elements.

65. The apparatus of claim 1, 4, 6, 8, 22, 45, 46, 47, 48, 51, or 59 wherein said processing means includes interpolation means for generating by interpolation additional matrix elements for skull locations intermediate the locations of said transducers.

66. The apparatus of claim 65 wherein said interpolation means includes means for computing the values of said additional matrix elements by three point interpolation from the values associated with the three closest transducer locations.

67. The apparatus of claim 66 wherein said three point interpolation is linear.

68. The apparatus of claim 1, 4, 6, 8, 22, 36, 45, 46, 47, 48, 51, or 59 wherein the number of said electrical-activity transducers is in the range of 10 to 200 and the number of elements in said topographic maps is at least 5 times the number of transducers.

69. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient,

storing responses of said transducers during first and second time periods,

processing said responses to generate first and second matrices each having elements representing brain activity at different skull locations, said first matrix representing information on brain activity during said first period, and said second matrix representing information on brain activity during said second period,

forming a difference matrix having elements each corresponding to the difference between corresponding elements of said first and second matrices, and

displaying said difference matrix as a topographic map of the skull, said matrix elements each forming a discrete point of said topographic map.

70. The method of claim 69 further comprising the step of providing as a stimulus for the brain during said first period a source of patterned light and providing as a stimulus for the brain during said second period a source of nonpatterned light.

71. A method of generating a topographic display of information on the EP response of the brain, said method comprising the steps of:

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient,

repeatedly providing a sensory stimulus for the brain so as to produce at said transducers repeated segments of data, each segment including a pre-stimulus response and a post-stimulus response,

averaging the repeated segments to produce an average segment for each transducer,

determining a zero baseline for each average segment from the mean level of at least a portion of the average pre-stimulus response,

subtracting the zero baselines from the respective average segments to produce zeroed average segments,

processing the zeroed average segments to generate one or more matrices of elements, with each matrix element representing information on the EP response at one location on the skull, and

displaying said one or more matrices as topographic maps of the skull, with each display point forming a discrete point on said maps.

72. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient,

repeatedly providing a sensory stimulus for activating the brain to produce EP responses at said transducers,

averaging said responses to produce average responses for each transducer,

processing said average responses to generate a time sequence of matrices,

displaying said matrices as a time sequence of topographic maps of the skull, said matrices having elements defining discrete points of said maps, and

displaying said topographic maps at a variable frame rate,

maps corresponding to different portions of said average responses being displayed respectively at different selected frame rates.

73. A method for generating a topographic display of information on the electrical activity of the brain, said method including the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull,

processing responses of said transducers to generate a time sequence of matrices, each said matrix having elements representing the instantaneous amplitudes of said responses at various locations on the skull and there being a sufficient number of said matrices for a selected time period of actual brain activity for capturing onset of a transient event that occurs with a rapidity on the order of that of an epileptic spike,

generating from said time sequence of matrices a running-average matrix which at any given time represents the current matrix averaged with a selected number of the matrices preceding it in time,

displaying said matrices as a time sequence of topographic maps of the skull at a variable frame rate, each running-average matrix having elements defining discrete points of said maps, and

selectably slowing the frame rate at which said topographic maps are displayed so as to permit observation of said transient event.

74. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient to measure the EEG response at said locations,

sampling the EEG responses during time intervals shorter than the anticipated interval between interruptions in the state of brain activity,

computing, for each of said transducers, the Fourier transforms of the sampled EEG responses and computing from said Fourier transforms, for each of said transducers, the spectral energy contained in selected frequency bands,

processing said computed spectral energy of said selected frequency bands to generate a plurality of matrices, one said matrix for each selected frequency band, said matrices having elements representing the spectral energy within the respective frequency band at one location on the skull, and

displaying said matrices as topographic maps of the skull, said matrix elements forming discrete points of said maps.

75. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient,

processing electrical responses measured at said transducers, said processing means including means for generating one or more matrices, each matrix containing a plurality of elements, said elements representing information on the electrical activity of the brain at particular skull locations,

processing at least two said matrices to generate a statistical comparison matrix said statistical comparison matrix having elements each of which representative of a statistical difference between the corresponding elements in said two matrices, and

displaying said statistical comparison matrix as a topographic map of the skull, said matrix elements forming discrete points of said map.

76. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient,

statistically processing responses at said electrical-activity transducers to generate a coefficient-of-variance matrix, said matrix having elements each of which represents the normalized standard deviation of the responses at one skull location, the normalized standard deviation being the standard deviation divided by the mean,

displaying said coefficient-of-variance matrix as a topographic map of the skull, thereby providing a map of the level of variation in brain activity.

77. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers for placement at spaced apart locations on the skull of a patient,

generating from responses measured at said transducers a time sequence of first matrices, each said first matrix having display elements representing the instantaneous response at various locations on said skull,

generating by interpolation second matrices interspersed in said sequence of first matrices, said second matrices having elements representing the approximate response at instants of time intermediate the instants of time associated with said first matrices,

displaying said first matrices and said interspersed second matrices as a time sequence of topographic maps of the skull, said matrix elements forming discrete points of said maps, said second matrices enhancing the visual smoothness of the transitions over time between said first matrices.

78. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient,

generating one or more matrices from responses measured at said transducers, each matrix having elements representing information on the electrical activity of the brain at one location on the skull,

displaying said one or more matrices as topographic maps of the skull, said matrix elements forming discrete points of said maps,

previewing said transducer responses or processed versions thereof, said previewing including at least two of the following steps

tagging a response with information on its waveform quality, including an indication of whether the response should be used in later processing,

eliminating a response from further processing at the discretion of the operator,

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automatically eliminating a response from further processing if a portion thereof exceeds a predeterminedthreshold,

smoothing a response to eliminate undesired high frequency components,

adjusting a zero baseline of a response, said zero baseline having been previously set automatically

eliminating selected portions of a response from further processing, and

displaying in numerical form the value of a response at a point in time selected by the operator.

79. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient,

sampling responses measured at said transducers and storing the sampled data as a series of data matrices, one matrix for each sampling time,

selectively viewing the sampled data corresponding to a single transducer as a plot of transducer output versus time,

adjusting portions of said selectively viewed data or eliminating said data from further processing,

processing said data matrices to generate one or more processed matrices said one or more processed matrices having elements each corresponding to one transducer location,

expanding the number of elements in said one or more processed matrices to provide elements corresponding to skull locations intermediate said transducer locations,

providing a video monitor capable of generating a matrix of grey tones for displaying said expanded matrices as topographic maps of the skull, said expanded matrix elements defining the grey tones of discrete points on said maps.

80. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient,

processing responses measured at said transducers to generate one or more matrices, each matrix having elements representing information on brain activity at different skull locations,

displaying one or more said matrices as topographic maps of the skull, said matrix elements forming discrete points of said maps,

providing a video monitor which generates a visible grey tone at each said discrete point, said tone being variable from a maximum tone to a minimum tone, and

scaling said matrix elements to the available tones.

81. The method of claim 80 wherein

said providing step comprises providing a said video monitor which generates a zero tone intermediate said maximum and minimum tone, and

said scaling step comprises at least two of the following steps

scaling the maximum matrix element to the maximum tone and the minimum matrix element to the minimum tone and linearly interpolating inbetween,

scaling the maximum matrix element to the maximum tone and the minimum matrix element to the zero tone and linearly interpolating in between,

scaling the maximum matrix element to an operator supplied tone,

scaling the minimum matrix element to an operator supplied tone,

excluding from the scaling operation selected unusually high or low valued matrix elements and assigning to matrix elements that fall outside the available tone range the closer of the maximum or minimum tone.

82. A method for generating a topographic display of information on the electrical activity of the brain, said method comprising the steps of

placing a plurality of electrical-activity transducers at spaced apart locations on the skull of a patient,

processing responses measured at said transducers to generate one or more matrices, each matrix having elements representing information on brain activity at different skull locations,

displaying said one or more matrices as a topographic map of the skull, said matrix elements forming discrete points of said map,

providing a video monitor which generates a tone at each said discrete point, said tone varying from a maximum tone to a minimum tone,

normalizing said matrix elements to a selected value, and

scaling said matrix elements to the available tones, said scaling means including means for assigning a selected tone to said selected normalization value.

* * * * *

US005213562A

United States Patent [19]

Monroe

[11] Patent Number: 5,213,562

[45] Date of Patent: May 25, 1993

[54] METHOD OF INDUCING MENTAL, EMOTIONAL AND PHYSICAL STATES OF CONSCIOUSNESS, INCLUDING SPECIFIC MENTAL ACTIVITY, IN HUMAN BEINGS

[75] Inventor: Robert A. Monroe, Nelson County, Va.

[73] Assignee: Interstate Industries Inc., Faber, Va.

[21] Appl. No.: 514,460

[22] Filed: Apr. 25, 1990

[51] Int. Cl.[5] A61M 21/00

[52] U.S. Cl. 600/28; 128/732

[58] Field of Search 600/26-28; 128/731-732, 905

[56] References Cited

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3,837,331	9/1974	Ross .	
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4,335,710	6/1982	Williamson .	
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5,036,858	8/1991	Carter et al.	128/732

Primary Examiner—Lee S. Cohen
Assistant Examiner—John P. Lacyk
Attorney, Agent, or Firm—Sughrue, Mion, Zinn, Macpeak & Seas

[57] ABSTRACT

A method having applicability in replication of desired consciousness states; in the training of an individual to replicate such a state of consciousness without further audio stimulation; and in the transferring of such states from one human being to another through the imposition of one individual's EEG, superimposed on desired stereo signals, on another individual, by inducement of a binaural beat phenomenon.

6 Claims, 5 Drawing Sheets

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FIG.1A

FIG.1B

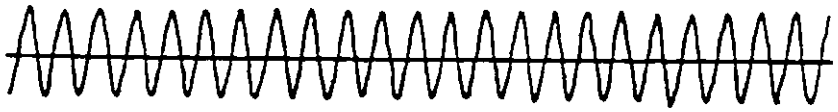

FIG.1C

FIG.2A

FIG.2B

FIG.2C

FIG.2D

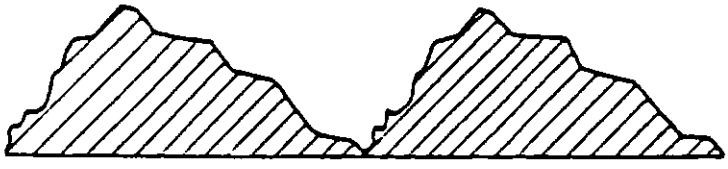

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FIG.3A

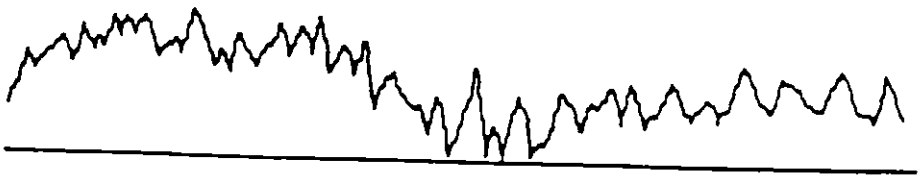

FIG.3B

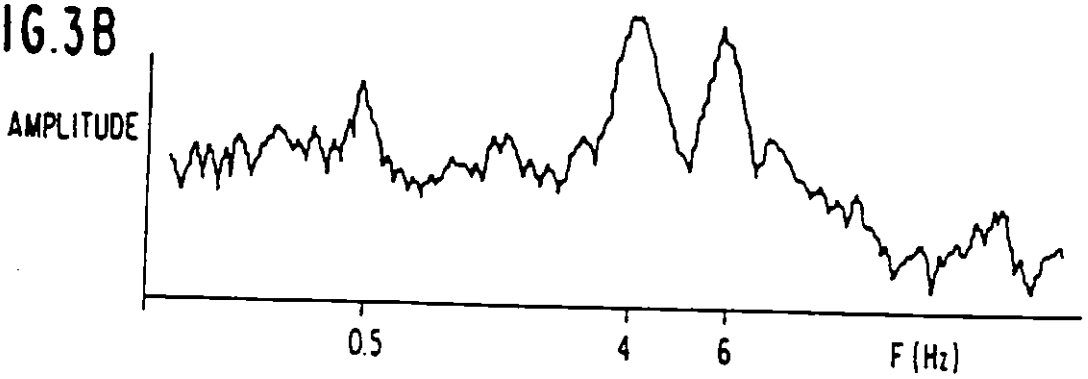

FIG.3C

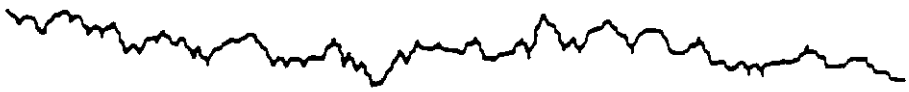

FIG.3D

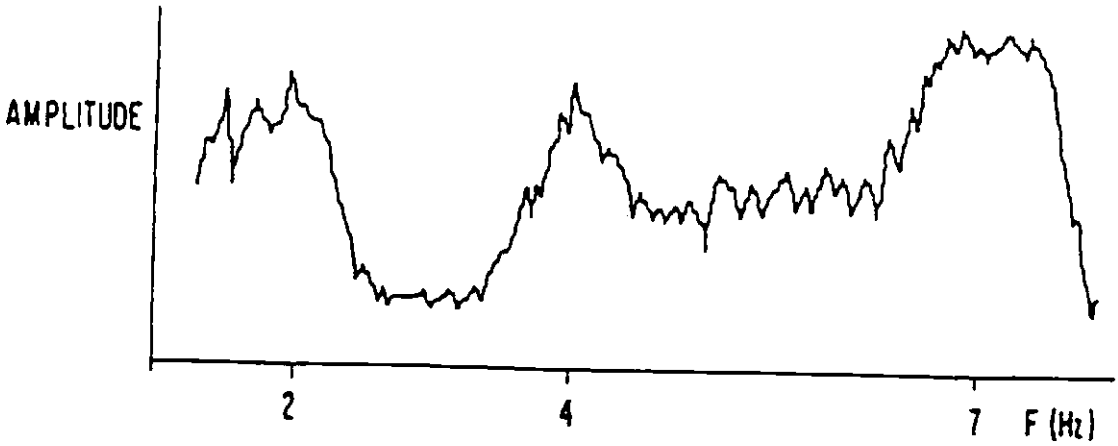

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FIG.3E

FIG.3F

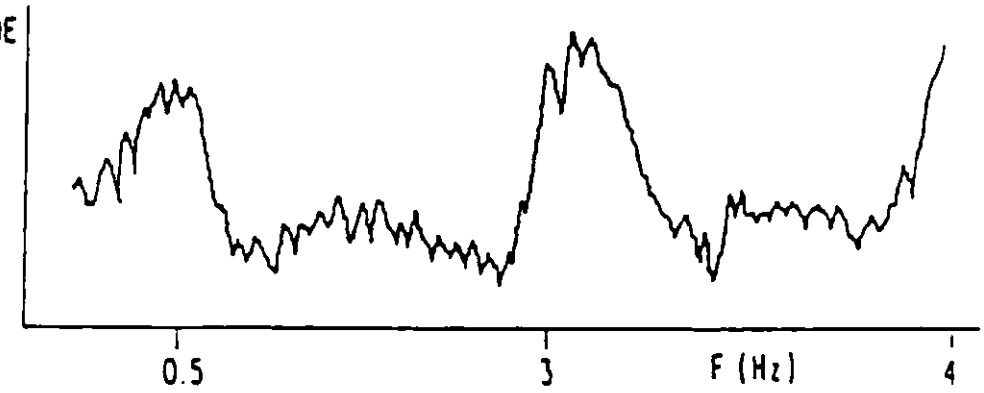


FIG.3G

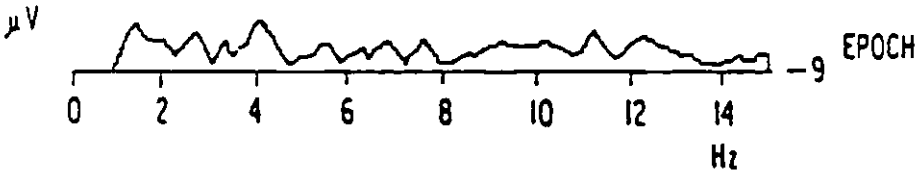
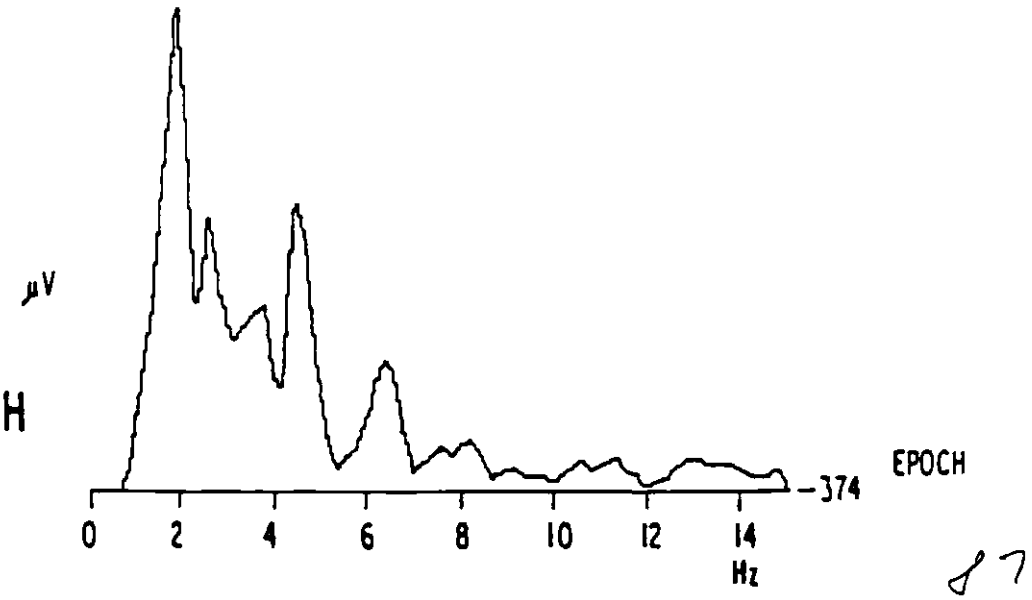


FIG.3H



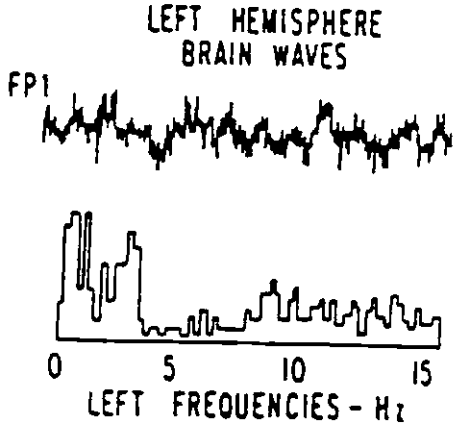


FIG. 4A

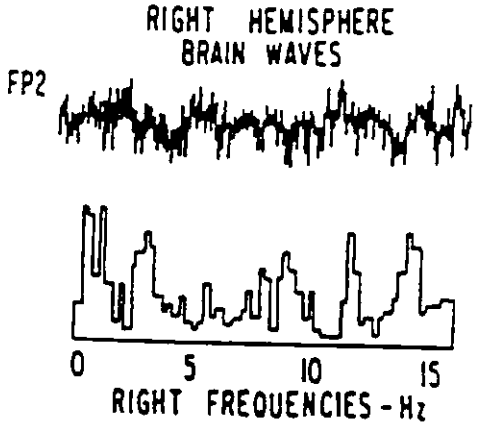


FIG. 4B

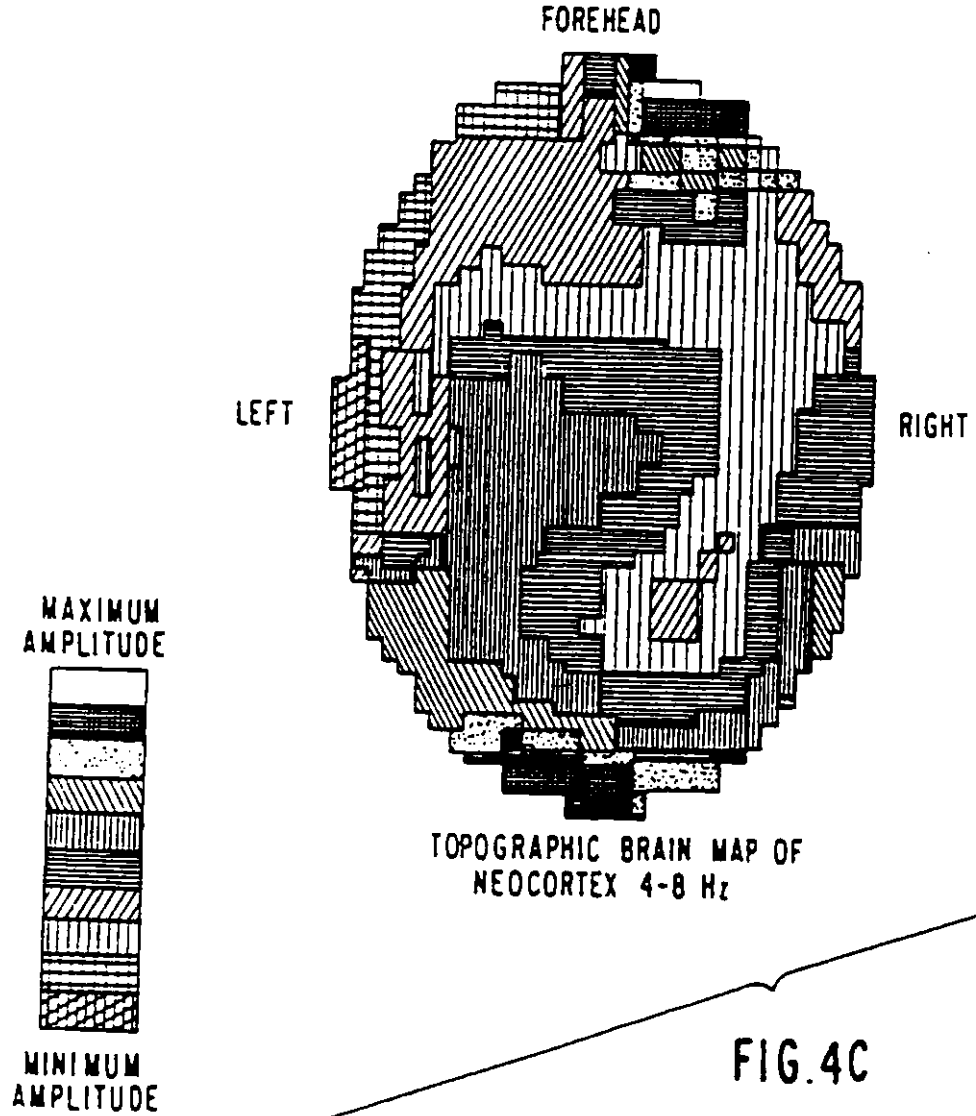


FIG. 4C

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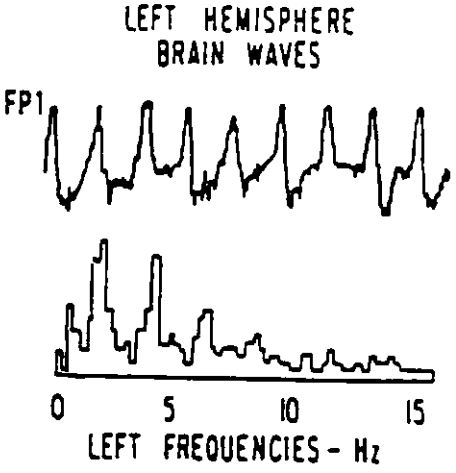

