

[54] **HEARING TESTING METHOD AND AUDIOMETER**

[75] Inventors: **Erwin Roy John**, Riverdale; **Robert Laupheimer**, Westbury, both of N.Y.

[73] Assignee: **Neuro-Data, Inc.**, Cliffside Park, N.J.

[22] Filed: **Oct. 6, 1971**

[21] Appl. No.: **187,003**

[52] U.S. Cl. **128/2.1 B, 128/2 Z**

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

[58] Field of Search. **128/2, 2 R, 2 Z, 2.1 B, 128/2.1R; 235/150.53; 179/1 N**

[56] References Cited

UNITED STATES PATENTS

3,087,487	4/1963	Clynes.....	128/2.1 B
3,392,241	7/1968	Weiss et al.....	179/1 N
3,237,711	3/1966	Bates et al.....	179/1 N
2,394,569	2/1946	Strommer.....	179/1 N

3,395,697	8/1968	Mendelson.....	128/2 Z
3,673,328	6/1972	Grason et al.....	179/1 N

OTHER PUBLICATIONS

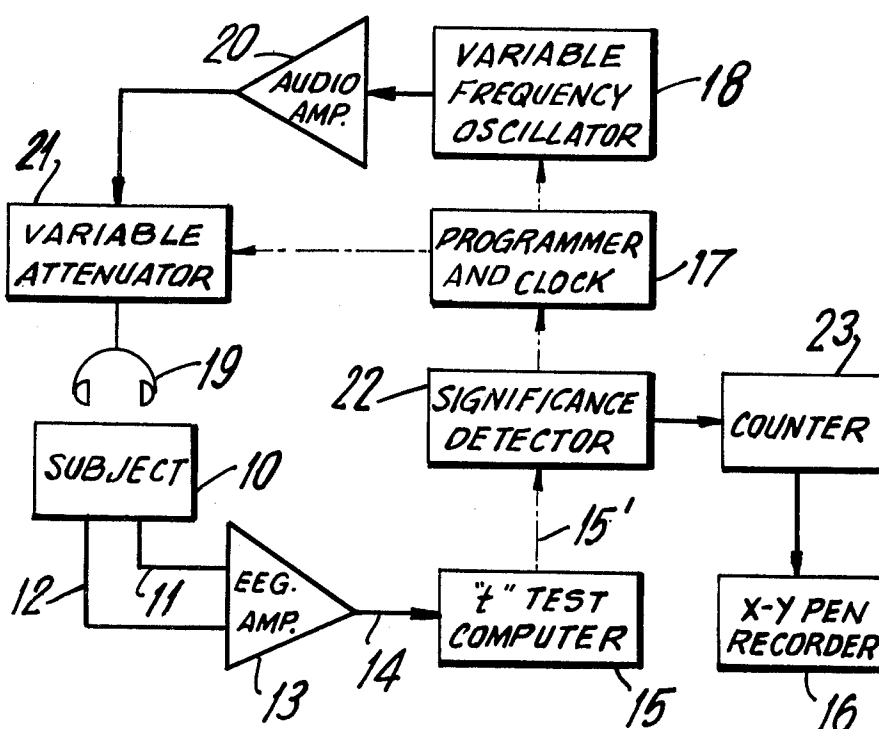
Marsoner et al., "Medical & Biological Engineering," Vol. 8, 1970, pp. 415-418.

Primary Examiner—William E. Kamm
Attorney, Agent, or Firm—Eliot S. Gerber

[57] ABSTRACT

A hearing testing method permits the testing of infants and others who cannot respond and provides an accurate and rapid test for others. A group of pure tones at selected amplitudes and frequencies is played, through earphones, to a subject. Electrodes connected to the subject's head detect the subject's brainwaves which are evoked responses to those tones. The brain waves are amplified, averaged according to the tone frequencies, automatically analyzed on a statistical basis using the "t" test, and used to display a profile of the subject's hearing ability.