FIG. 4D

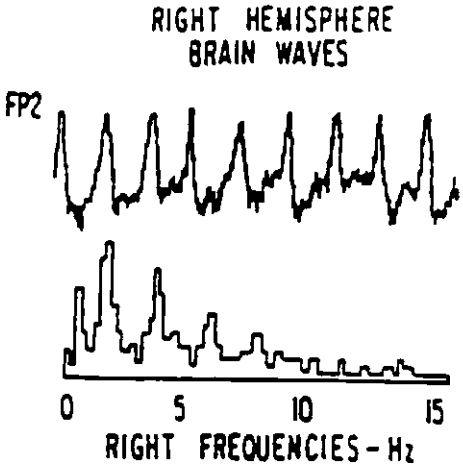

FIG. 4E

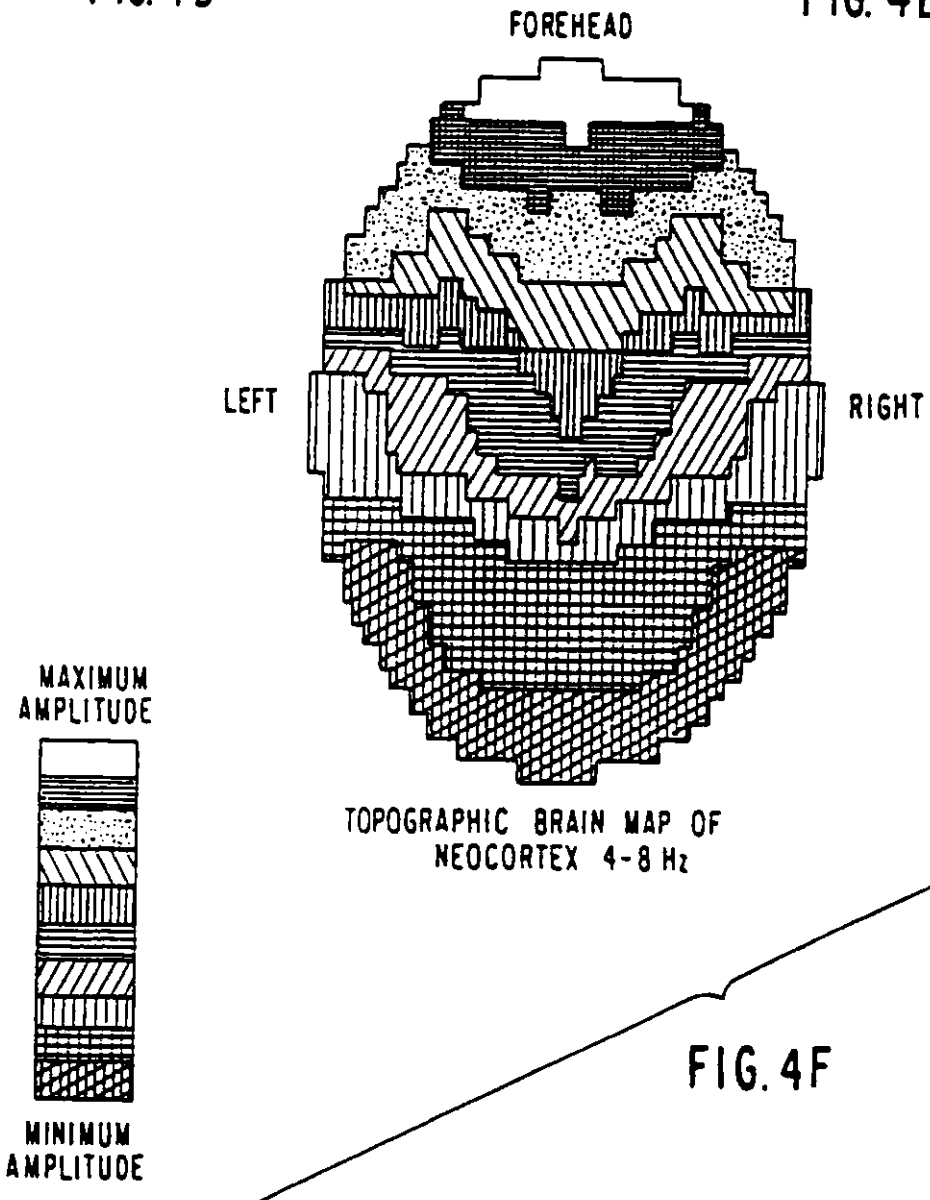

FIG. 4F

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METHOD OF INDUCING MENTAL, EMOTIONAL AND PHYSICAL STATES OF CONSCIOUSNESS, INCLUDING SPECIFIC MENTAL ACTIVITY, IN HUMAN BEINGS

BACKGROUND OF THE INVENTION

The present invention relates to a method of inducing various states of consciousness in human beings. More particularly, the invention relates to a method of inducing such states of consciousness through generation of stereo audio signals having specific wave shapes which act as a carrier of a binaural beat. The resultant binaural beat acts to entrain brain waves into unique waveforms characteristic of identified states of consciousness. The invention is applicable in areas of learning and behavior replication as well as in the area of sleep inducement, and thus represents a significant departure from and improvement over known audio-based sleep inducement techniques, some of which will be discussed below.

The binaural beat phenomenon was discovered in 1839 by H. W. Dove, a German experimenter. Generally, this phenomenon works as follows. When an individual receives signals of two different frequencies, one signal to each ear, the individual's brain detects a phase difference or differences between these signals. When these signals are naturally occurring, the detected phased difference provides directional information to the higher centers of the brain. However, if these signals are provided through speakers or stereo earphones, the phase difference is detected as an anomaly. The resulting imposition of a consistent phase difference between the incoming signals causes the binaural beat in an amplitude modulated standing wave, within each superior olivary nucleus (sound processing center) of the brain. It is not possible to generate a binaural beat through an electronically mixed signal; rather, the action of both ears is required for detection of this beat.

FIGS. 1A and 1B show two superposed waves of different frequencies. FIG. 1C shows the resulting wave, which has a clear beat phenomenon. Assuming the two waves have equal amplitude but different respective frequencies f_1, f_2, the combination of the two waves may be represented mathematically as follows:

$$\begin{aligned} X &= X_1 + X_2 \\ &= a\cdot\cos(2\pi f_1 t) + a\cdot\cos(2\pi f_2 t) \\ &= a\cdot[\cos(2\pi f_1 t) + a\cdot\cos(2\pi f_2 t)] \\ &= 2a\cdot\cos\left(2\pi\frac{[f_1 - f_2]}{2}t\right)\cdot\cos\left(2\pi\frac{[f_1 + f_2]}{2}t\right) \end{aligned}$$

The beat phenomenon arises from the variation in amplitude of a resulting carrier frequency. Pulses appear every $\frac{1}{2}(f_1-f_2)$, with two maxima occurring each cycle, when $\cos(2\pi)\frac{1}{2}[f_1-f_2]=\pm 1$. That is, the beat frequency is simply f_1-f_2, a result which agrees with experience.

Known consciousness state inducing techniques have not used this binaural beat phenomenon, but have relied on other techniques, as follows. For example the use of audio generators to induce a state of consciousness known as sleep is well known in the prior art, as exemplified by U.S. Pat. No. 2,711,165 and 3,384,074. In one type of technique exemplified in these patents, generated audio signals include pleasing and harmonious

study sounds or vibrations, fixed frequency signals which are buried cyclically with respect to amplitude, and repetitive sounds such as the falling of rain on the roof and the sighing wind through the trees.

U.S. Pat. No. 2,304,095 relates to a method of inducing sleep by generation of an audible or tactual signal which is related to the physiological process of heartbeat and respiration. In the disclosed method, the pitch and amplitude of a pleasing audio signal are varied at a rate somewhat slower than either the rate of heartbeat or the rate of respiration. As a result, heartbeat and respiration tend to synchronize with the audio signal, thus lowering heartbeat and respiration rates and inducing sleep.

Of course, there are other naturally-occurring sounds which have been recorded, and which are not varied, but which instead induce a state of relaxation which leads to sleep for a similar reason. For example, the pounding of waves on a shore line occurs at a frequency generally lower than that of heartbeat or respiration, and induces a state of relaxation.

The use of an electroencephalogram (EEG) as a research and diagnostic tool has led to findings that particular brain wave patterns are indicative of different states of consciousness. In 1934, researchers discovered that brain waves, and their associated states of consciousness, could be altered with repetitive visual stimulation at a known frequency, an effect known as entrainment. Scientific interest in entrainment continued throughout the 1960's. In the 1970's, numerous independent studies repeatedly confirmed that rhythmic flashing lights rapidly entrained brain waves.

A sonic equivalent of photic entrainment also is known, as disclosed for example in commonly-assigned U.S. Pat. No. 3,884,218, the inventor of which is the inventor of the present application. This patent discloses a method of inducing sleep in a human being by generating an audio signal which is made up of a familiar pleasing repetitive sound modulated by frequencies usually associated with an EEG sleep pattern. There are different EEG patterns related to various levels or depths of sleep, and it has been found that by modulating the repetitive sound with these different sleep patterns, it is possible to induce various levels of sleep. The inventor has coined the term frequency following response, or FFR, to describe this phenomenon.

Other known techniques for inducing various states of consciousness, or for performing brainwave analysis and related functions, are shown, for example, in the following U.S. patents:

2,466,054	4,034,741	3,160,159	4,141,344
3,576,185	4,227,516	3,712,292	4,335,710
3,753,433	4,573,449	3,826,243	4,834,701
3,837,331.			

The binaural beat phenomenon described above also can create a frequency entrainment effect. If a binaural beat is within the range of brain wave frequencies, generally less than 30 cycles per second, the binaural beat will become an entrainment environment. This effect has been used to study states of consciousness, to improve therapeutic intervention techniques, and to enhance educational environments. However, the modulation of the binaural beat signals with brain waves associated with particular activities has not been attempted previously.

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SUMMARY OF THE INVENTION

In view of the foregoing, it is one object of the invention to provide a method of inducing states of consciousness by generating stereo audio signals having specific wave shapes. These signals act as a carrier of a binaural beat. The resulting beat acts to entrain brain waves into unique waveforms characteristic of identified states of consciousness.

The method of the invention extends beyond the confines of the frequency entraining concept, and incorporates waveform entrainment by altering the wave shape of the binaural beat. Conventional binaural beat frequency entrainment previously has been limited to conventional wave shapes, i.e., square triangular sinusoidal, or in some cases, the various musical instruments. For example, it is known that radiant energy, such as sound in this case, may be defined by its frequency, amplitude, and wave shape. A musical note is a particularly suitable example of this. Generally, the musical note A above middle C in the twelve tone diatonic scale is assigned a frequency of 440 cycles per second. The amplitude of that note is expressed as the loudness of the signal. However, the wave shape of that note is related strongly to the instrument used. An A played on a trumpet is quite different from an A played on a violin.

The similarity results from the distinct shapes of the waveforms of each instrument. Similarly, human brain waves also have unique wave shapes, wave contours which are neither sinusoidal, nor square, nor triangular, nor like those of any musical instrument.

In accordance with the invention, human brain waves, in the form of EEGs, are superimposed upon specific stereo audio signals, known as carrier frequencies which are within the range of human hearing. Thus the invention relates not only to techniques of generating the binaural beat, but also to specific waveforms of the binaural beat in frequency, waveshape, and amplitude, and most particularly to the source of the data used to produce such waveforms.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1C show two waves at different frequencies, and the resulting binaural beat, respectively;

FIGS. 2A-2D show an input wave, two stereo carrier waves as determined by Fourier analysis, and the resultant binaural beat wave, which matches the contour of the input wave;

FIGS. 3A-3B, 3C-3D, 3E-3F, and 3G-3H are pairs of graphs showing a normal waking EEG and FFR responses in different signal ranges, respectively; and

FIGS. 4A-4F show topographic brain maps of the neocortex of a subject in a normal waking state, and after listening to a binaural beat sound pattern.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

As will be discussed below, different regions of the brain produce distinct electrical waveforms during various physical, mental, and emotional states of consciousness. In the method of the invention, binaural beat audio wave shapes are made to match such particular brain waves as they occur during any mental physical, and emotional human condition of consciousness. Thus, it is possible to convert waveforms from specific brain regions, as well as complete brain surface electrical topography.

In the audio application of the invention, using sampled EEG waveforms from a subject in specific states of consciousness and activity, mental and/or physical, these waveforms are impressed upon multiple sets of sound carrier waves within the human spectrum of hearing. Thus, the waveforms translate into wave amplitude modulations of the carrier to effect what is called a frequency following response, or FFR, as mentioned above.

Some description of the empirical procedure used in the course of developing the invention will be useful, as background. In the 1970s, testing was done on various subjects for effective EEG frequencies using audio signals as a human stimulus. Such frequencies were replicated as amplitude modulation of single-channel audio signals within human hearing ranges, for use in sleep-inducing, attention-focusing, etc.

Where particular subjects responded especially well, those signals were converted to binaural beat patterns. The binaural beat signals were derived by first selecting frequencies of the single-channel audio signals based on the well-known "Oersted Curve", named after the famous 19th century physicist. Using this curve permitted selection of specific audio frequencies to provide the greatest binaural beat frequencies at a much lower range. The effectiveness of the tests were doubled as a result of using binaural beat signals.

In the mid 1980s, EEG waveforms themselves were examined as produced by the binaural signals employed. FFR and entrainment factors thought to be responsible for success were verified. One of the results identified as the probable cause of such effectiveness was the synchronization of the brain hemispheres in such signal frequency ranges (i.e. the induced signals were present simultaneously in major portions of both brain hemispheres).

Experimentation expanded to different subjects in similar states of consciousness. Isolation of EEG patterns in these states of consciousness, and conversion of these patterns to binaural sound, with subsequent reapplication of the binaural sounds produced significantly enhanced results. The effect was especially apparent among naive subjects.

Recently, EEG neuromapping began of subjects with particular talents, where those subjects could utilize those talents (e.g. playing a piano sonata, or solving a mathematical equation) at a mental or visualization level. It was possible to isolate the EEG waveforms related to utilization of those talents, and to convert those waveforms to binaural sound. Subsequent exposure of the subject to such patterns enhanced the individual's ability to replicate the process. Exposing other subjects to the signals produced a learned response through repetition.

Thus, the inventor believes that the inventive process, while not necessarily creating a musician or a mathematician, will set up an EEG ambiance in which learning will be facilitated.

Looking more closely now at the implementation and effects of the invention, FIGS. 2A-2D show a phenomenon wherein an input brain wave signal from a particular brain region is superimposed on stereo carrier waves. FIG. 2D shows the resultant binaural beat wave which matches the contour of the input wave.

The generation and propagation of the binaural beat may be understood from the following series of equations, based on the following.

taking the components from FIGS. 1A-1C, and scaling each component to an appropriate factor (say, α and β).

These components could be recombined to form a beat in accordance with the original components. Linearity and orthogonality principles make these manipulations possible. First, assign the measured wave to be the beat frequency, x.

$$x=\alpha-\beta$$

From the beating waves discussed with respect to FIGS. 1A-1C:

$$\sin(\alpha)+\sin(\beta)=2\cos\left(\frac{\alpha-\beta}{2}\right)\sin\left(\frac{\alpha+\beta}{2}\right)=$$

$$2\cos\left(\frac{x}{2}\right)\sin\left(\frac{2\alpha-x}{2}\right)$$

$$\cos(\alpha)+\cos(\beta)=2\cos\left(\frac{\alpha-\beta}{2}\right)\cos\left(\frac{\alpha+\beta}{2}\right)=$$

$$2\cos\left(\frac{x}{2}\right)\cos\left(\frac{2\alpha-x}{2}\right)$$

Now, let us alter the Fourier series $f(x)$ to produce the beat in the shape of the original wave, $f'(x)$:

$$f(x)=\frac{1}{2}a_0+\frac{1}{2}\sum_{n=1}^{\infty}\cos\left(\frac{nx}{2}\right)\left[a_n\cos\left(n\frac{2\alpha-x}{2}\right)+b_n\sin\left(n\frac{2\alpha-x}{2}\right)\right]$$

$$=\frac{1}{2}a_0+\frac{1}{2}\sum_{n=1}^{\infty}\cos\left(n\frac{\alpha-\beta}{2}\right)\left[a_n\cos\left(n\frac{\alpha+\beta}{2}\right)+b_n\sin\left(n\frac{\alpha+\beta}{2}\right)\right]$$

$$=\frac{1}{2}a_0+\frac{1}{2}\sum_{n=1}^{\infty}\cos\left(n\frac{\alpha-\beta}{2}\right)a_n\cos\left(n\frac{\alpha+\beta}{2}\right)+\cos\left(n\frac{\alpha-\beta}{2}\right)b_n\sin\left(n\frac{\alpha+\beta}{2}\right)\right]$$

$$=\frac{1}{2}a_0+\frac{1}{2}\sum_{n=1}^{\infty}a_n[\cos(\alpha)+\cos(\beta)]+b_n[\sin(\alpha)+\sin(\beta)])$$

$$=\frac{1}{4}a_0+\frac{1}{2}\sum_{n=1}^{\infty}[a_n\cos(\alpha)+b_n\sin(\alpha)]+\frac{1}{4}a_0+\frac{1}{2}\sum_{n=1}^{\infty}[a_n\cos(\beta)+b_n\sin(\beta)]$$

$$=\frac{1}{2}\left(\frac{1}{2}a_0+\sum_{n=1}^{\infty}[a_n\cos(\alpha)-b_n\sin(\alpha)]\right)+\frac{1}{2}\left(\frac{1}{2}a_0+\sum_{n=1}^{\infty}[a_n\cos(\beta)+b_n\sin(\beta)]\right)$$

$$=\frac{1}{2}g(\alpha)+\frac{1}{2}h(\beta)$$

From the foregoing, it can be seen readily that $g(\alpha)$ and $h(\beta)$ have become two waves, each having half the amplitude of the original wave, the combination of these waves producing a beat which is the input shape $f(x)$.

Thus, using two-channel stereo sound, it is possible to modulate two separate sets of carrier waves so tha: :he replicated EEG waveforms are created as differential beat frequencies between the separate sets. Thus, the method permits the direct application on a frequency base without having to consider the limitation of the spectrum of human hearing. The brain itself synthesizes the signals which cause the effect.

One example may be as follows. If a carrier frequency of 100 Hz were employed in one channel of the audio signal, and a carrier frequency of 104 Hz were employed in the other channel, a binaural beat of 4 Hz would result. In EEG waveform synthesis, as many as 100 separate carrier pairs may be used or a single broadbanded carrier pair may be used to generate a similar number of specific binaural beats that replicate the EEG waveforms in both frequency and amplitude.

A 4 Hz, or a 5 Hz binaural beat would be too low in frequency to hear. Using the Oersted curve mentioned above, the most effective harmonic carrier would be 275 Hz, which is within hearing range. For the multiple waveform situation just discussed, the differential between carrier waves on a single channel also is utilized to produce an FFR.

One type of audio pattern found to be particularly useful in implementing the inventive method is what is known to the inventor as Phased Pink Sound. The full spectrum of audible sound is known commonly as "white" noise. "Pink" sound is known to result from an adjustment in amplitude of white sound to compensate for decline in perception by the human ear at both ends of the audible spectrum.

Phased Pink Sound results from the relative rotational shifting of pink sound from one stereo audio channel to another with cyclic changes in amplitude, frequency, and rate of panning. Such changes generally are synchronous with selected waveforms within the multiple patterns of the binaural beat generating system. Studies have shown that using Phased Pink Sound at a level at least 10 dB lower than the binaural beat signals produces as much as a 30% enhancement in FFR within the EEG waveforms of the listening individual. There is some basis for concluding that Phased Pink Sound provides an audio base that assists the brain in "synthesizing" the binaural beat frequencies normally inaudible in the human hearing process.

Basically, Phased Pink Sound is generated by a digital processor, which converts mathematical sequences, derived from appropriate algorithms, into audible sound. Such digital processors and their operation are well-known in the art, and so are not discussed here. Inherent in such a system is a frequency sensor that synchronizes the phasing with dominant EEG waveforms as those waveforms are introduced from another source.

Examples of suitable algorithms for implementing Phased Pink Sound are as follows:

```
/*****************************************************************************
 * Algorithm to generate 8-bit PCM samples in array pink[] of the            *
 * single channel sound that serves as the source for the stereo             *
 * "phased pink" sound                                                       *
 *****************************************************************************/

#include <math.h>
#include <stdio.h>

#define M2PI   -6.283185307179586
#define SAMPLES_PER_SECOND 10466.5
#define CUTOFF 200.0      /* cutoff frequency for low-pass filter */
#define S 83732           /* number of samples to generate */
#define MINDELAY 60       /* minimum flanging delay (samples) */
#define MAXDELAY 80       /* maximum flanging delay (samples) */

extern short w[];         /* 8192 entry table of 16-bit sine values
                             scaled from 0x8001 to 0x7FFF */
extern double st_entries;/* count of entries in sine table */

long phase;               /* random number generator phase */
long fa;                  /* filter accumulator */
long fc;                  /* filter constant */
long sweep;               /* flanging filter phase */
long sweep0;              /* flanging filter initial phase */
long ds;                  /* flanging filter phase step */
long count;               /* samples remaining in flanging filter cycle */
long count0;              /* samples in flanging filter cycle */
long delay;               /* current flanging filter delay (XXXX.XXXX) */
long delay0;              /* flanging filter delay constant */
long range;               /* flanging filter delay range */
short gainNS;             /* noise sound gain (gain = gainNS/1024) */
short gainFS;             /* flanging sound gain (gain = gainFS/1024) */
short noise[S+MAXDELAY]; /* array to receive noise samples */
short offset;             /* final sample offset to balance values */
short scaleF;             /* final scale factor to range samples */
char pink[S];             /* array to receive "phased pink" samples */


/*****************************************************************************
 * Main program                                                              *
 *****************************************************************************/

main()
{
   long control_base;     /* initial flanging delay */
   long control_range;    /* range of flanging control */
   int i;                 /* loop index */
   short *np;             /* pointer to filtered noise sample array */
   short *fsnp;           /* pointer to initial/final noise sequence */
   short NoiseGen();      /* next filtered noise sample */
   short Flange();        /* flanging sample */
   short xx;              /* output before final scaling */
   /* Initialize the white noise generator */
   phase = 0x8000;
```

```
        /* Initialize low-pass filter */
        fa = 0;
        fc = (1.0 - exp(M2PI * CUTOFF / SAMPLES_PER_SECOND)) * 65536.0;

        /* Initialize flanging filter for 8 second cycle.  Delay sweeps
           sinusodially around 5*PI/2.  Flanginging tone gain is 75%
           of the noise tone */
        sweep = sweep0 = ((long)((.75 * st_entries) * 65536.0 + 0.5))
           & 0x1FFFFFFF;
        control_base = w[sweep0 >> 16];
        control_range = 0x0007FFFL - control_base;
        range = (((double)(MAXDELAY - MINDELAY) * 32767.0) / control_range)
          * 16.0 + 0.5;
        delay0 = (MINDELAY << 16) - control_base * (range >> 3);
        ds = (st_entries / (8.0 * SAMPLES_PER_SECOND)) * 65536.0 + 0.5;
        count =  8.0 * SAMPLES_PER_SECOND + 0.5;
        gainNS = 585;
        gainFS = 439;

        /* Initialize the final offset and scale factor for these filter
           parameters (empirically determined) */
        offset = 153;
        scaleF = 0x245;

        /* Generate an initial sequence of noise samples to provide for
           delayed samples */
        np = fsnp = noise;
        for (i = 0; i < MAXDELAY; i++) *np++ = NoiseGen();

        /* Generate the next S samples of "phased pink" sound */
        for (i = 0; i < S; i++) {

           /* Generate the next colored noise sample.  For looping,
              finish off with the initial noise sequence */
           if (i < S-MAXDELAY) *np = NoiseGen();
           else *np = *fsnp++;

           /* Apply a sweeping cosine comb filter to flange the sound */
           xx = (*np*gainNS + Flange(np)*gainFS) >> 10;
           pink[i] = ((xx + offset) * scaleF) >> 16;
           np++;

        }
}

/*****************************************************************************
 * NoiseGen — function to generate a filtered noise sample                   *
 *****************************************************************************/

short NoiseGen(nsp)
{
    long x;                 /* current noise sample */
    long y;                 /* current filtered noise sample */

    /* Generate sinusodial density noise from white */
    phase = phase << 1;
```

```
    if (phase & 0x10000) phase = phase ^ 0x1DE7;
    phase = phase & 0xFFFF;
    x = w[phase >> 3];

    /* Apply 1st order low-pass digital filter */
    y = (fc*fa) >> 16;
    fa += (x >> 4) - y;
    return((short)(y << 4));
}


/*****************************************************************************
 * Flange — function to generate a flanging noise sample                     *
 *****************************************************************************/

short Flange(nsp)
   short *nsp;              /* pointer to current noise sample */
{
   short f;                 /* flanging noise sample */
   short *dnp;              /* pointer to delayed noise sample */

   /* Apply a sinusodially sweeping comb filter to flange the sound */
   if (count--) sweep = (sweep + ds) & 0x1FFFFFFF;
   else {
      sweep = sweep0;
      count = count0;
   }

   /* Compute the filter delay and linearly interpolate between
      noise samples to simulate a continuously variable delay */
   delay = delay0 + ((w[sweep >> 16] * range) >> 3);
   dnp = nsp - (delay >> 16);
   f = *dnp +
      ((((*(dnp-1) - *dnp) >> 1) * ((delay & 0xFFFF) >> 1)) >> 14);
   return(f);
}
```

Looking at some results of the inventive method, FIG. 3A shows the EEG of a subject in a normal waking state. FIG. 3B shows an EEG of the individual after listening to binaural beat sounds produced in accordance with the invention. The Figure shows an FFR response in the 1.5, 4, and 6 Hz signal range.

Likewise, FIG. 3C shows the EEG of a subject in a normal waking state, and FIG. 3D shows an EEG of the individual after listening to other binaural beat sounds produced in accordance with the invention. The Figure shows an FFR response in the 2, 4, and 7 Hz signal range.

FIG. 3E shows the EEG of a subject in a normal waking state, and FIG. 3F shows an EEG of the individual after listening to still other binaural beat sounds produced in accordance with the invention. The Figure shows an FFR response in the 0.5, 3, and 4 Hz signal range.

Finally, FIG. 3G shows the EEG of a subject in a normal waking state, and FIG. 3*h* shows an EEG of the individual after listening to still other binaural beat sounds produced in accordance with the invention. The Figure shows FFR response to 1.5, 2, and 4 Hz signals in amplitude, by frequency.

FIGS. 4A–4C shows a typical contour map of a subject in a normal waking state. It should be noted that the map shows a lack of continuity. Note also the lack of significant amplitude patterns ranging between temporal lobes, and the relative lack of intensity within the frontal area.

In contrast, FIGS. 4D–4F shows a contour map of the same individual after listening to binaural beat sound in accordance with the invention. Note the synchronization between hemispheres, and the high amplitude of activity at the frontal portion of the brain. Note also how the left and right hemisphere brain waves exhibit significantly higher amplitudes in the frequencies found in the original sound stimulus.

The application of the binaural beat signals by headphones or other second producing devices causes the following results:

1. When such audio signals are provided simultaneously with the state of being itself, those specific states can be enhanced. The additional pattern superposed upon the original provides a powerful setting to maintain and/or expand the condition.
2. By recording the audio signals and playing them back, an individual may return to an original or

previously-experienced state of consciousness whenever desired.

3. By listing to recordings of these audio signals, an original pattern or condition induced in one individual may be replicated in other individuals.

4. An individual can be trained, based on sufficient repetition of application of these waveforms, to the point that the individual can recall and replicate these waveforms themselves, without further outside stimulation.

The method of the invention has applications in a number of different areas, not the least of which is the inducement of a state of sleep. Other areas of application include inducement of wakefulness of varying degrees; focusing of attention; inducement of mental and physical relaxation; enhancing intellectual performance in various mental disciplines such as mathematics; enhancement of creativity; the reexperience of previous activity; the acquisition of new abilities which others already have; reinforcement and restoration of weak areas in the mind and body; enhancement and strengthening of mental and/or muscular coordination; and development of integration of entire brain function. Human beings have EEG patterns which are unique to the various states of consciousness and mental and/or physical activity just mentioned, so that the imposition of the appropriate stereo audio signals on the desired EEG wave produces the binaural beat which is necessary to induce the state.

While the invention has been described above in detail with reference to a particular specific embodiment, various modifications within the spirit and scope of the invention will be apparent to those of working skill in this technological field. Thus, the invention should be considered as limited only by the scope of the appended claims.

What is claimed is:

1. A method of inducing states of consciousness in human beings, comprising:

providing a replicated electroencephalogram (EEG) waveform indicative of a desired state of consciousness;

superimposing said EEG waveform on two separate sets of carrier waves using stereo sound;

creating differential beat frequencies between said sets of carrier waves in accordance with said superimposing step; and

providing the resulting signals in audio form to respective ears of a human being, to induce said state of consciousness.

2. A method as claimed in claim 1, wherein said creating step includes the step of combining pink with said sets of carrier waves by shifting of said pink sound with respect to said EEG waveform from one stereo audio channel to another, with cyclic changes in amplitude, frequency, and rate of panning.

3. A method as claimed in claim 1, wherein all of said steps are performed repeatedly on a particular individual over a period of time so that the individual is able eventually to reproduce said desired state of consciousness without further audio stimulation.

4. A method as claimed in claim 1, wherein all of said steps are performed using the EEG of one individual, but said applying step is carried out with another individual, so as to transfer the desired state of consciousness of one individual to another.

5. A method as claimed in claim 1, wherein said first providing step comprises the step of providing a plurality of EEG waveforms, indicative of different respective states of consciousness, and each of said superimposing, creating, and second providing steps are performed with each of said plurality of EEG waveforms.

6. A method as claimed in claim 1, wherein said second providing step results in substantial synchronization of major portions of both brain hemispheres of said human being.

* * * * *

United States Patent [19]
Monroe

[11] Patent Number: 5,356,368
[45] Date of Patent: * Oct. 18, 1994

[54] **METHOD OF AND APPARATUS FOR INDUCING DESIRED STATES OF CONSCIOUSNESS**

[75] Inventor: **Robert A. Monroe**, Nelson County, Va.

[73] Assignee: **Interstate Industries Inc.**, Faber, Va.

[*] Notice: The portion of the term of this patent subsequent to May 25, 2010 has been disclaimed.

[21] Appl. No.: **664,176**

[22] Filed: **Mar. 1, 1991**

[51] **Int. Cl.**[5] **A61M 21/00**
[52] **U.S. Cl.** **600/28**; 128/732
[58] **Field of Search** 600/26–28; 128/731–732

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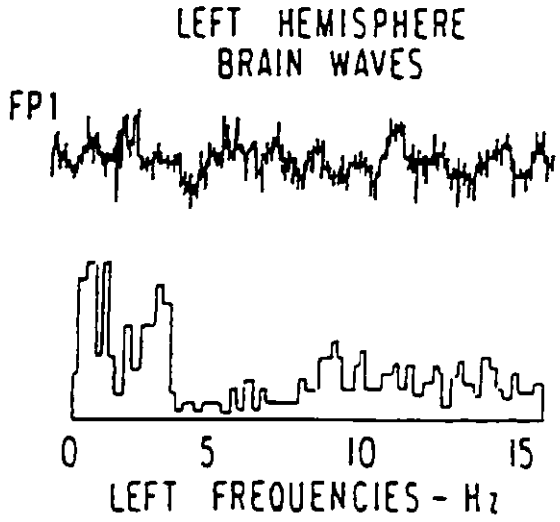
Primary Examiner—Lee S. Cohen
Assistant Examiner—J. P. Lacyk
Attorney, Agent, or Firm—Sughrue, Mion, Zinn, Macpeak & Seas

[57] **ABSTRACT**

Improved methods and apparatus for entraining human brain patterns, employing frequency following response (FFR) techniques, facilitate attainment of desired states of consciousness. In one embodiment, a plurality of electroencephalogram (EEG) waveforms, characteristic of a given state of consciousness, are combined to yield an EEG waveform to which subjects may be susceptible more readily. In another embodiment, sleep patterns are reproduced based on observed brain patterns during portions of a sleep cycle; entrainment principles are applied to induce sleep. In yet another embodiment, entrainment principles are applied in the work environment, to induce and maintain a desired level of consciousness. A portable device also is described.

28 Claims, 21 Drawing Sheets



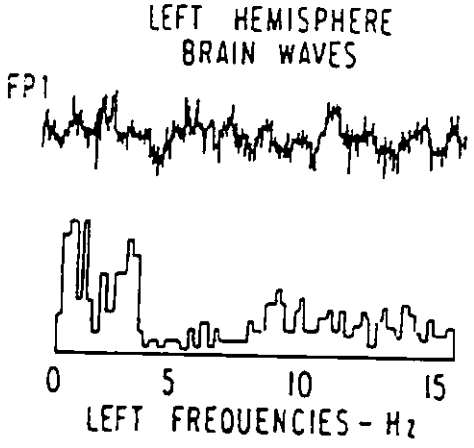


FIG. 1A

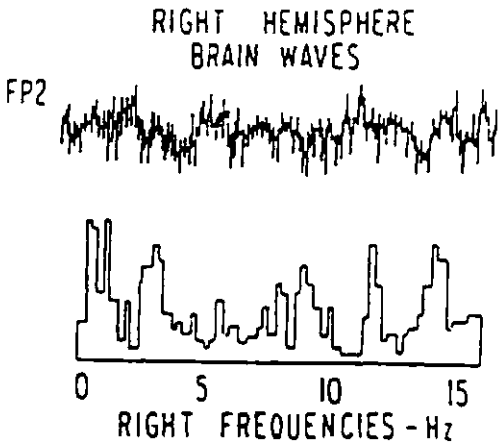


FIG. 1B

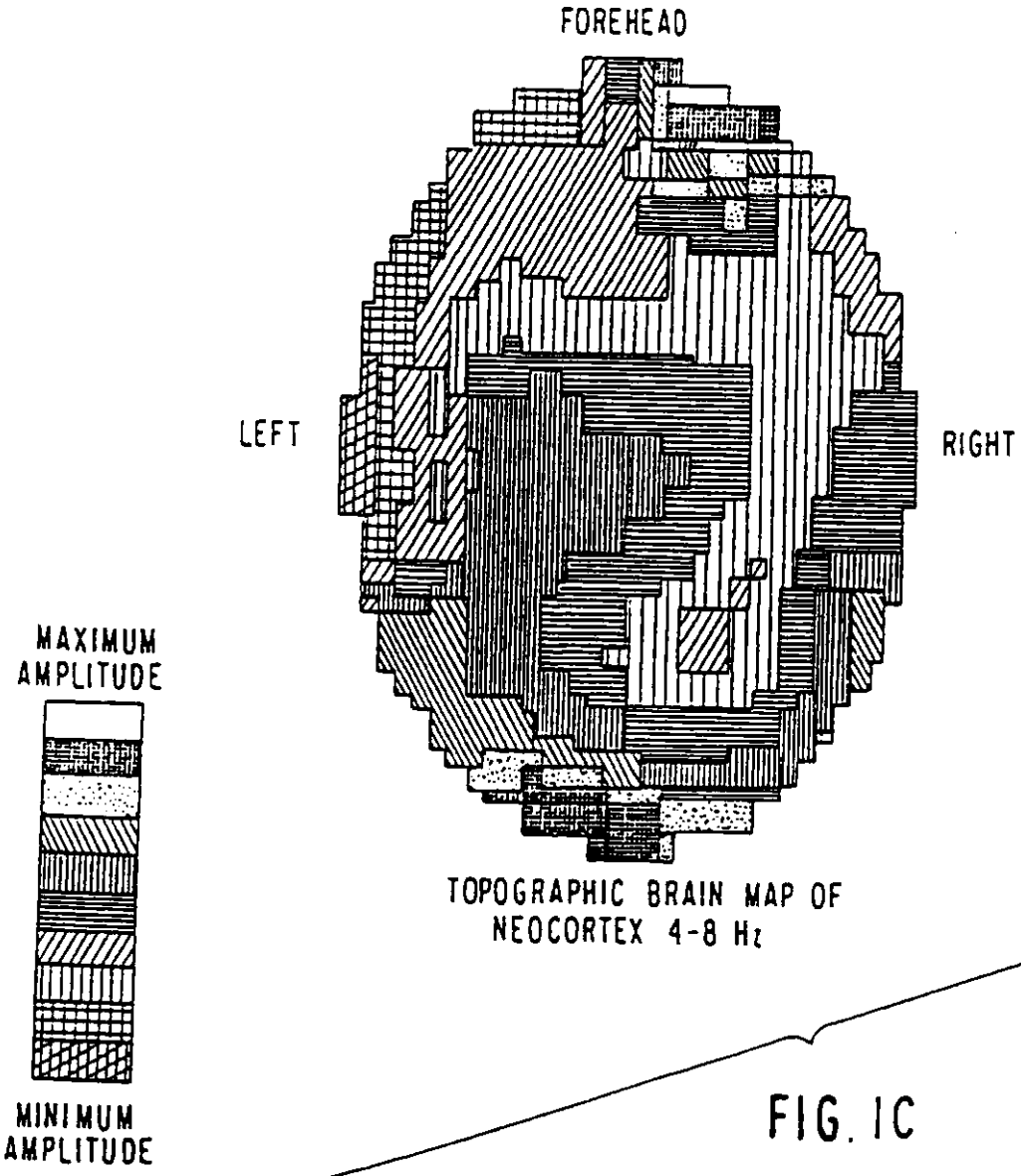


FIG. 1C

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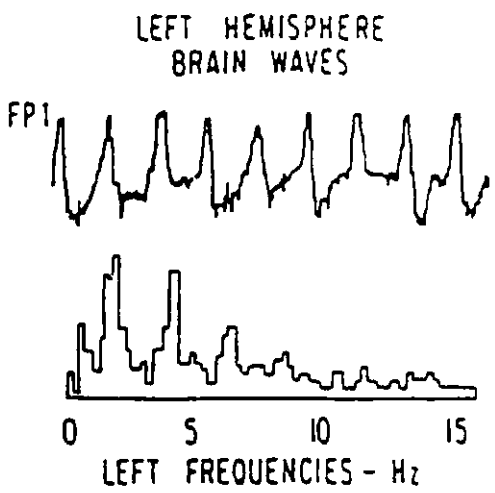


FIG. 1D

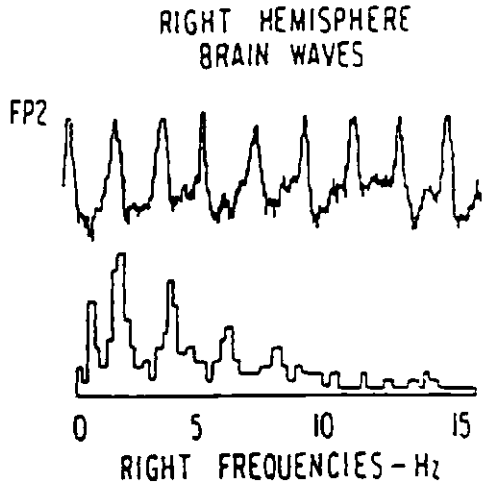


FIG. 1E

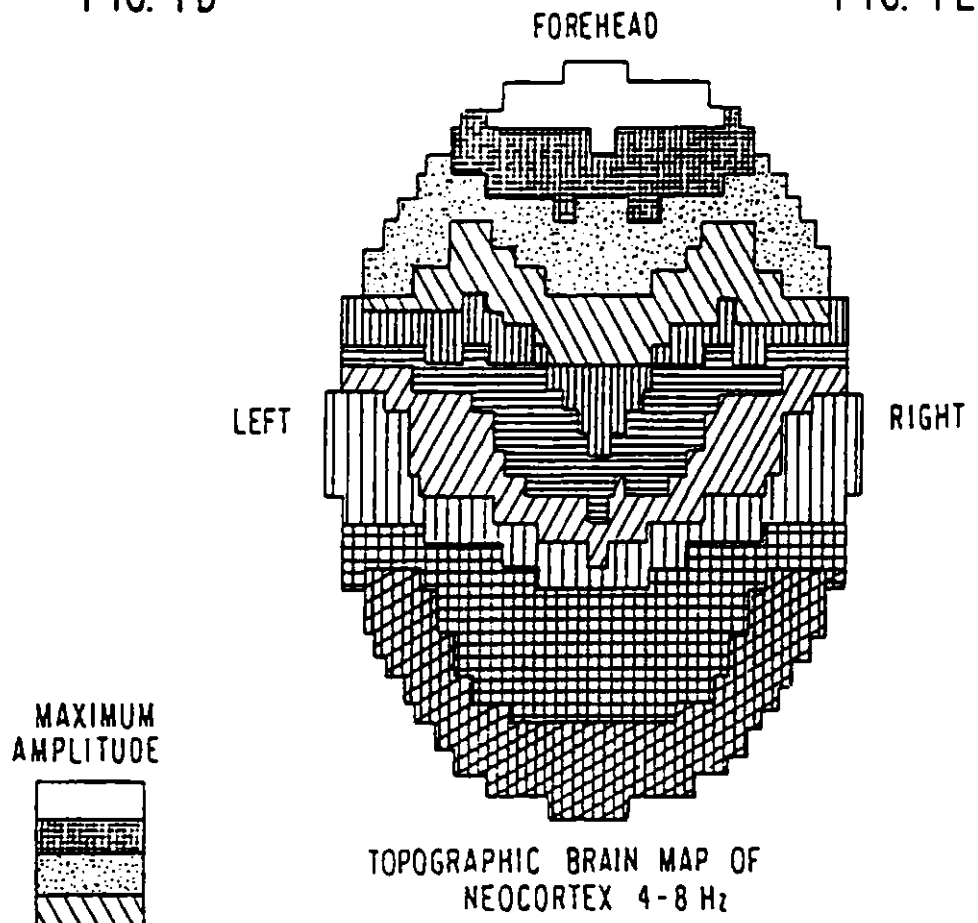
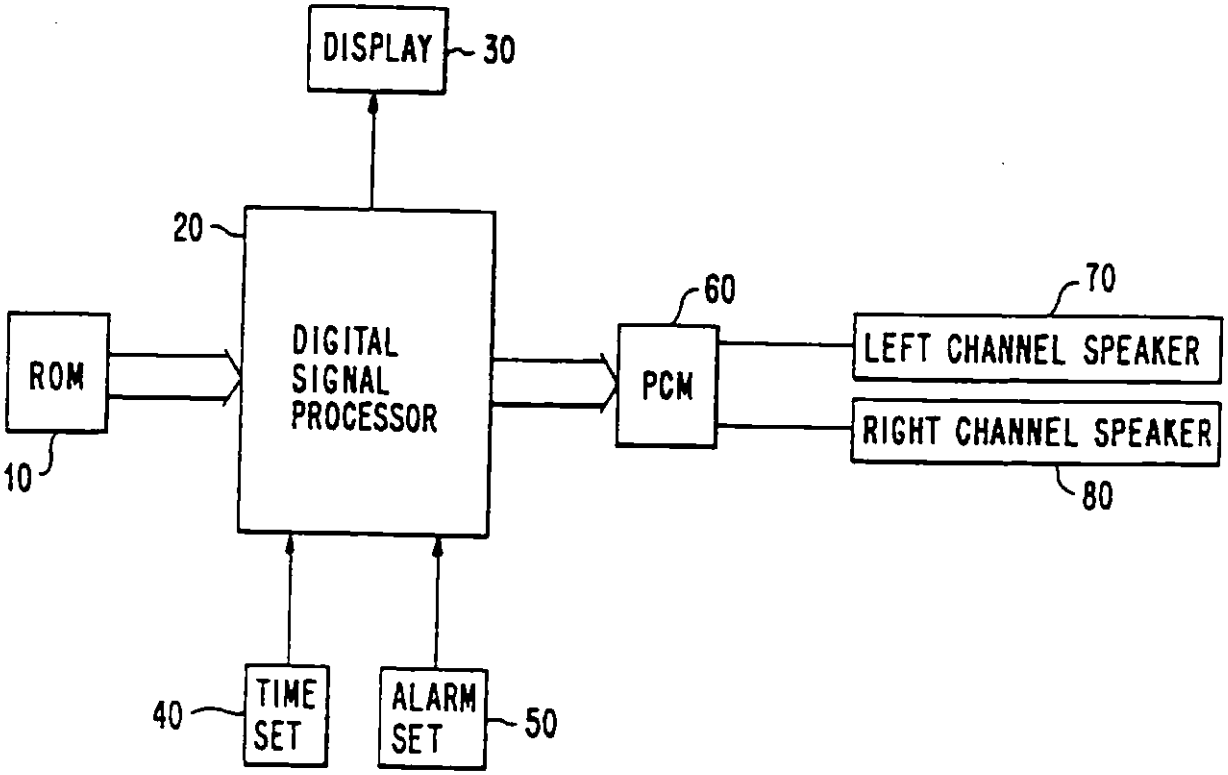