10 Claims, 17 Drawing Figures



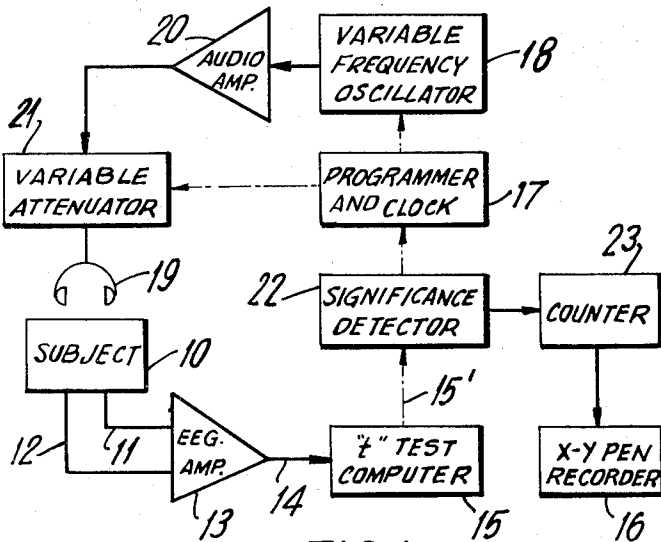


FIG. 1

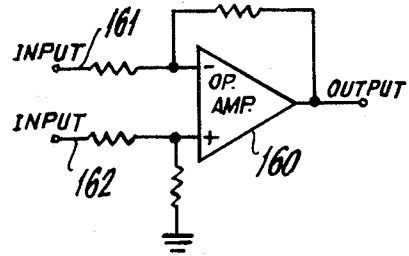


FIG. 4A

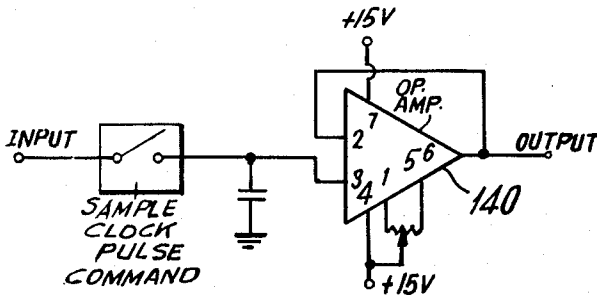


FIG. 3A

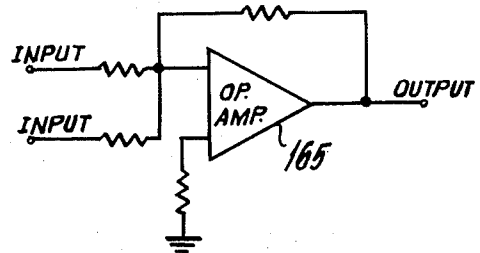


FIG. 4B