FIG. 1F

99

FIG. 2


DISPLAY
30
20
ROM
10
DIGITAL SIGNAL PROCESSOR
60
PCM
70
LEFT CHANNEL SPEAKER
RIGHT CHANNEL SPEAKER
80
40
TIME SET
ALARM SET
50

100

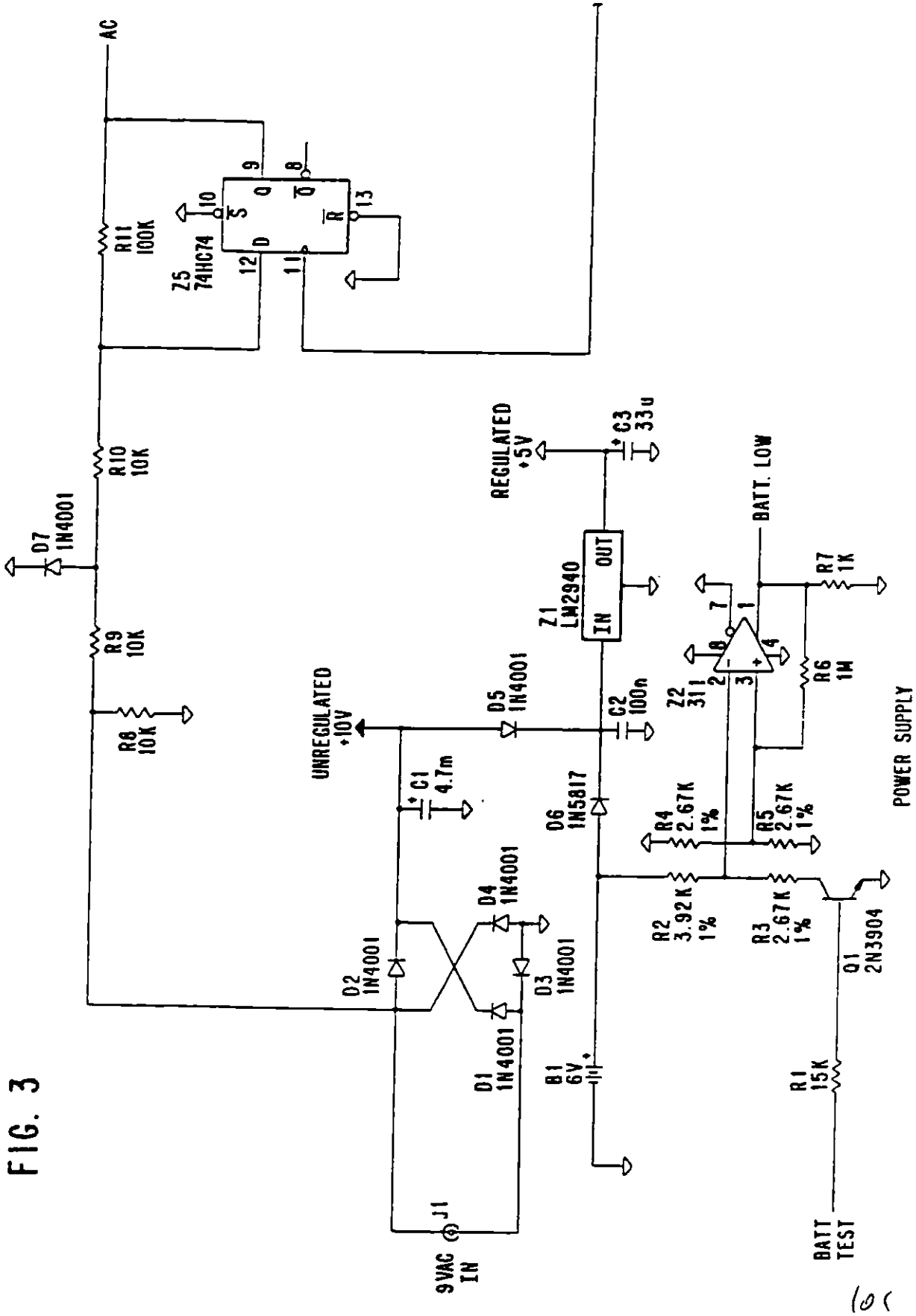

AC
R11 100K
Z5 74HC74
R10 10K
D7 1N4001
R9 10K
R8 10K
REGULATED +5V
C3 33u
Z1 LM2940
IN
OUT
BATT. LOW
R7 1K
Z2 311
R6 1M
UNREGULATED +10V
D5 1N4001
C2 100n
C1 4.7m
D6 1N5817
R4 2.67K 1%
R5 2.67K 1%
POWER SUPPLY
D4 1N4001
D2 1N4001
D3 1N4001
D1 1N4001
B1 6V
R2 3.92K 1%
R3 2.67K 1%
Q1 2N3904
R1 15K
J1
9VAC IN
BATT TEST

FIG. 3

101

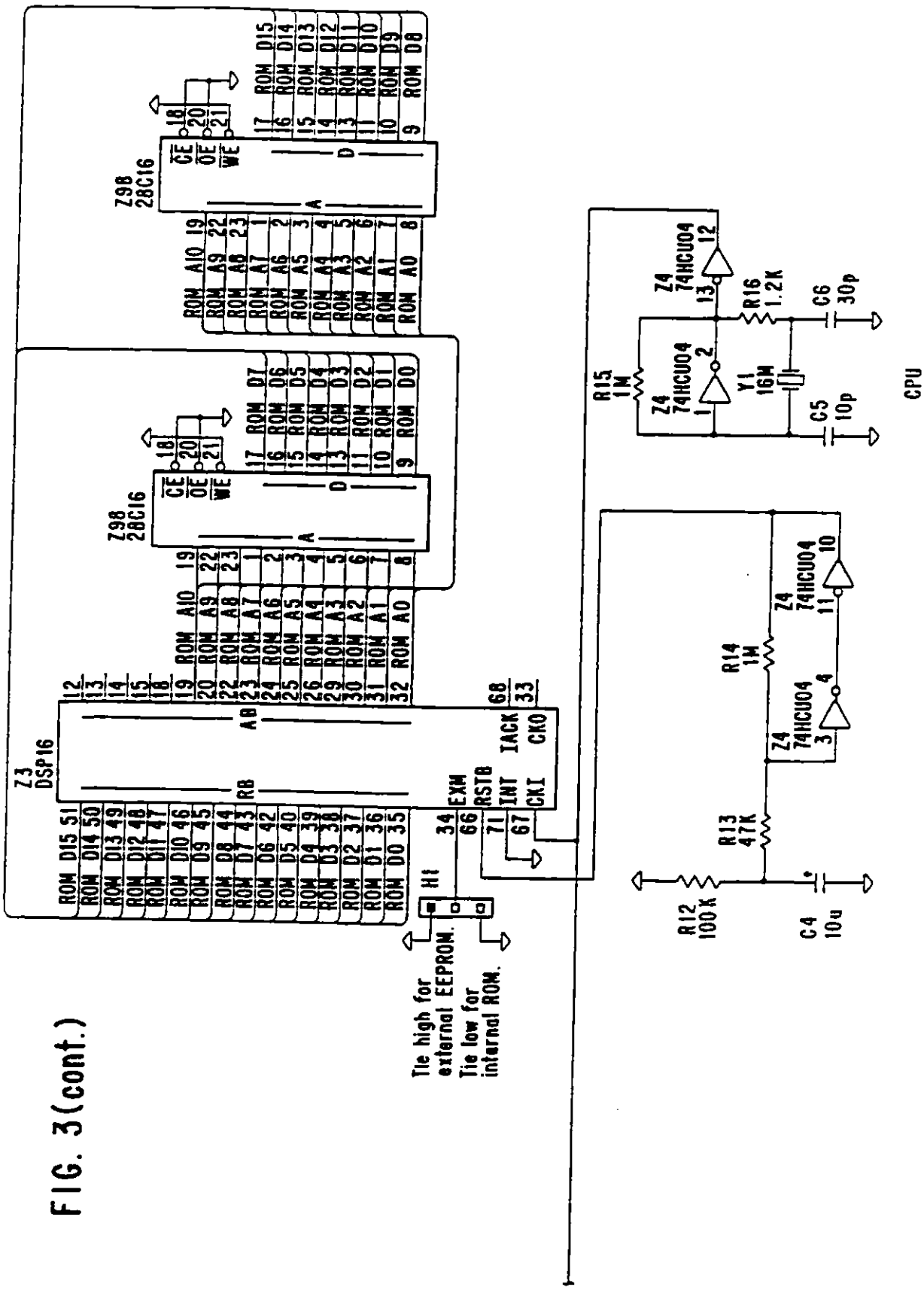


FIG. 3(cont.)

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FIG. 4

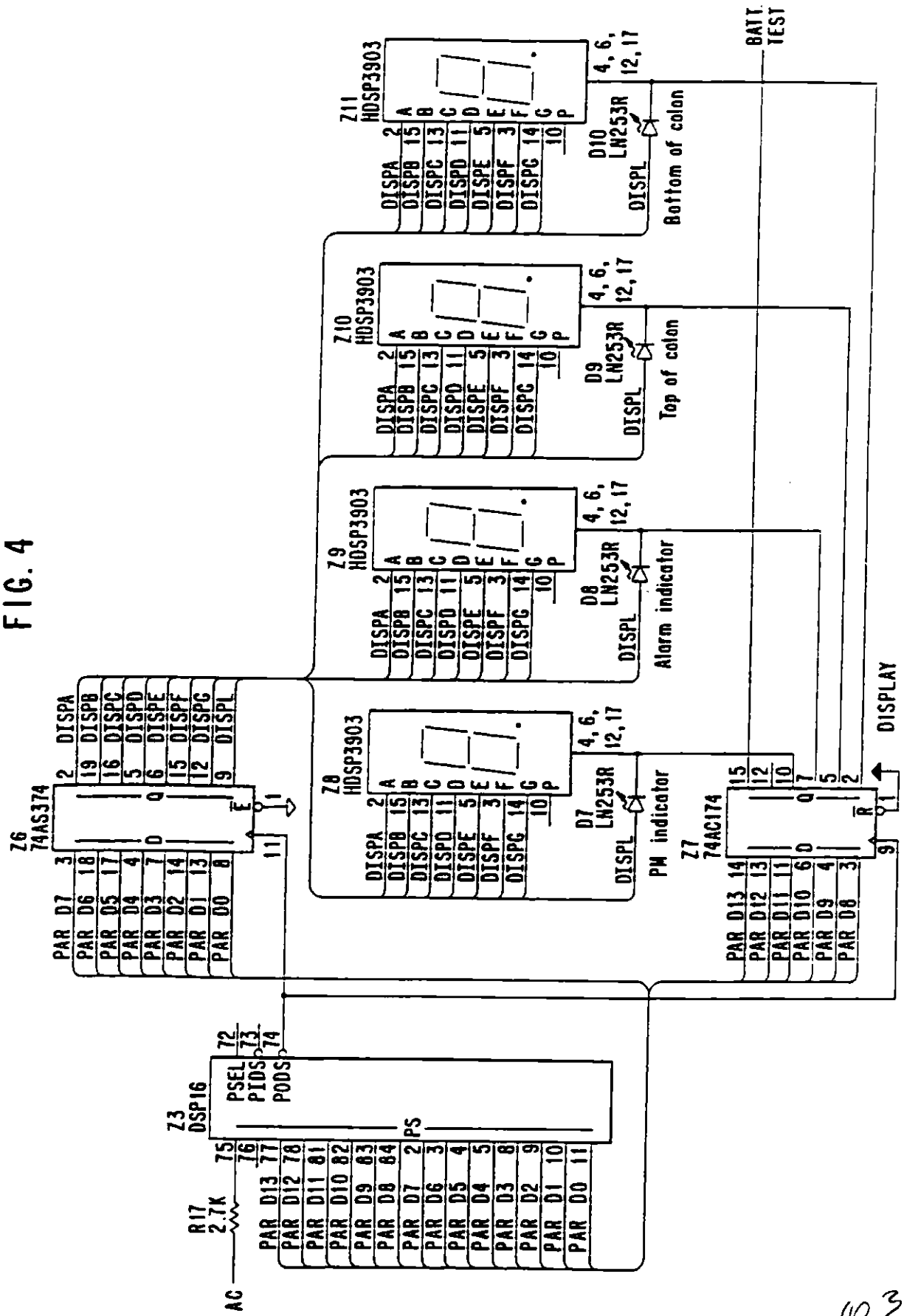
Z11 HDSP3903
Z10 HDSP3903
Z9 HDSP3903
Z8 HDSP3903
D10 LN253R
D9 LN253R
D8 LN253R
D7 LN253R
Bottom of colon
Top of colon
Alarm indicator
PM indicator
BATT TEST
DISPLAY
Z6 74AS374
Z7 74AC174
Z3 DSP16
PSEL
PIDS
PODS
PS
R17 2.7K
AC
DISPA
DISPB
DISPC
DISPD
DISPE
DISPF
DISPG
DISPL
PAR D7
PAR D6
PAR D5
PAR D4
PAR D3
PAR D2
PAR D1
PAR D0
PAR D13
PAR D12
PAR D11
PAR D10
PAR D9
PAR D8

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FIG. 5

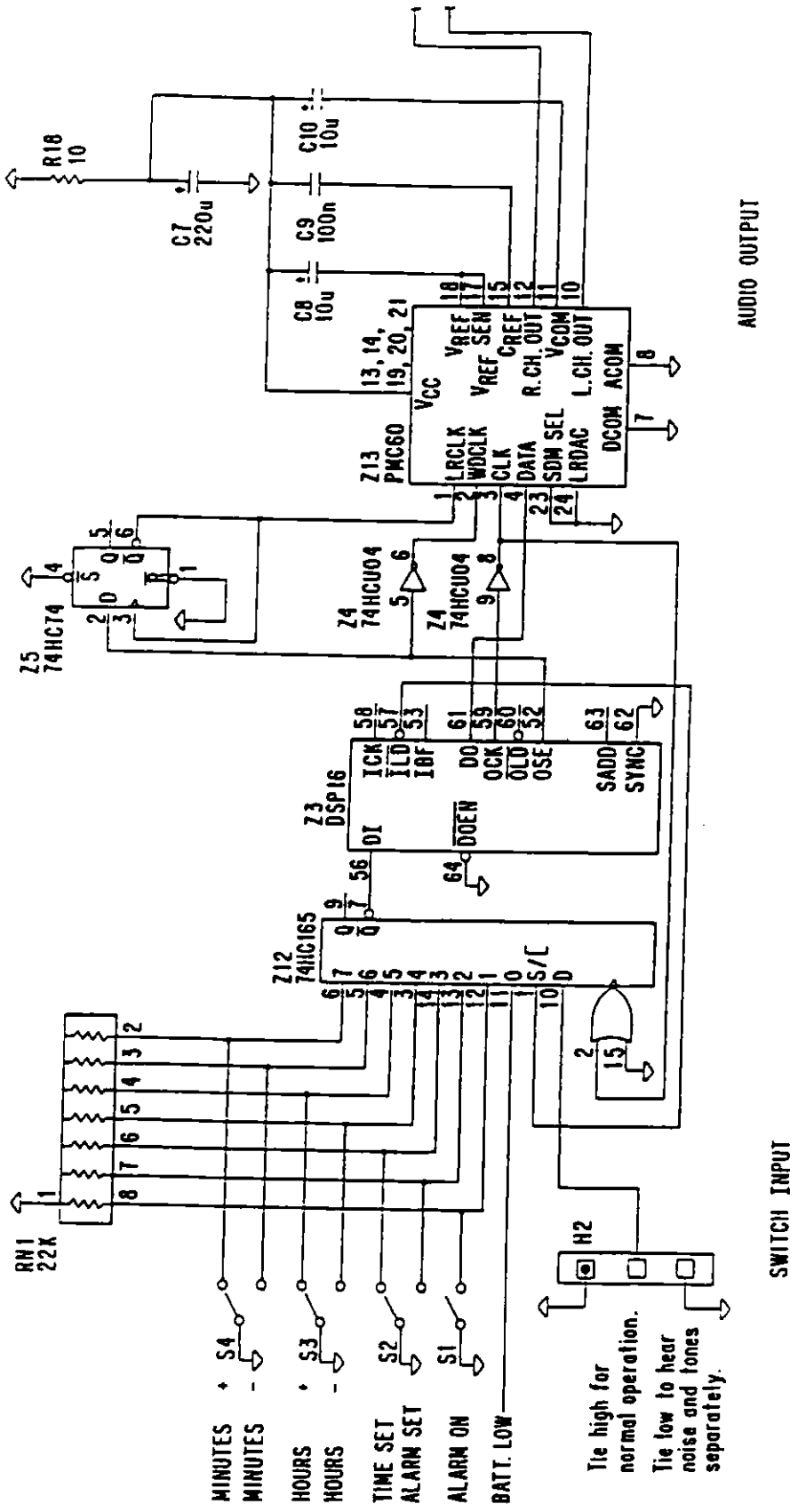
AUDIO OUTPUT
SWITCH INPUT
R18 10
C7 220u
C9 100n
C10 10u
C8 10u
Z13 PMC60
VCC
VREF
VREF SEN
CREF
R.CH. OUT
VCOM
L.CH. OUT
ACOM
DCOM
LRCLK
WDCLK
CLK
DATA
SDW SEL
LRDAC
Z5 74HC74
Z4 74HCU04
Z4 74HCU04
Z3 DSP16
ICK
ILD
IBF
DO
OCK
OLD
OSE
SADD
SYNC
DI
DOEN
Z12 74HC165
S/L
RN1 22K
S4
S3
S2
S1
H2
MINUTES + S4
MINUTES - S3
HOURS + S2
HOURS - S1
TIME SET
ALARM SET
ALARM ON
BATT. LOW
Tie high for normal operation.
Tie low to hear noise and tones separately.

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FIG. 6A

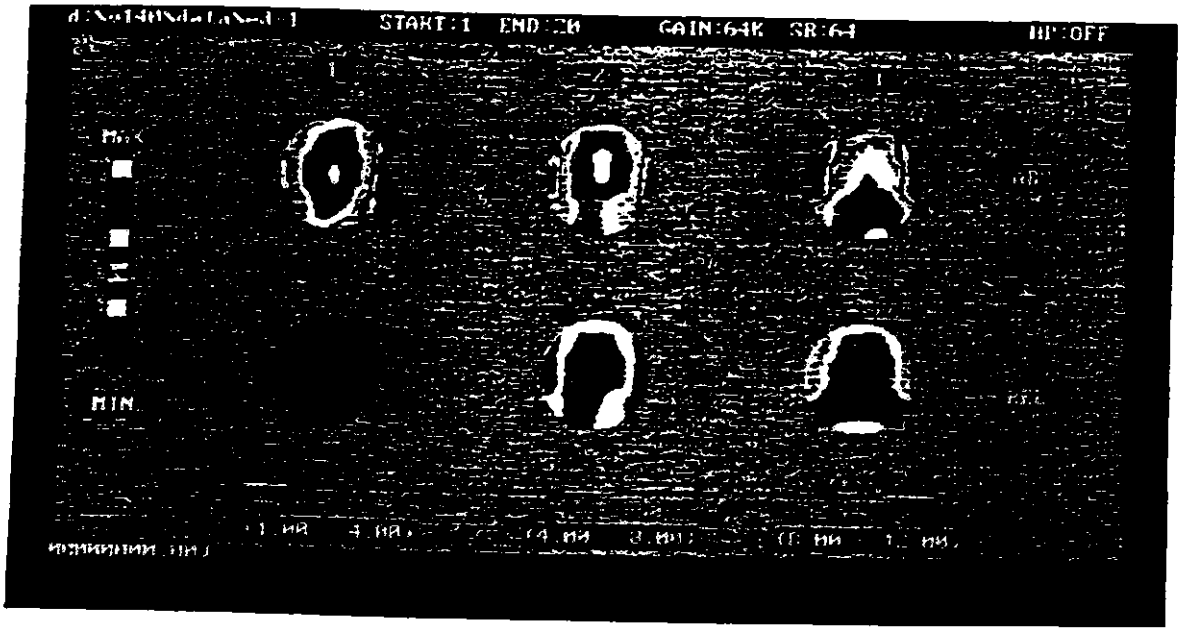

START:1 END:20 GAIN:64K SR:64 HP:OFF
Max
MIN

FIG. 6B

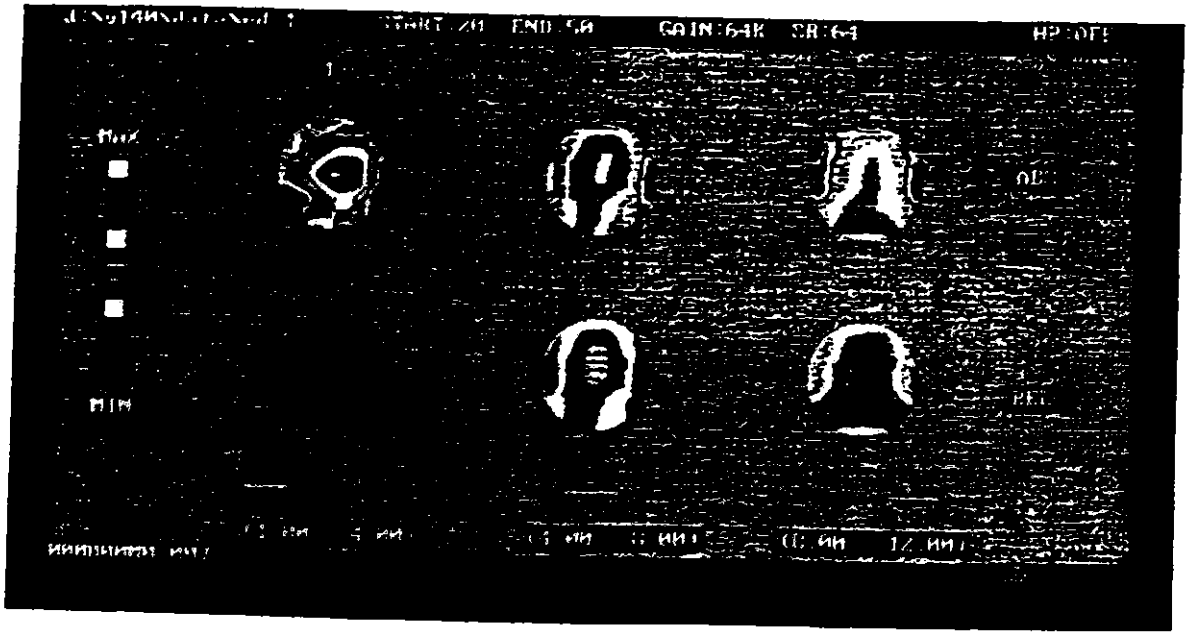

GAIN:64K SR:64 HP:OFF
Max
MIN

FIG. 6C

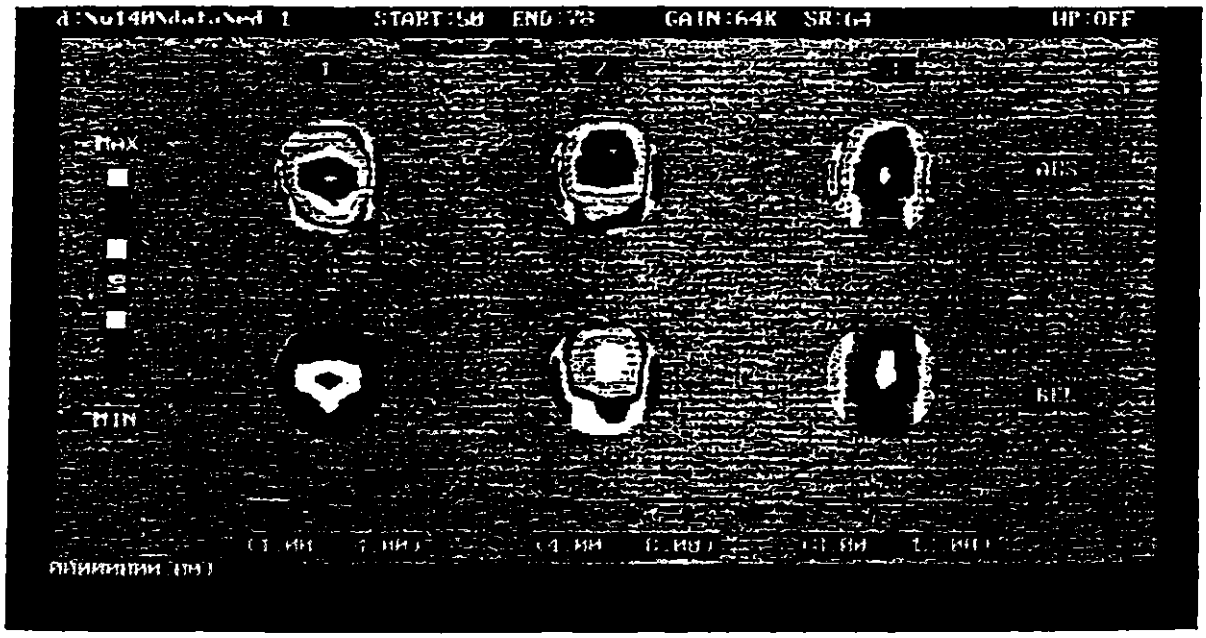
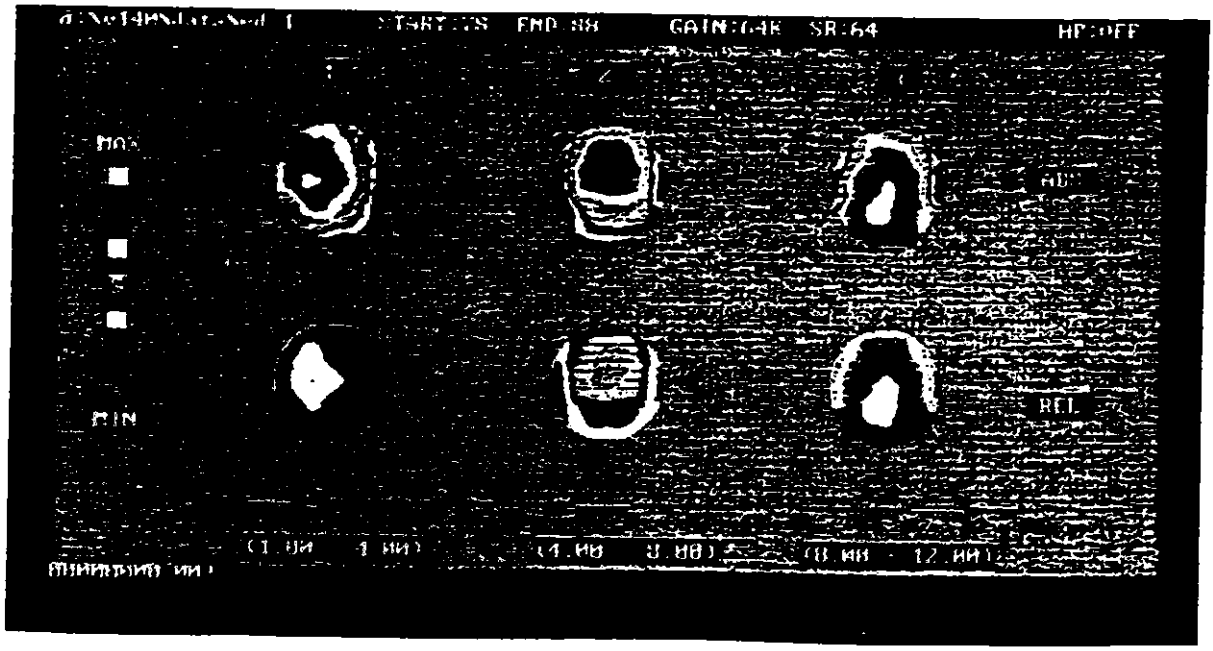


FIG. 6D



106

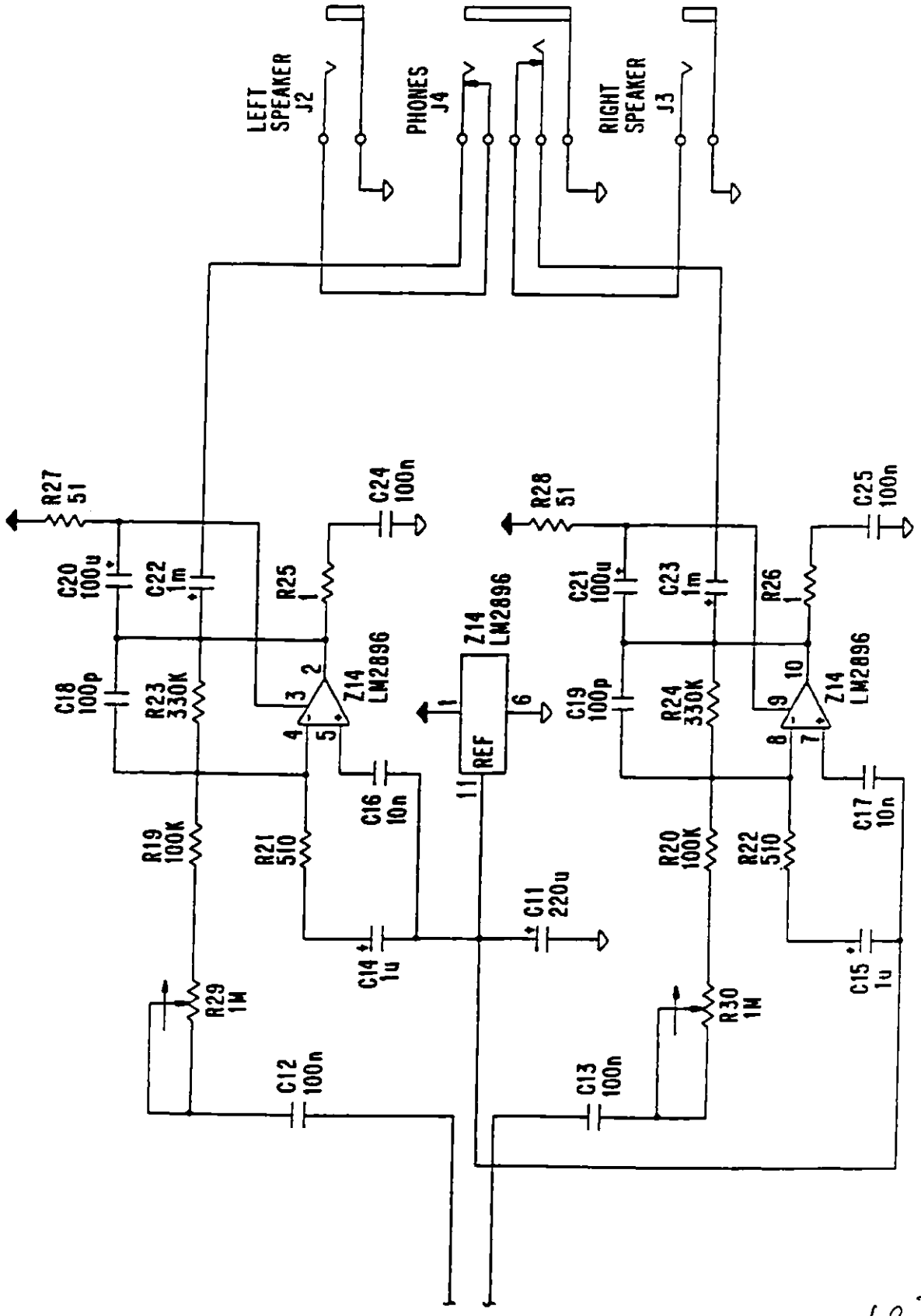


FIG. 5 (cont.)

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FIG. 6E

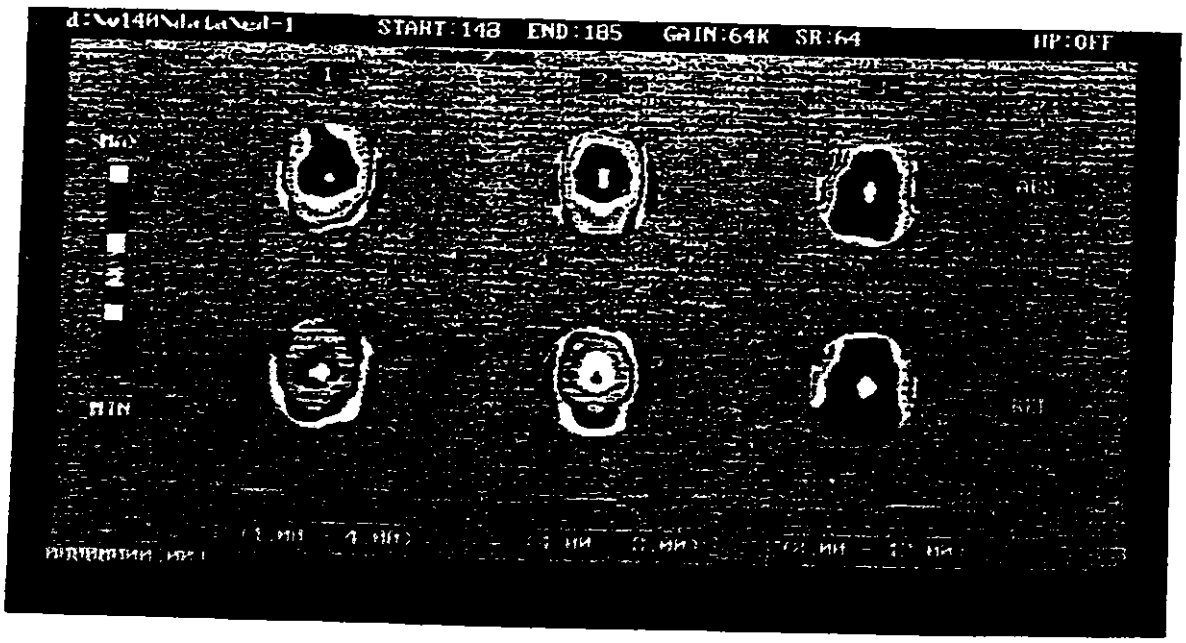

FIG. 6F

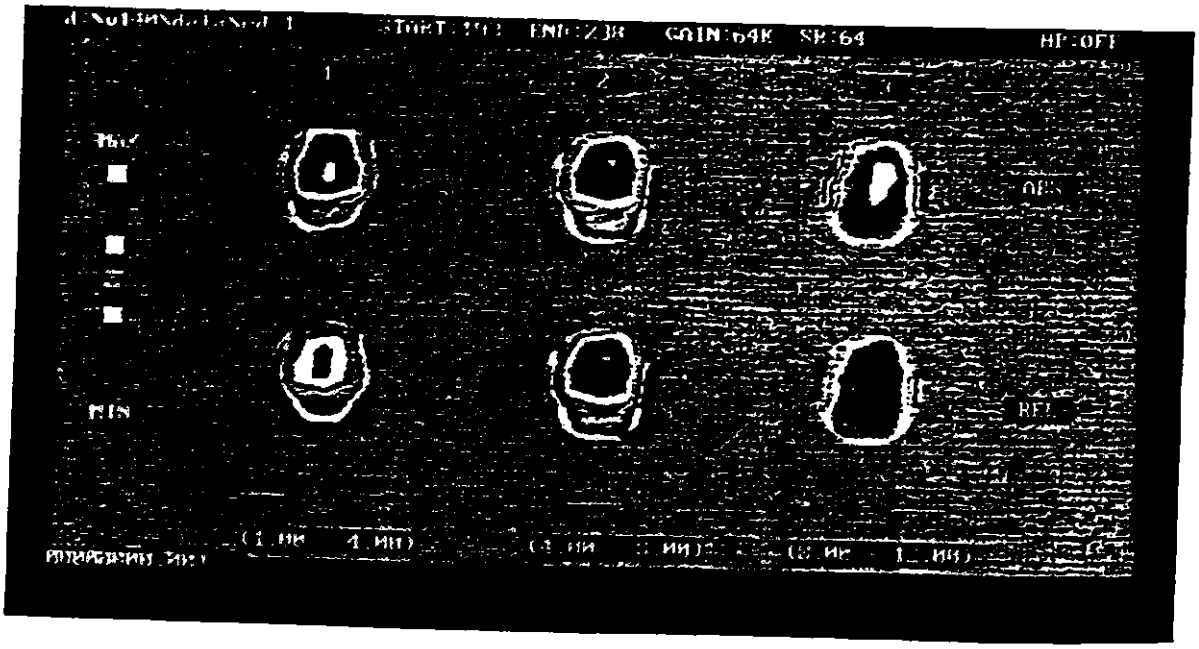

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FIG. 6G

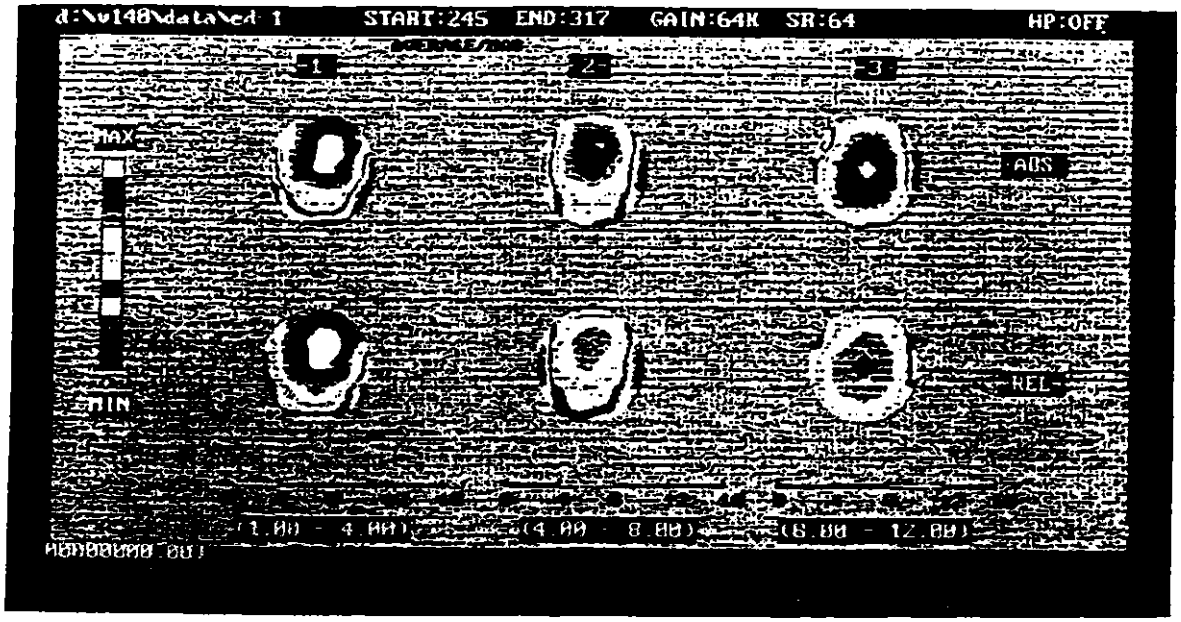

START:245 END:317 GAIN:64K SR:64 HP:OFF
1
2
3
MAX
MIN
ABS
REL
(1.00 - 4.00)
(4.00 - 8.00)
(8.00 - 12.00)

FIG. 6H

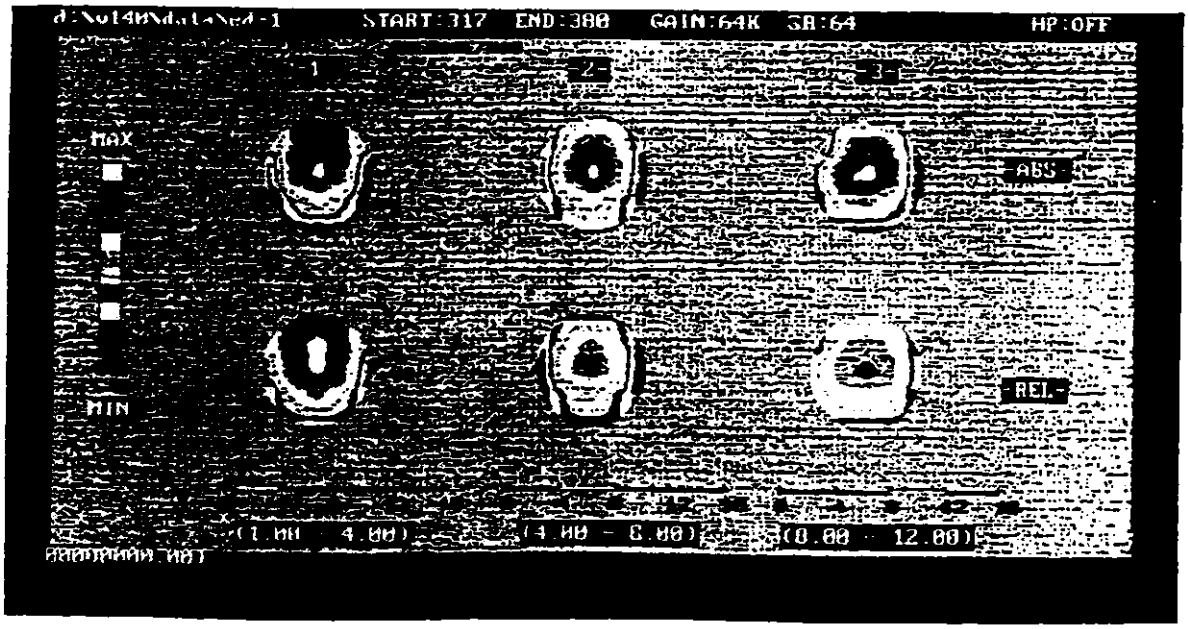

START:317 END:388 GAIN:64K SR:64 HP:OFF
1
2
3
MAX
MIN
ABS
REL
(1.00 - 4.00)
(4.00 - 8.00)
(8.00 - 12.00)

FIG. 6I

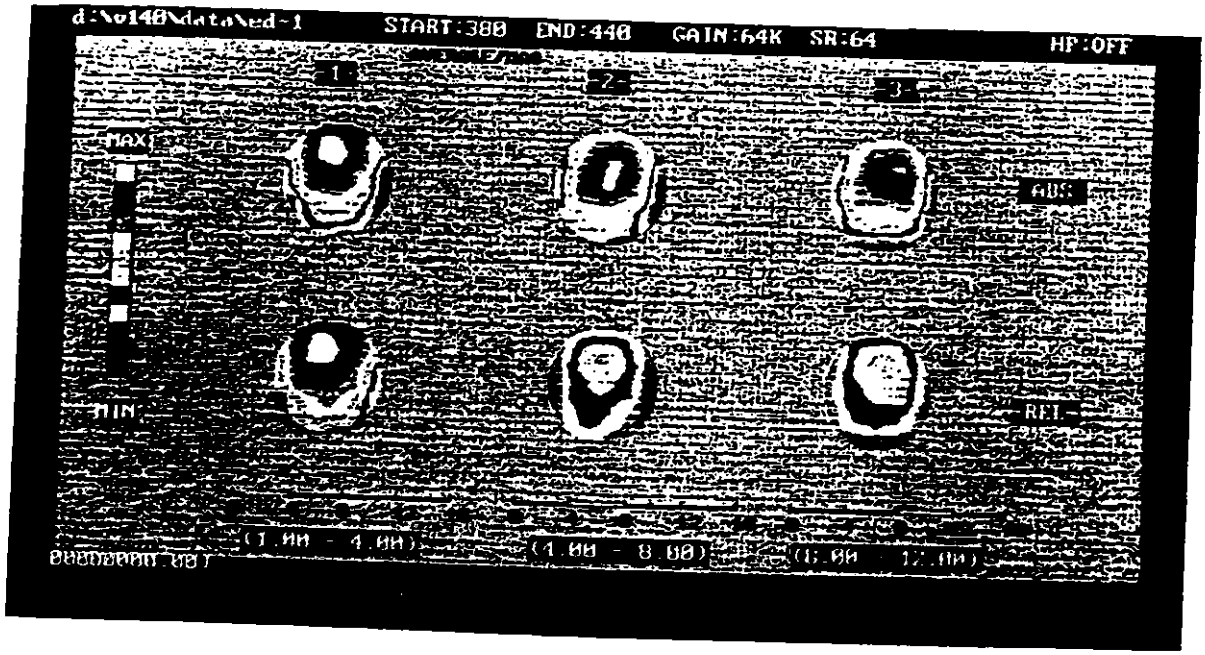

START:380
END:440
GAIN:64K
SR:64
HP:OFF
MAX
MIN
ABS
REL

FIG. 6J

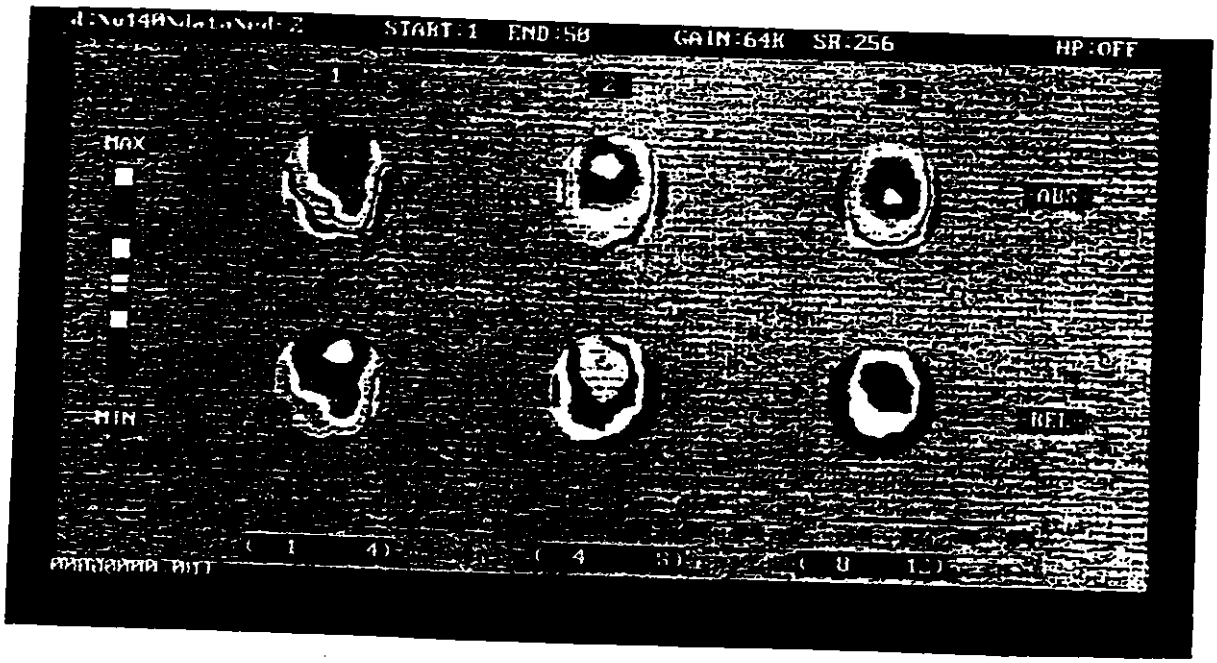

START:1
END:50
GAIN:64K
SR:256
HP:OFF
MAX
MIN
ABS
REL

FIG. 7

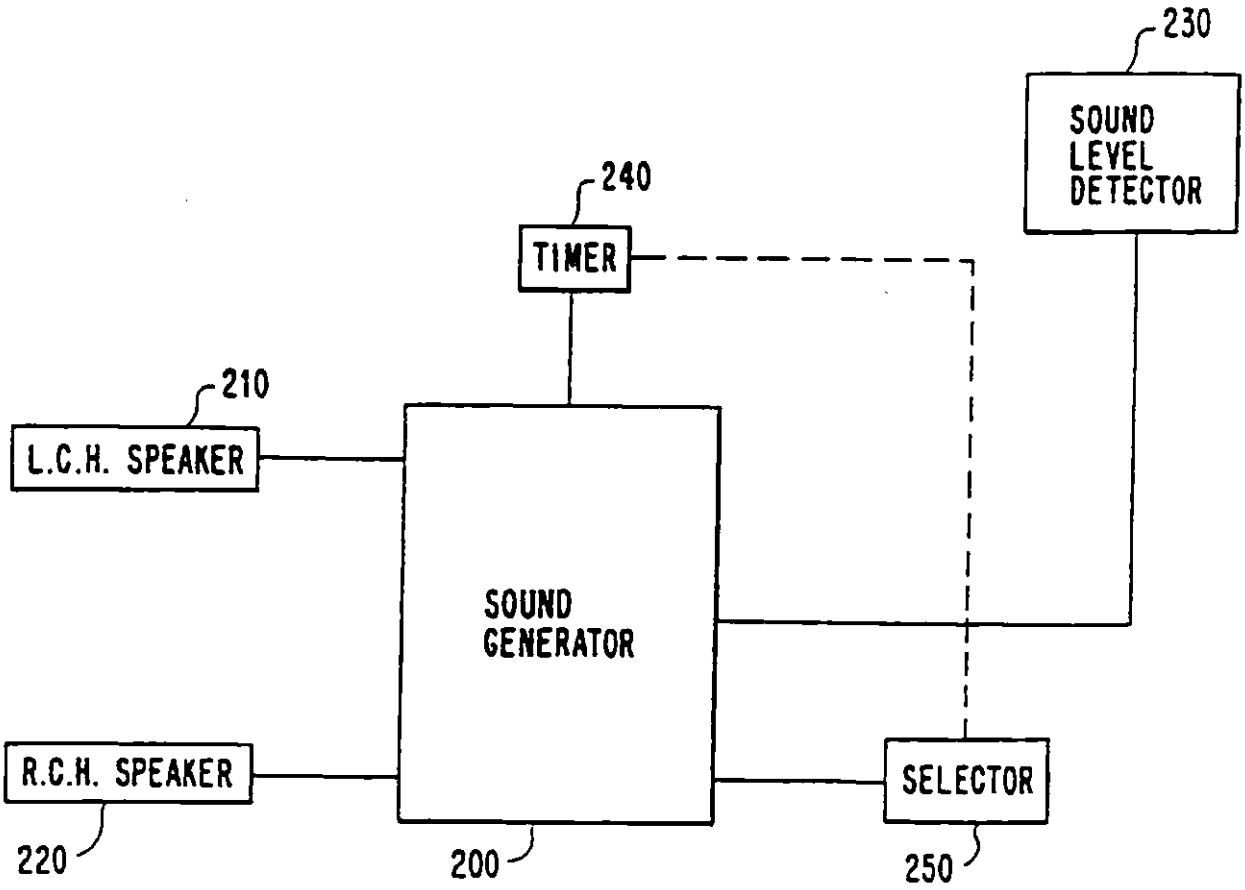
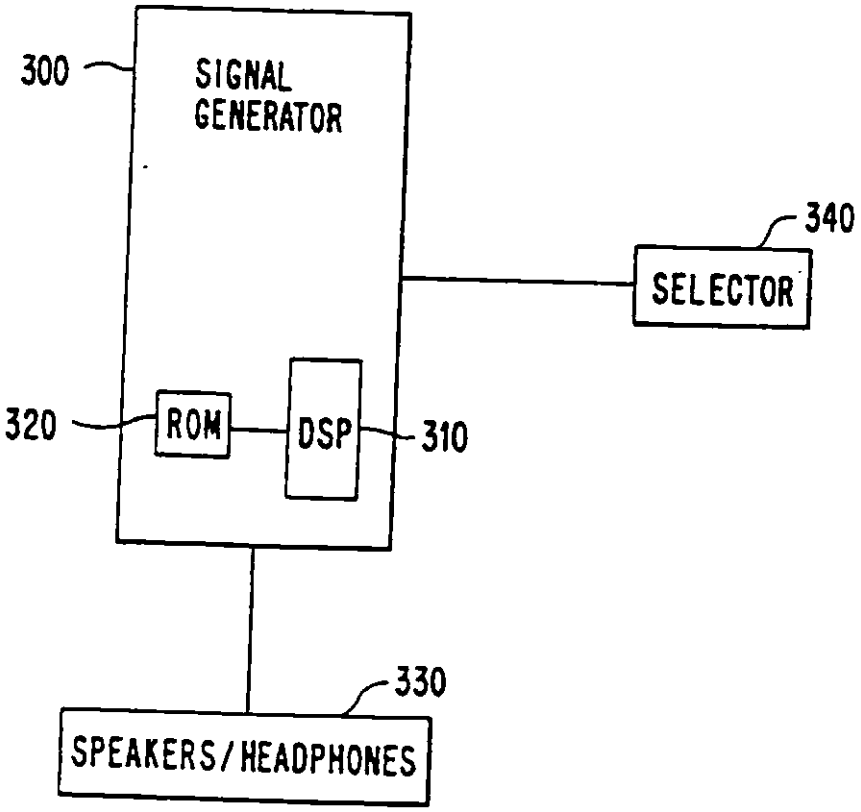

230
SOUND LEVEL DETECTOR
240
TIMER
210
L.C.H. SPEAKER
SOUND GENERATOR
R.C.H. SPEAKER
SELECTOR
220
200
250

FIG. 8A


300
SIGNAL GENERATOR
340
SELECTOR
320
ROM
DSP
310
330
SPEAKERS/HEADPHONES

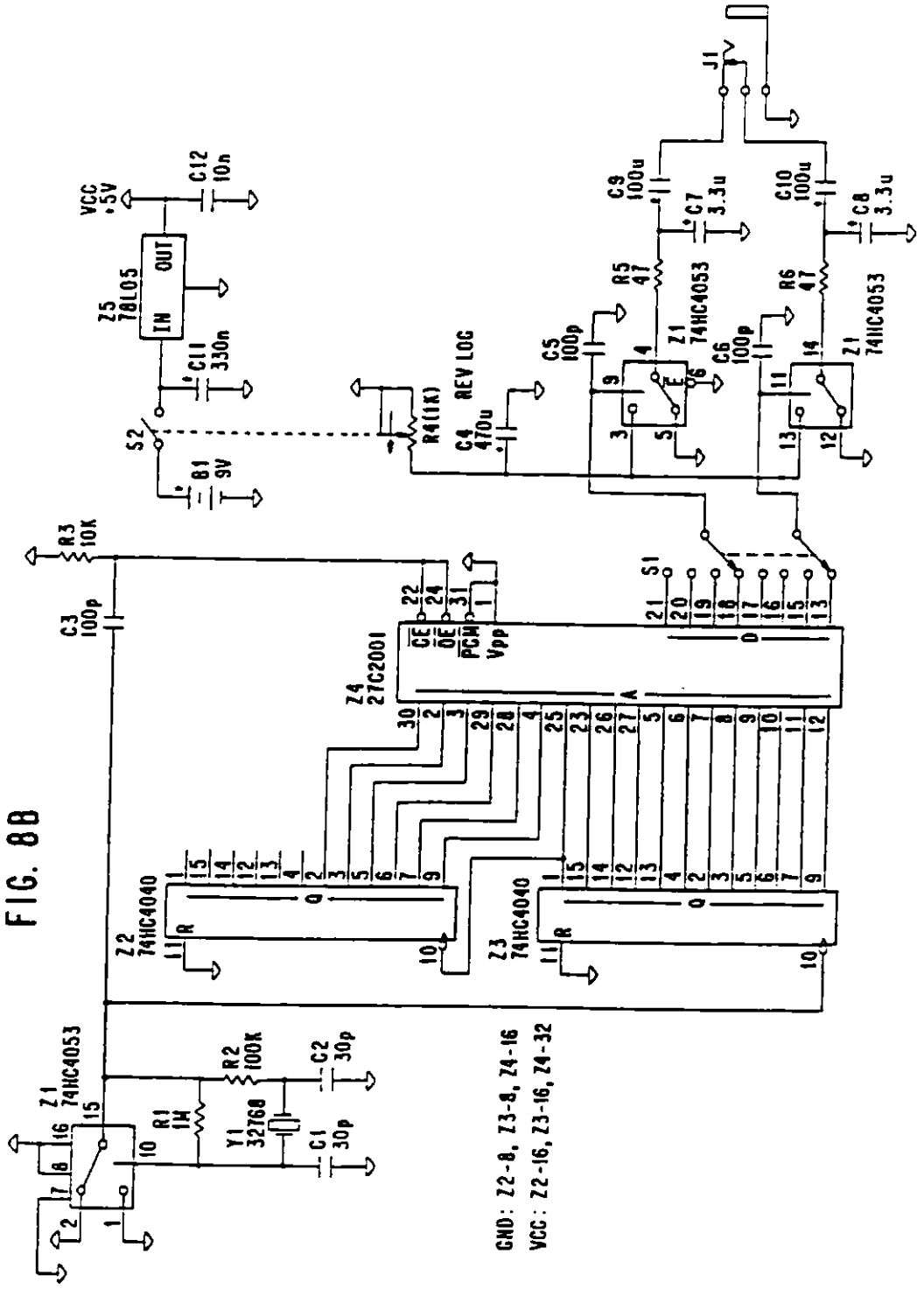

J1
C9 100u
C7 3.3u
C10 100u
C8 3.3u
R5 47
R6 47
Z1 74HC4053
C5 100p
C6 100p
REV LOG
R4(1K)
C4 470u
VCC +5V
C12 10n
Z5 78L05
IN OUT
C11 330n
S2
B1 9V
R3 10K
C3 100p
S1
Z4 27C2001
CE OE PGM Vpp
A
O
Z2 74HC4040
Z3 74HC4040
R
R2 100K
C2 30p
R1 1M
Y1 32768
C1 30p
GND: Z2-8, Z3-8, Z4-16
VCC: Z2-16, Z3-16, Z4-32

FIG. 8B

FIG. 9A

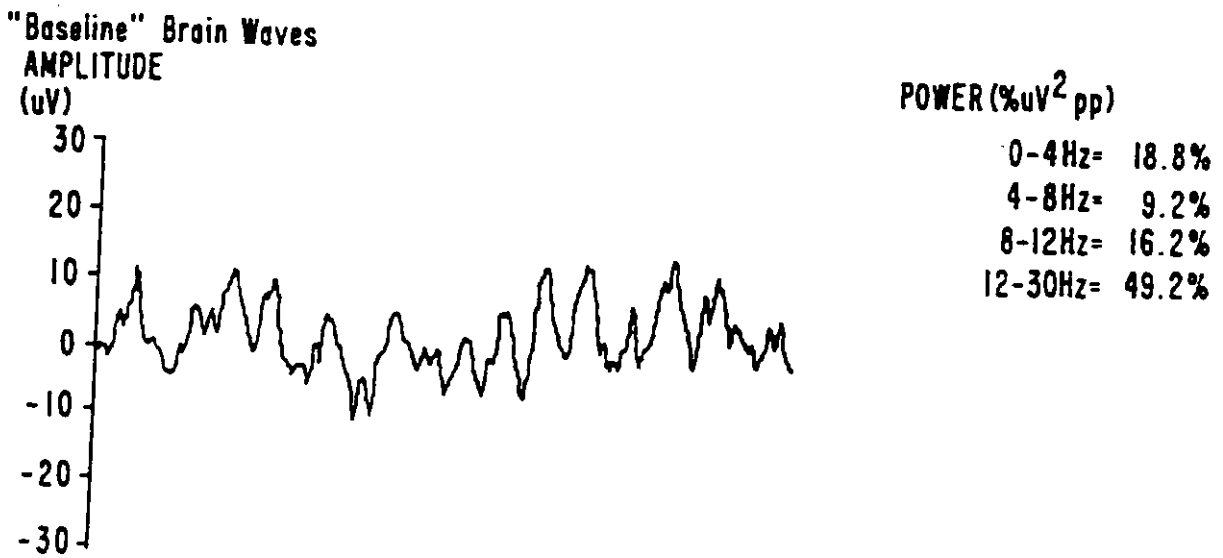
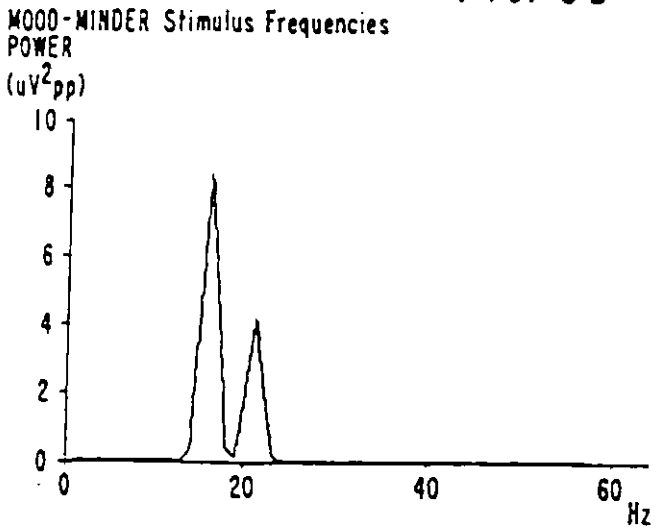
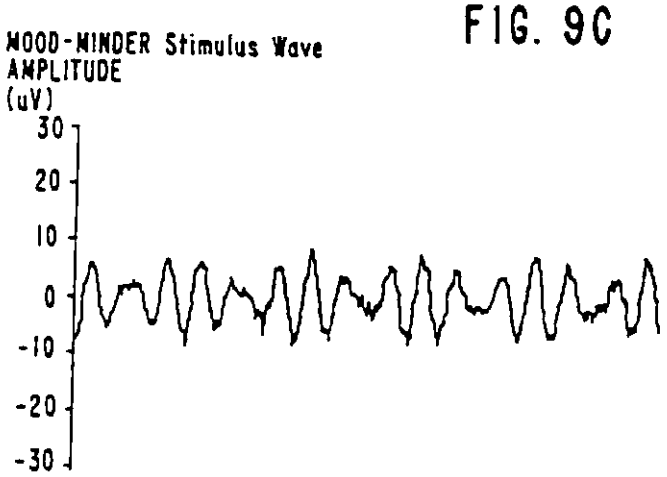

"Baseline" Brain Waves
AMPLITUDE
(uV)
30
20
10
0
-10
-20
-30
POWER (%uV2 pp)
0-4Hz= 18.8%
4-8Hz= 9.2%
8-12Hz= 16.2%
12-30Hz= 49.2%

FIG. 9B



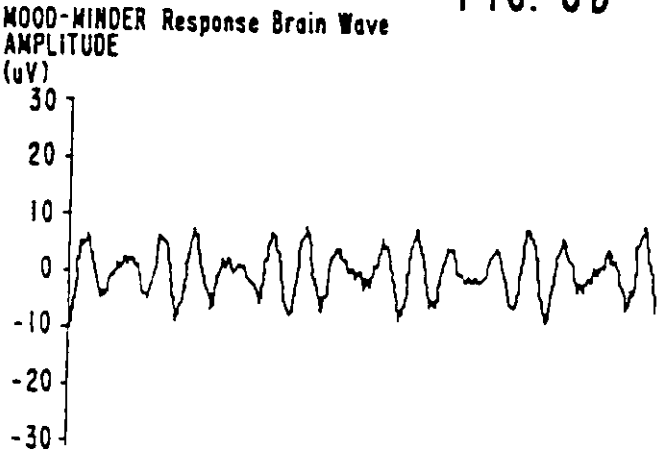
POWER(%uV²pp)
16Hz= 47.6%
21Hz= 23.2%
Awake and Alert

FIG. 9C



POWER(%uV²pp)
16Hz= 47.6%
21Hz= 23.2%
Awake and Alert

FIG. 9D



POWER(%uV²pp)
16Hz= 46.5%
21Hz= 23.7%
Awake and Alert

FIG. 9E

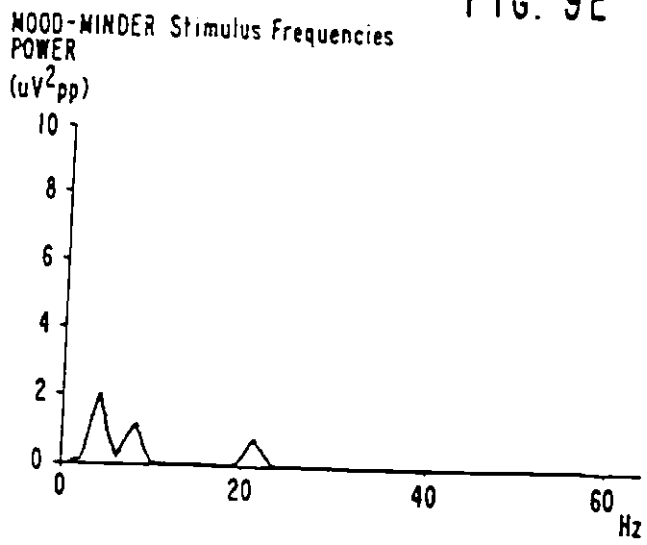


FIG. 9F

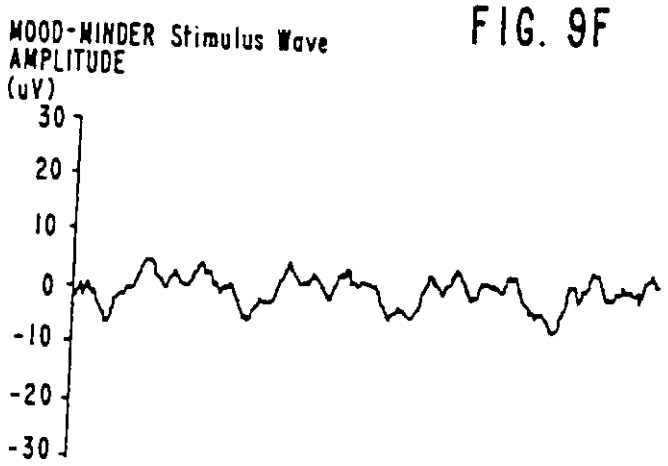


FIG. 9G

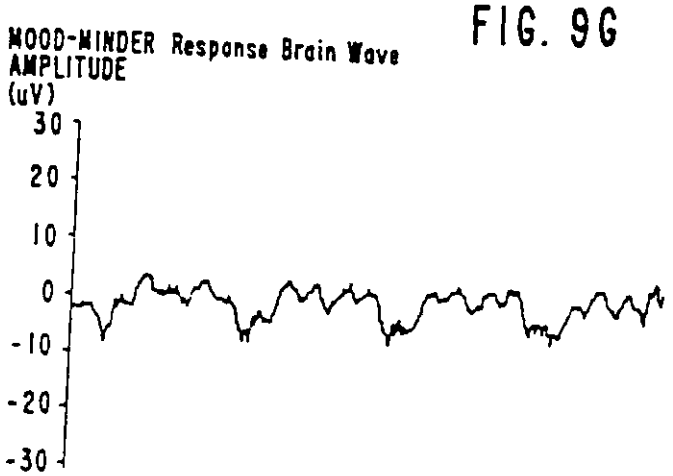
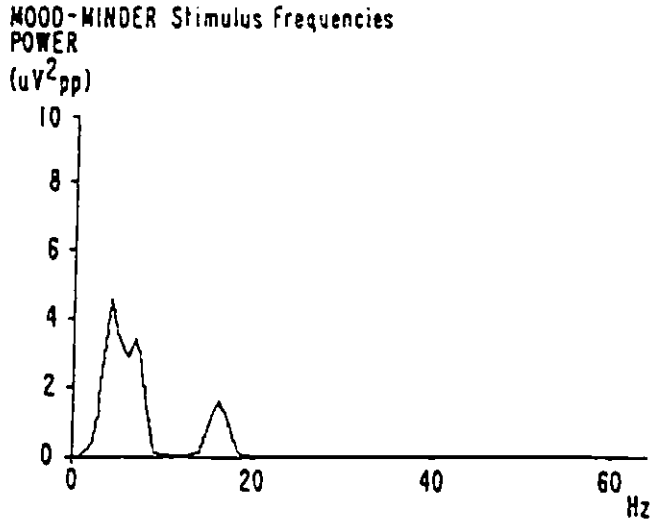


FIG. 9H

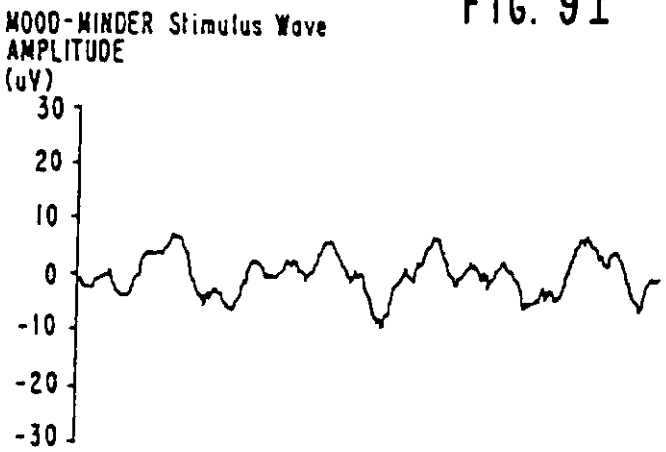


POWER(%uV²pp)

16Hz= 11.5%
7Hz= 28.4%
4Hz= 30.2%

Attention

FIG. 9I

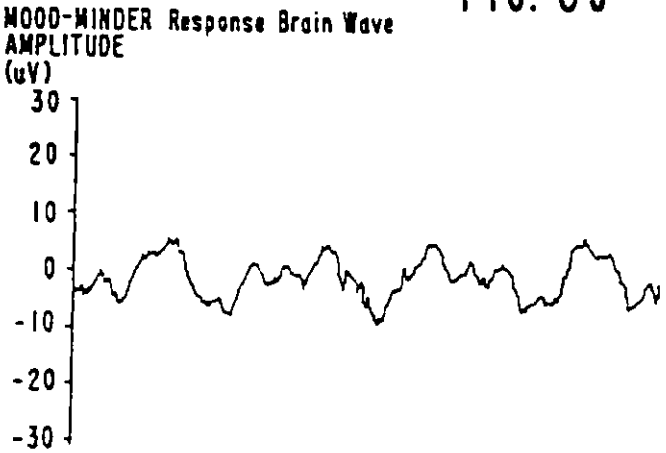


POWER(%uV²pp)

16Hz= 11.5%
7Hz= 28.4%
4Hz= 30.2%

Attention

FIG. 9J

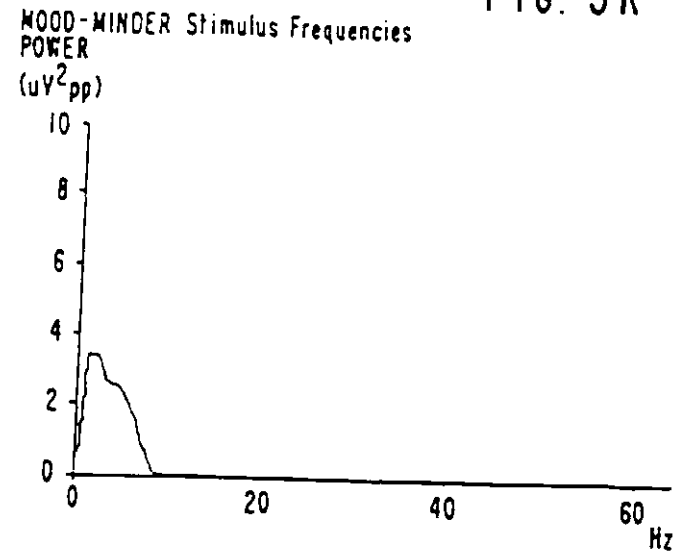


POWER(%uV²pp)

16Hz= 8.2%
7Hz= 28.7%
4Hz= 32.6%

Attention

FIG. 9K

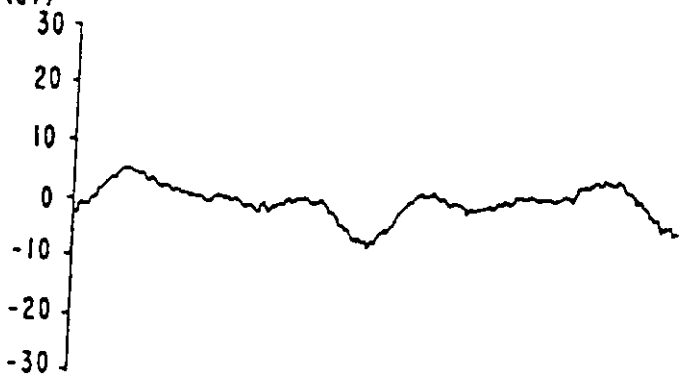


POWER(%uV²pp)

6Hz= 9.5%
4Hz=15.4%
1.5Hz=19.6%

Relaxation

FIG. 9L

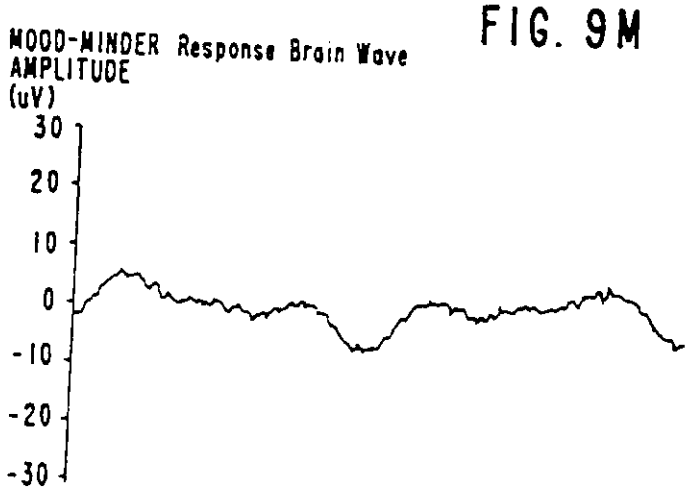


POWER(%uV²pp)

6Hz= 9.5%
4Hz=15.4%
1.5Hz=19.6%

Relaxation

FIG. 9M



POWER(%uV²pp)

6Hz= 7.9%
4Hz=16.8%
1.5Hz=20.0%

Relaxation

METHOD OF AND APPARATUS FOR INDUCING DESIRED STATES OF CONSCIOUSNESS

CROSS-REFERENCE TO RELATED APPLICATION

The present application is related to copending application No. 07/514,460, filed Apr. 16, 1990 now U.S. Pat. No. 5,213,562.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an improved method of inducing desired states of consciousness, including different levels of sleep, in human beings, using a technique known as frequency following response (FFR), developed by the present inventor. The invention also relates to apparatus for performing the method. A number of areas of applicability of the invention are described, in accordance with different preferred embodiments.

2. Description of the Background Art

In a prior patent, U.S. Pat. No. 3,884,218, the present inventor described a method of inducing different levels of sleep, using the FFR technique, in which brain waves could be made to follow superimposed frequency patterns. These frequency patterns were provided as sine waves, at frequencies known to correspond to different levels of sleep, such as alpha (exhibiting brain wave activity in the range of 8–12 Hz), theta (6–8 Hz), and delta (1–4 Hz). EEGs exhibiting frequencies between 12 and 30 Hz (known as a beta range) are characteristic of awake individuals, though beta activity at even higher frequencies has been observed in different types of mental activities. Gamma activity has been characterized as all activity above 30 Hz; until recently, it has not been possible to monitor brain activity in the gamma range. (It should be noted that the boundaries between gamma and beta, beta and alpha, alpha and theta, and theta and delta are somewhat arbitrary; the foregoing delineations are intended to be exemplary and not limiting.)

The present inventor discovered that the human brain could be entrained to output brain wave patterns these different frequencies. While frequencies corresponding to these different levels of sleep are not audible, by superimposing those frequencies on some type of sound, such as music, it was determined to be possible to induce desired levels of sleep. The individual listening to the music would "hear" the low frequencies, with the desired effect on brain activity.

An improvement on the inventor's patented technique, to induce varied states of alertness, is the subject of copending Application No. 07/514,460, the contents of which are hereby incorporated herein by reference. This copending application describes a general FFR technique using what is known as a binaural beat phenomenon, details of which are provided in that application. Briefly, a binaural beat is produced by sending signals at different frequencies (some Hz apart, depending on the desired effect) to an individual's left and right ears. The difference between the frequencies defines the frequency of the binaural beat. Using this technique, the desired frequency can be introduced into the individual's brain activity, inducing the desired state of consciousness.

The induction of FFR in the human brain in this manner results in the synchronization of activity in the hemispheres of the brain. FIG. 1A shows brain activity without FFR, and FIG. 1B shows brain activity with FFR. The inventor has coined the term HEMI-SYNC (for Hemisphere Synchronization) to describe this phenomenon.

The copending application describes a technique wherein, in one form, sine waves having a frequency corresponding to a consciousness state are superimposed on two different carrier frequencies to form two different signals to set up the binaural beat. In another form, an actual brain pattern, based on an electroencephalogram (EEG) waveform indicative of that consciousness state is superimposed on the different carrier frequencies to form two different signals. In use, each signal is provided to one ear of a subject. The difference in carrier frequencies sets up the binaural beat.

Another, more limited application of the binaural beat phenomenon is found in U.S. Pat. No. 4,834,701. In contrast to the narrow range of frequencies discussed in that patent, in the above-mentioned copending application, the applicability of the binaural beat phenomenon is investigated over a much wider range of frequencies, spanning the spectrum of brain activity.

Through additional investigation involving mapping of brain activities of different individuals, the present inventor has discovered some significance to the fact that, while brain waves at certain frequencies are characteristic of different levels of sleep, brain patterns of different individuals still vary. The inventor has investigated possible enhancements to the FFR effect by making it more generic among individuals, yet still more specific to brain activity than a simple sine wave, or an EEG of a particular individual.

Another area of investigation being performed by the present inventor relates to human sleep patterns. Based on current knowledge of human sleep patterns, it appears that sleep is composed of a series of 90-minute cycles. As stated earlier, the beta stage is one of alertness. The first sleep state is alpha, or mental and physical relaxation. The second is theta, or light sleep. Next is delta, or deep sleep. The inventor has investigated the possibility of providing FFR waveforms in cyclic patterns, replicating these human sleep patterns, to facilitate sleep. Another possibility is to take advantage of the cyclic nature of sleep patterns to provide a more gentle wake-up for a sleeper.

In considering the need for alertness during activities such as work, the inventor also considered how it might be possible to introduce FFR waveforms into ambient noise in one's surroundings to facilitate maintenance of desired states of consciousness. Particularly in environments such as factories, or in offices where office equipment puts out consistent types of noise, it would be desirable to be able to introduce a binaural beat into that noise at different frequencies, to enhance the degree of alertness of factory or office workers as desired.

SUMMARY OF THE INVENTION

In view of the foregoing, according to one aspect of the invention, EEGs for a number of individuals in different states of consciousness are sampled, and EEG waveforms for the group of individuals, corresponding to each identifiable state of consciousness, are combined. A binaural beat then is generated using the combined EEGs.

According to this aspect of the invention, it has been determined that using groups of EEG waveforms from different individuals and combining them to obtain a

representative waveform yields a waveform that a person's brain is more likely to replicate than an individual EEG waveform, or a sine wave representation of the EEG waveform. The combination may be simple averaging, though other combination techniques, such as weighted averaging, for combining different numbers of EEG waveforms as desired, are contemplated. Now that the inventor has discovered that combinations of EEG waveforms provide a particularly effective entrainment environment, it will be seen that various ways of combining these waveforms may yield greater or lesser effects.

In accordance with another aspect of the invention, a method for replicating cyclic sleep patterns for a desired sleep period is provided. In a preferred embodiment according to this aspect of the invention, a subject is led from beta, to alpha, to theta, to delta, then back to theta, then alpha, then a rapid-eye movement (REM) or light dreaming sleep, in a sequence of 90-minute cycles, during a sleep period of desired duration. After the expiration of the period, the subject may wake up voluntarily. Alternatively, the invention can provide a gentle external stimulus to lead the subject to a beta state.

With respect to this aspect of the invention, an apparatus is provided which automatically leads an individual through these cyclic sleep patterns, and enables the individual to set a desired sleep period. This device preferably takes advantage of the techniques to be described relative to the first-mentioned aspect of the invention, but is not so limited. The inventive contributions of this second aspect of the invention are considered to lie in the combination of hardware itself which generates the desired sequence of binaural beats, as opposed to the particular software which determines the nature of those binaural beats. In one form, the invention is constituted by an alarm clock which provides a fade-in theta-alpha signal followed by a strong beta-gamma signal shortly before a desired wake-up time.

According to yet another embodiment of the invention, selectable mind-affecting sound patterns are provided to suppiement constant ambient noise in any environment. When the noise is not present, the patterns are not provided. The patterns vary in amplitude in accordance with changes in the environmental noise.

In accordance with still another embodiment of the invention, a portable system is provided to enable the wearer to introduce binaural beat signals of frequencies that are selectable in accordance with a desired level of awareness. Depending on the level of sophistication of the device, the binaural beat may be generated using the combined EEG waveforms of the first aspect of the invention, but this last aspect of the invention is not so limited.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other aspects of the invention will be understood by those of working skill in this technological field by reference to the following detailed description of the preferred embodiments of the invention, read in conjunction with the accompanying drawings, wherein:

FIGS. 1A–1C and 1D–1F taken from the above-mentioned copending application, show one example of the results which can be achieved using the inventive techniques;

FIG. 2 is a block diagram of the hardware according to a second embodiment of the invention, and FIGS. 3–5 are more detailed schematics therefor;

FIGS. 6A–6J are drawings, similar to FIGS. 1A and 1B, but showing brain activity during various stages of a sleep cycle, using a technique in accordance with the second embodiment of the invention;

FIG. 7 is a block diagram of hardware in accordance with a third embodiment of the invention;

FIG. 8A is a block diagram of hardware in accordance with a fourth embodiment of the invention, and FIG. 8B a schematic of that hardware; and

FIGS. 9A–9M are graphs of different possible effects of the embodiment of FIGS. 8A and 8B, showing a baseline brain pattern, selected stimulus frequencies and corresponding stimulus waves, and associated response waves.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The method according to a first preferred embodiment of the invention, which has been developed through extensive experimentation, derives from the empirically-observed phenomenon that brain patterns of human subjects are entrained more readily to brain patterns which more closely match their own. In prior implementations of the FFR technique, such as in the inventor's prior patent, in which sine waves having frequencies corresponding to desired levels of sleep were superimposed upon a given frequency, entrainment did occur. Use of the binaural beat phenomenon yielded better results, through synchronization of the hemispheres of the brain.

However, simple repetitive frequencies, or even combinations of such frequencies within different ranges, do not represent brain patterns per se, but rather provide entrainment environments for the brain to follow. It has been determined that, the more closely the entrainment environment parallels normal brain function at different levels of consciousness, the more effective the entrainment effect. This phenomenon is what led to the improvement disclosed in the above-mentioned copending application.

As a further improvement on that technique, as mentioned above, the present inventor investigated the possibility of creating more generic models of brain function at different levels of consciousness. As a result of that investigation, it was determined that combinations of EEG waveforms from different individuals functioning at the same identifiable level of consciousness (e.g. alpha sleep, theta sleep, or delta sleep) provided a superior entrainment environment. In the inventive method according to this aspect of the invention, the brain patterns of 40 to 50 individuals were combined to yield the entrainment environment.

One area of applicability of the techniques of the present invention is in the area of sleep therapy. Many individuals suffer from sleep disorders to varying degrees. It is possible to provide a suitable entrainment environment, based on known sleep cycles prevalent in humans, to help individuals to regulate their sleep patterns, and thus help to solve their sleep disorders. One embodiment of the invention, shown in FIG. 2 and also in FIGS. 3–5, implements the inventive techniques in what the inventor calls a Sleep Processor to aid in the regulation of human sleep cycles.

In FIG. 2, a read-only memory (ROM) 10 stores frequency sequences corresponding to different parts of

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a human sleep cycle. The stored frequency sequences may be in accordance with a predetermined algorithm, or alternatively may provide a less complex entrainment environment, such as simple averaging. A digital signal processor (DSP) 20 selects different ones of these sequences based on the current time and the time to which an alarm is set. The time is displayed on display 30, and is set using time set 40. The alarm is set to a desired wake-up time using alarm set 50.

During operation, the DSP 20 accesses the ROM 10 and provides an output to a pulse code modulator unit (PCM) 60 accordingly. The PCM 60 provides an output to each of left and right channel speakers 70, 80 which are provided in close proximity to the ears of a human subject. Using headphones enhances the effect.

Some additional detail of operation of the DSP 20 in one aspect of this embodiment now will be provided. A serial port in the DSP 20 generates an interrupt at a 50 KHz rate. An interrupt handler in the DSP 20 computes the various sounds, in one form, by generating sine waves using a pair of integrators:

cosine = cosine + frequency × sine

sine = sine − frequency × cosine

The Sleep Processors needs ten frequencies, five for each channel, and all of these frequencies are generated at the same time. The results are multiplied by ten envelopes, most of which are zero at any moment.

Noise is generated by a well-known 16-bit shift-register algorithm. This algorithm generates a noise signal that repeats every 65535 samples, or about every five seconds. The noise is filtered to sound more like pink or red noise, and less like white noise, and is written into a delay line in RAM. For each channel, the filtered noise is averaged with an earlier sample from the delay line, thus imparting a comb filter response to it.

An additional low-frequency sine/cosine pair is generated, to sweep the comb filter delay. 32-bit arithmetic is used here. The approximate sweep rate is about 1/8 Hz. The low-frequency sine wave is used directly to sweep the delay on one channel. The delay on the other channel is controlled by some mix of the sine and cosine waves. By choosing these and other coefficients properly, any phase and amplitude relationship between the left and right sweep can be obtained. The comb filtered noise for each channel is multiplied by a noise envelope value.

The device is operated as follows. A desired wake-up time is set, much like an alarm clock, and the desired volume is selected. A start/stop button then is pressed to start the cycles for the selected sleep period. Throughout the sleep period, the device repeats a 90 minute cycle of sound that leads the subject through alpha, theta, delta, and back to dreaming sleep. Five minutes before the scheduled wake-up time, a beta signal is introduced to bring the subject back to complete physical wakefulness. When the subject wakes up, he/she hits the start/stop button again to stop the sound sequence.

The sounds produced by the DSP 20 include binaural beat carrier sound patterns utilizing both amplitude and frequency modulation, masking pink sound (a known type of sound described in the copending application), and, optionally, occasional single-word voiced affirmations. The binaural beat audio signals may be in the form of appropriate sine waves, or alternatively may be replicas of actual EEG brain waveforms. In the latter case, either the just-described combined EEG waveforms or a single EEG waveform (as described in the copending

application) may be used. The entire pattern of sound and control is generated algorithmically.

One aspect of the effectiveness of the device of FIGS. 2–5 is the spacing of sound carriers at related frequencies so as to engender binaural beat signals not only from channel to channel, but also monaurally, in each audio channel. In this preferred embodiment, three binaural beat frequency signals are created between audio carrier channels, and two amplitude beats per channel also are created, yielding a total of seven beat signals. The inventor has coined the term Septon for this set of beat signals. One example of a septon is as follows:

Left Channel		Right Channel
200 Hz carrier (4 Hz monaural beat)	(4 Hz binaural beat)	204 Hz carrier (4 Hz monaural beat)
204 Hz carrier (4 Hz monaural beat)	(4 Hz binaural beat)	208 Hz carrier (4 Hz monaural beat)
208 Hz carrier	(4 Hz binaural beat)	212 Hz carrier

A standard program according to this preferred embodiment would employ the following sound sequence:

0–5 minutes:

Signal Group A (comprised of replicated EEG waveforms having dominant values in the alpha range)

Signal Group B (15 dB below Group A, generated simultaneously with the sounds of Group A, and comprised of replicated EEG waveforms having dominant values in the theta range)

Phased Pink Sound (six seconds, peak-to-peak, on both left and right channels, 20 dB below Group A)

Voice Inserts (repeated at 40 second intervals, 10 dB below Group A, simultaneously with the other sounds, and comprising short sequences of phrases like "relax" "let go", and "sleep")

5–20 minutes:

Signal Group B

Signal Group C (20 dB below Group B, generated simultaneously with Group B, and comprised of replicated EEG waveforms having dominant values in the delta range)

Phased Pink Sound (15 dB below Group B, having a duration as in the first interval)

Voice Inserts (10 dB below Group B, comprised as above)

20–40 minutes:

Signal Group C

Signal Group D (10 dB below Group C, generated simultaneously with Group C, and comprised of replicated EEG waveforms having dominant values in the lower delta range)

Phased Pink Sound (10 dB below Group C, having a duration as in the first interval)

Voice Inserts (20 dB below Group C, comprised as above) 40–65 minutes:

Signal Group D

Phased Pink Sound (10 dB below Group D, having a duration as in the first interval)

Voice Inserts (20 dB below Group D, comprised as above) 65–80 minutes:

Signal Group C

Signal Group D (10 dB below Group C, generated simultaneously with Group C)

Phased Pink Sound (15 dB below Group C, having a duration as in the first interval)

NO voice inserts
80–90 minutes:
Signal Group B
Signal Group C (10 dB below B, generated simultaneously with Group B)
Phased Pink Sound (15 dB below Group B, having a duration as in the first interval)
NO voice inserts

The foregoing sequence is repeated through the sleep period until the wakeup sequence, approximately five minutes before the set wake-up time:
Signal Group AA (a wakeup sequence, comprising replicated EEG waveforms having dominant values in the beta range, or alternatively a 400 Hz/416 Hz envelope yielding frequencies in the beta range)
Voice inserts (10 dB below Group AA, comprised of short phrases such as "waking up", "refreshed", "bright", and repeated at intervals)

One variation of the foregoing embodiment is an alarm clock which, instead of sounding a loud alarm or other jarring noise at wake-up time, starts a gentle sequence of signals some minutes before, to bring an individual up gently through the various levels of sleep to full wakefulness. A fade-in theta-alpha signal may be provided, followed by a stronger beta-gamma signal.

FIGS. 6A to 6J show the effects of the just-described "sleep processor" embodiment. Column 1 shows distribution of delta frequencies; column 2 shows distribution of theta frequencies; and column 3 shows distribution of alpha frequencies. The top row of graphs is the actual pattern observed in the individual, and the bottom row is the baseline pattern.

FIG. 6A corresponds to a normal waking state. Dominant alpha activity is shown in the occipital area of the brain. In FIG. 6B, pink noise has been applied, without any beat frequencies. A narrower focus of waking state is shown.

In FIG. 6C, a signal sequence corresponding to Signal Group A has been applied. Some gain in theta frequencies are seen, with rapid diffusion of alpha frequencies and movement toward the vertex of the head. In FIG. 6D, a signal sequence corresponding to Signal Group B has been applied. There is further diffusion of alpha frequencies, with some movement of delta and theta activity toward the pre-frontal cortex of the brain.

In FIG. 6E, a signal sequence corresponding to Signal Group C has been applied. There is rapid diffusion of alpha frequencies, and increased power of theta and delta frequencies. In FIG. 6F, a signal sequence corresponding to Signal Group D has been applied. Alpha frequencies are diffused further toward the pre-frontal cortex, and there is a marked increase in theta and delta frequencies.

FIG. 6G, continuing application of Signal Group D frequencies, shows a marked increase in delta activity in the pre-frontal cortex, with a steady decrease in alpha activity at the vertex. In FIG. 6H, another binaural beat stimulation has been applied, and characteristics of stage 3 and 4 sleep may be observed. In FIG. 6I, further evidence of the further binaural beat stimulation is observed. Delta is the dominant frequency here. Alpha and theta activity has moved to the prefrontal cortex. Finally, FIG. 6J shows early awakening activity, with a diffusion of delta activity.

FIG. 7 is a block diagram of hardware in accordance with another embodiment of the invention, having application to the work environment, or anywhere a constant source of noise is present, to allow workers, for example, to maintain a desired state of awareness. The device may contain suitable digital signal processor circuitry, as in the preceding embodiment. One difference is that the operation of the device is keyed to the presence of ambient noise, not to a given time duration or selected sleep period.

The device of FIG. 7 includes a sound generator 200 which, as just mentioned, may comprise a digital signal processor. The generator 200 outputs sound patterns via one or more speakers (left and right channel speakers 210, 220 are shown). A sound level detector 230 detects the level of ambient noise in the room, and provides a signal to the sound generator 200, or activates a cut-off switch (not shown), to discontinue output of the sound generator 200 when the ambient noise level drops below a predetermined level.

The sound level detector also preferably provides a signal to the sound generator 200 to boost the sound pattern output when the ambient noise level increases, so that the effect of the provision of the sound pattern is commensurate with the noise level in the room. Alternatively, the user may simply adjust the volume manually, using one or more knobs (not shown) on the sound generator 200.

A timer 240 may be provided to control the duration of provision of the selected sound pattern, or even to change the sound pattern at different times of day by controlling a selector 250 which the user accesses to select a particular sound pattern to be output. The user may select a given sound pattern in the morning, and the timer 240 may change that pattern automatically, based on a need at different times of day for sound patterns providing different states of alertness.

The sound pattern produced by the device of FIG. 7 varies automatically in amplitude in accordance with changes in the ambient noise, and is discontinued when the noise stops. As a result, the sound remains unobtrusive. Depending on the setting, the produced sound pattern can enhance wakefulness, promote relaxation (as, for example, in rest areas in the workplace), reduce anxiety and stress, or focus attention, among other characteristics.

The basic system of FIG. 7 produces and inserts four different sound patterns which are selected manually so as to merge the output into the constant ambient noise. More sound patterns are possible, depending on the desired overall capabilities of the system. Various modifications are possible. For example, a programmable version may be provided, which changes the form of the sound patterns throughout a work day or night, in accordance with the responses desired.

Selectability of patterns may be accomplished differently in a model intended for use in conjunction with a computer system. The computer operator can input a selection, and may vary that selection as desired throughout the work day.

FIG. 8A is a diagram of a portable embodiment of the invention, for use in providing a desired level of consciousness on an individualized basis. A signal generator 300 preferably includes a digital signal processor 310 and a ROM 320 for storing predetermined signals or sequences of signals which correspond to various desired states of awareness. The signal generator 300 may be a simple tone generator or pair of tone generators which provide outputs to speakers or headphones 330 (such as button-sized headphones) to set up a binaural beat. Output of pink sound or phased pink sound by the generator 300 is desirable to facilitate defocusing of the

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listener and consequent ability to concentrate on the sounds being produced. A selector **340** enables a user to instruct the signal generator **300** to output signals corresponding to the level of consciousness (e.g. focused concentration, relaxation, alertness) that a user desires.

FIG. **8B** shows a schematic of this embodiment, which the inventor calls a "Mood Minder". This embodiment includes a selector for selecting one of four possible types of signals, corresponding to four respective levels of awareness: awake and alert; concentration; attention; and relaxation. However, the invention is not so limited, as the generator **300** may be capable of producing other possible types of signals. Alternatively, pre-set patterns in the generator **300** may vary when specialized use is required. The key to this embodiment is its portability, enabling the user to carry the device everywhere. The device is battery-operated, and is small enough to fit in an upper coat pocket, for example.

FIGS. **9A–9M** show examples of prestored patterns produced by the generator **300**, and of results achieved in use. FIG. **9A** shows baseline brain waves, with relative power output shown at the right for different frequencies. FIGS. **9B**, **9E**, **9H**, and **9K** show the stimulus frequencies produced for four different respective states of consciousness. FIGS. **9C**, **9F**, **9I**, and **9L** show the stimulus waves corresponding to the superposition of the stimulus frequencies on the baseline wave. FIGS. **9D**, **9G**, **9J**, and **9M** show the results achieved in use. As can be seen, the peak-to-peak amplitudes for the response brain waves correspond closely to those of the stimulus waves.

While the present invention has been described in detail with reference to preferred embodiments, various modifications within the scope and spirit of the invention will be apparent to those of working skill in this technological field. Consequently, the invention should be considered as limited only by the scope of the appended claims.

What is claimed is:

1. A method of inducing desired states of consciousness in human beings, comprising the following steps:

combining a plurality of replicated electroencephalogram (EEG) waveforms, each indicative of a particular desired state of consciousness, to produce a combined EEG waveform;

superimposing said combined EEG waveform on two separate sets of carrier waves using stereo sound;

creating differential beat frequencies between said sets of carrier waves based on said superimposing step; and

providing the resulting signals in audio form to respective ears of a human being, to induce said state of consciousness.

2. A method as claimed in claim **1**, wherein said combining step comprises mathematically averaging said EEG waveforms to produce said combined EEG waveform.

3. A method as claimed in claim **1**, further comprising the step of repeating said combining, superimposing, and creating steps for each of a set of desired states of consciousness, and producing a cycle of sets of resulting audio signals, said providing step comprising providing said cycle of sets of resulting audio signals to respective ears of a human being, to induce each of said desired states of consciousness in cyclic fashion.

4. A method as claimed in claim **3**, wherein said cycle corresponds to human sleep patterns, said desired states of consciousness comprising wakefulness, alpha sleep, delta sleep, and theta sleep.

5. A method as claimed in claim **3**, wherein said cycle corresponds to human sleep patterns, said desired states of consciousness comprising alpha sleep, delta sleep, and theta sleep, said cycle being approximately 90 minutes long.

6. A method as claimed in claim **5**, said method further comprising the steps of providing a plurality of repetitions of said cycle, followed by providing a set of audio signals containing a binaural beat at a frequency indicative of beta consciousness.

7. A method as claimed in claim **1**, wherein said creating step includes the step of combining pink sound with said sets of carder waves by shifting of said pink sound with respect to said combined EEG waveform from one stereo audio channel to another, with cyclic changes in amplitude, frequency, and rate of panning.

8. Apparatus for facilitating sleep in a human subject, comprising:

means for setting a wake-up time to select a desired sleep duration;

means for generating a first sequence of signals in a cycle corresponding to a human sleep pattern, frequencies of said signals in said first sequence being substantially equal to frequencies of human brain patterns at different levels of sleep;

means for repeating said cycle a plurality of times based on the selected wake-up time; and

means for waking up said human subject at the selected wake-up time.

9. Apparatus as claimed in claim **8**, wherein said means for waking up said human subject comprises means for generating a second sequence of signals a predetermined time before the selected wake-up time, frequencies of said signals in said second sequence being substantially equal to frequencies of human brain patterns at or near an awakened state.

10. Apparatus as claimed in claim **9**, wherein said predetermined time is approximately five minutes.

11. Apparatus as claimed in claim **8**, wherein said first sequence of frequencies comprises, in order, alpha frequencies, theta frequencies, delta frequencies, and theta frequencies.

12. Apparatus as claimed in claim **8**, further comprising means for generating phased pink sound in conjunction with said first sequence of frequencies.

13. Apparatus as claimed in claim **8**, wherein said first sequence of signals comprises a plurality of sets of combined brainwaves, each of said sets corresponding to a different level of sleep, said combined brainwaves within a given set being constituted by combined electroencephalogram (EEG) waveforms of a pluraiity of individuals, taken when said individuals had attained a different respective level of sleep.

14. Apparatus as claimed in claim **13**, wherein said EEG waveforms are mathematically averaged.

15. Apparatus for awakening an individual using brain pattern entrainment, said apparatus comprising:

means for selecting a wake-up time;

means for keeping time; and

means, operative a predetermined period before said wake-up time as determined by said means for keeping time, for producing a first sequence of signals having frequencies in the theta-alpha range, followed by a second sequence of signals having frequencies in the beta-gamma range.

16. Apparatus as claimed in claim 15, wherein said means for producing said first and second sequences of signals comprises means for producing said second sequence of signals at a higher amplitude than said first sequence of signals.

17. Apparatus as claimed in claim 15, wherein said first sequence of signals comprises a plurality of sets of combined brainwaves, each of said sets corresponding to a different level of consciousness, said combined brainwaves within a given set being constituted by combined electroencephalogram (EEG) waveforms of a plurality of individuals, taken when said individuals had attained a different respective level of consciousness.

18. Apparatus as claimed in claim 16, wherein said EEG waveforms are mathematically averaged.

19. Apparatus for inducing a desired state of consciousness, said apparatus comprising:

means for detecting presence of a predetermined level of ambient noise;

means, responsive to said detecting means, for generating signals having frequencies substantially equal to frequencies of human brain patterns when said ambient noise is present; and

means for selecting said signals in accordance with desired human activity in said areas.

20. Apparatus as claimed in claim 19, further comprising timer means, connected to said generating means, for generating said signals for a predetermined time set by said timer means.

21. Apparatus as claimed in claim 19, wherein said timer means is connected to said selecting means to enable selection of different ones of said signals in accordance with desired human activity at different times of day.

22. Apparatus as claimed in claim 19, wherein said generating means comprises means, responsive to said detecting means, for increasing an amplitude of said signals in response to an increase in amplitude of said ambient noise, and for decreasing an amplitude of said signals in response to a decrease in amplitude of said ambient noise.

23. Apparatus as claimed in claim 22, wherein said generating means further comprises means for discontinuing said signals when said ambient noise falls below said predetermined level.

24. Apparatus as claimed in claim 19, wherein said generating means comprises a digital signal processor and a read-only memory (ROM) connected to said digital signal processor, said ROM storing a plurality of sets of signals, each of said sets of signals having frequencies substantially equal to human brain patterns at a desired state of consciousness.

25. Apparatus as claimed in claim 24, wherein each of said sets of signals comprises a plurality of sets of combined brainwaves, each of said sets corresponding to a different level of consciousness, said combined brainwaves within a given set being constituted by combined electroencephalogram (EEG) waveforms of a plurality of individuals, taken when said individuals had attained a different respective state of consciousness.

26. Apparatus as claimed in claim 25, wherein said EEG waveforms are mathematically averaged.

27. Apparatus for awakening an individual using brain pattern entrainment, said apparatus comprising:

means for selecting a wake-up time; and

means, operative a predetermined period before said wake-up time, for producing a first sequence of signals having frequencies in a first predetermined range corresponding to a first state of consciousness, followed by a second sequence of signals having frequencies in a second predetermined range corresponding to a second state of consciousness.

28. Apparatus as claimed in claim 27, wherein said first predetermined range is the theta-alpha range, and said second predetermined range is the beta-gamma range.

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MIND CONTROL TECHNOLOGY PATENTS II

Technology To Boggle Your Mind...

Part II in a series of research projects focusing on the official US Patent Office patents detailing technologies for mental monitoring, mind alteration and inducing states of consciousness.

This research project is in progress.
IDN is currently obtaining USPTO documents.
Please find abstract of technologies being researched.

TECHNOLOGY TO BOGGLE YOUR MIND...

This is a listing of various technologies available which can be combined for use in direct or subliminal mind-control systems. Please note that these are mainly private inventions intended for positive uses, but could be applied for negative purposes as well.

• Silent Subliminal Presentation System, US Patent #5,159,703, Oliver Lowery, October 27, 1992. A silent communications system in which non-aural carriers in the very low or very high audio-frequency range, or in the adjacent ultrasonic frequency spectrum, are amplitude-modulated with the desired intelligence and propagated acoustically or vibrationally for inducement into the brain.

• Hearing System, US Patent #4,877,027, Wayne Brunkan, October 31, 1989. A method for directly inducing sound into the head of a person, using microwaves in the range of 100 MHz to 10,000 MHz, modulated with a waveform of frequency-modulated bursts.

• Psycho-Acoustic Projector, US Patent #3,568,347, Andrew Flanders, February 23, 1971. A system for producing aural psychological disturbances and partial deafness in the enemy during combat situations.

• Noise Generator and Transmitter, US Patent #4,034,741, Guy Adams and Jess Carden, Jr, July 12, 1977. An analgesic noise-generator.

• Method and System for Altering Consciousness, US Patent #5,123,899, James Gall, June 23, 1992. A system for altering the states of human consciousness involving the use of simultaneous application of multiple stimuli, preferably sounds, having differing frequencies.

• Subliminal Message Generator, US Patent #5,270,800, Robert Sweet, December 14, 1993. A combined subliminal and supraliminal message generator for use with a television receiver; permits complete control of subliminal messages and their presentation. Also applicable to cable television and computers.

• Superimposing Method and Apparatus Useful for Subliminal Messages, US Patent #5,134,484, Joseph Wilson, July 28, 1992.

US Patent #4,717,343, Alan Densky, January 5, 1988. A method of conditioning a person's unconscious mind in order to effect desired change in the person's behaviour, and which does not require the services of a trained therapist.

• Auditory Subliminal Message System and Method, US Patent #4,395,600, Rene Lundy and David Tyler, July 26, 1983. An amplitude-controlled subliminal message may be mixed with background music.

• Auditory Subliminal Programming System, US Patent #4,777,529, Richard Schultz and Raymond Dolejs, October 11, 1988.

• Apparatus for Inducing Frequency Reduction in Brain Wave, US Patent #4,834,701, Kazumi Masaki, May 30, 1989.

• Ultrasonic Speech Translator and Communication System, US Patent #5,539,705, M. A. Akerman, Curtis Ayers, Howard Haynes, July 23, 1996. A wireless communication system, undetectable by radio-frequency methods, for converting audio signals, including human voice, to electronic signals in the ultrasonic frequency range, transmitting the ultrasonic signal by way of acoustic pressure waves across a carrier medium, including gases, liquids and solids, and reconverting the ultrasonic acoustic pressure waves back to the original audio signal. This invention was made with government support under Contract DE-ACO5-840R21400, awarded by the US Department of Energy to Martin Marietta Energy Systems, Inc.

• Non-Audible Speech Generation Method and Apparatus, US Patent #4,821,326, Norman MacLeod, April 11, 1989.

• Apparatus for Electrophysiological Stimulation, US Patent #4,227,516, Bruce Meland and Bernard Gindes, October 14, 1980.

• Method and Recording for Producing Sounds and Messages to Achieve Alpha and Theta Brainwave States and Positive Emotional States in Humans, US Patent #5,352,181, Mark Davis, October 4, 1994.

• Method and Apparatus for Translating the EEG into Music to Induce and Control Various Psychological and Physiological States and to Control a Musical Instrument, US Patent #4,883,067, Knispel et. al., November 28, 1989.

• Method of and Apparatus for Inducing Desired States of Consciousness, US Patent #5,356,368, Robert Monroe, October 18, 1994. Improved methods and apparatus for entraining human brain patterns, employing frequency-following-response (FFR) techniques and facilitating attainment

• Method of Inducing Mental, Emotional and Physical States of Consciousness, including Specific Mental Activity, in Human Beings, US Patent #5,213,562, Robert Monroe, May 25, 1993.

• Device for the Induction of Specific Brain Wave Patterns, US Patent #4,335,710, John Williamson, June 22, 1982. Brainwave patterns associated with relaxed and meditative states in a subject are gradually induced without deleterious chemical or neurologic side effects.

• Method and Apparatus for Repetitively Producing a Noise-like Audible Signal, US Patent #4,191,175, William Nagle, March 4, 1980.

• Apparatus for the Treatment of Neuropsychic and Somatic Diseases with Heat, Light, Sound and VHF Electromagnetic Radiation, US Patent #3,773,049, L. Y. Rabichev, V. F. Vasiliev, A. S. Putilin, T. G. Ilina, P. V. Raku and L. P. Kernitsky, November 20, 1973. Don't let the nice title fool you. This is the patent for *LIDA*, the infamous Soviet brainwashing machine.

• Non-Invasive Method and Apparatus for Modulating Brain Signals through an External Magnetic or Electric Field to Reduce Pain, US Patent #4,889,526, Elizabeth Rauscher and William Van Bise, December 26, 1989.

• Nervous System Excitation Device, US Patent #3,393,279, Gillis Patrick Flanagan, July 16, 1968. A method of transmitting audio information via a radiofrequency signal modulated with the audio info through electrodes placed on the subject's skin, causing the sensation of hearing the audio information in the brain.

• Method and System for Simplifying Speech Waveforms, US Patent #3,647,970, G. Patrick Flanagan, March 7, 1972. A complex speech waveform is simplified so that it can be transmitted directly through earth or water as a waveform and understood directly or after amplification.

• Means for Aiding Hearing, US Patent #2,995,633, Henry Puharich and Joseph Lawrence, August 8, 1961. Means for converting audible signals to electrical signals and conveying them to viable nerves of the facial system.

• Means for Aiding Hearing by Electrical Stimulation of the Facial Nerve System, US Patent #3,170,993, Henry Puharich, February 23, 1965.

• Hearing Device, US Patent #4,858,612, Philip Stocklin, August 22, 1989. A method and apparatus for simulation of hearing in mammals by introduction of a plurality of microwaves into the regions of