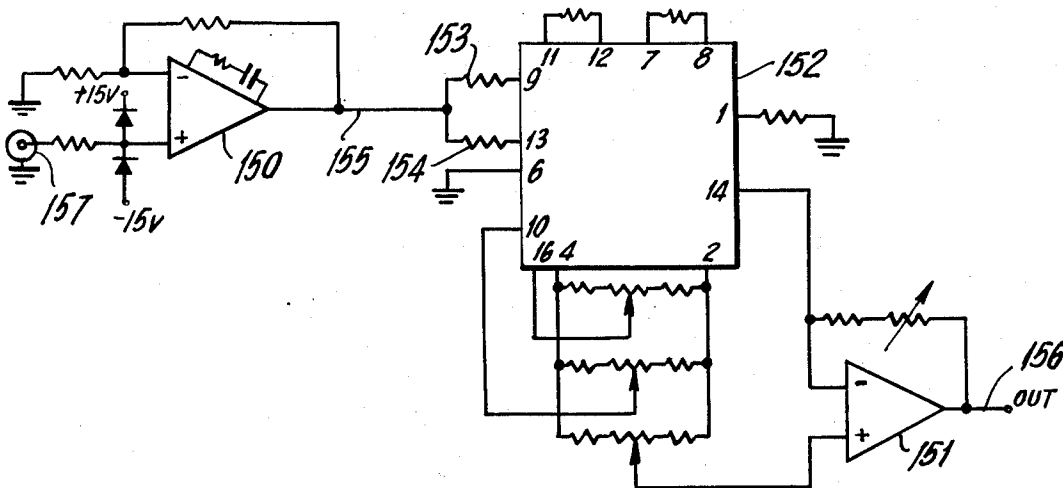


FIG. 3B

INVENTORS
E. ROY JOHN
ROBERT LAUPHEIMER
BY

Eliot S. Garber
ATTORNEY

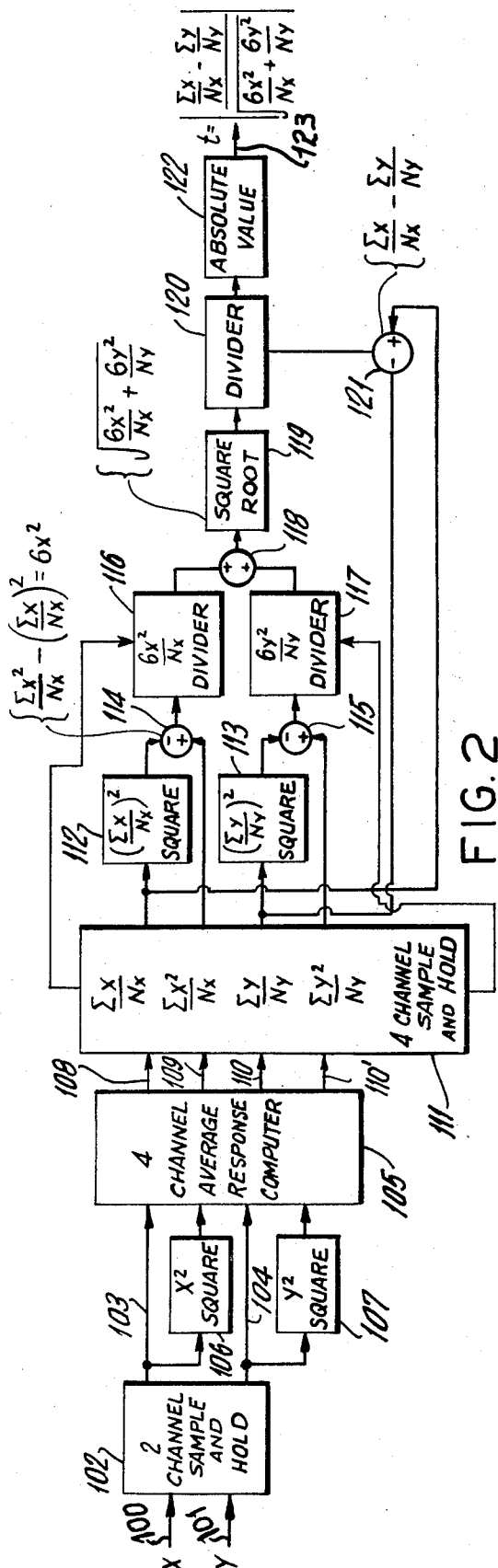


FIG. 2

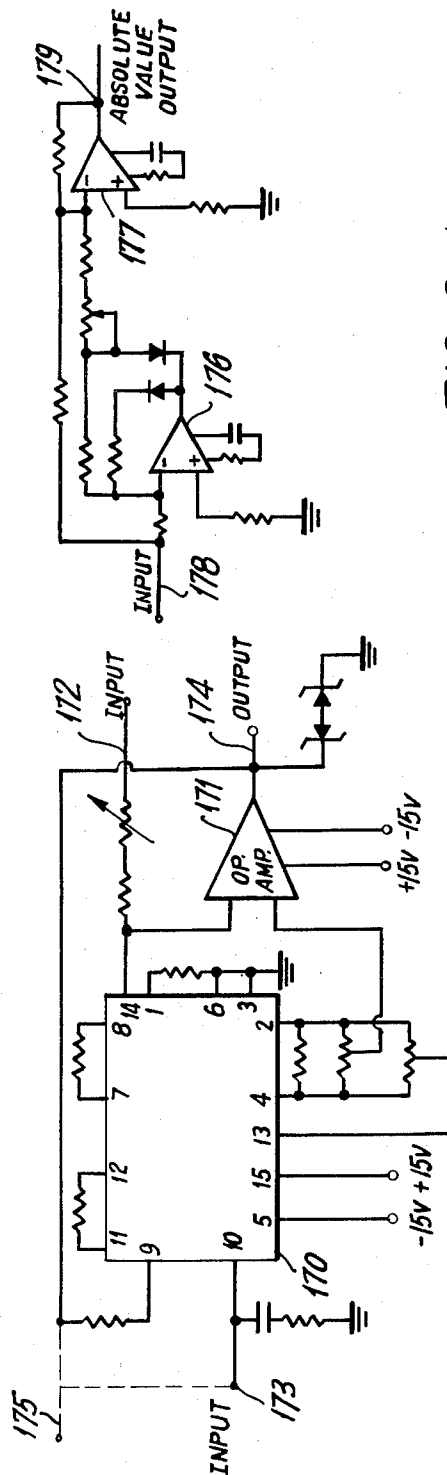
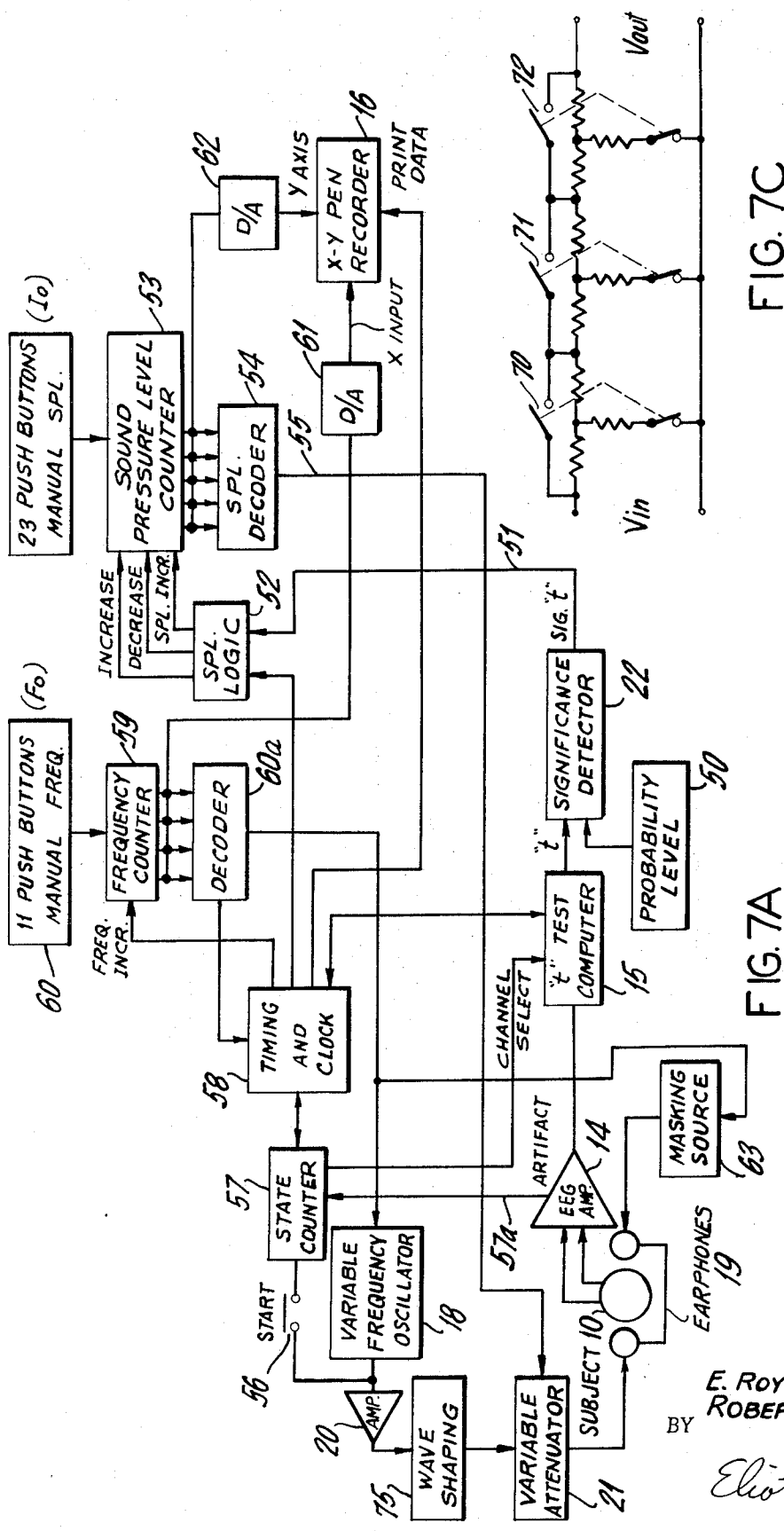
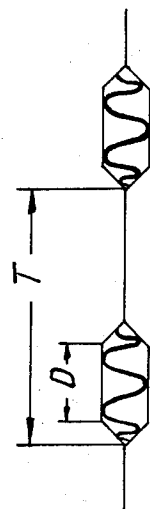
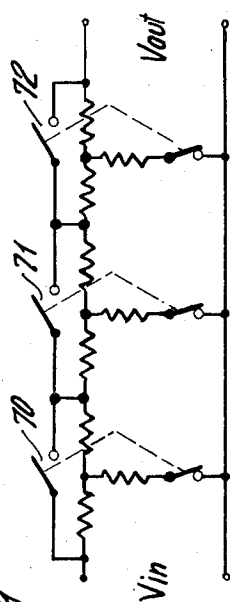


FIG. 6

FIG. 5

INVENTORS
E. ROY JOHN
BY ROBERT LAUPHEIMER
Elot S. Herber
ATTORNEY



INVENTORS
 F. ROY JOHN
 ROBERT LAUPHEIMER
 BY
 Eliot S. Garber
 ATTORNEY

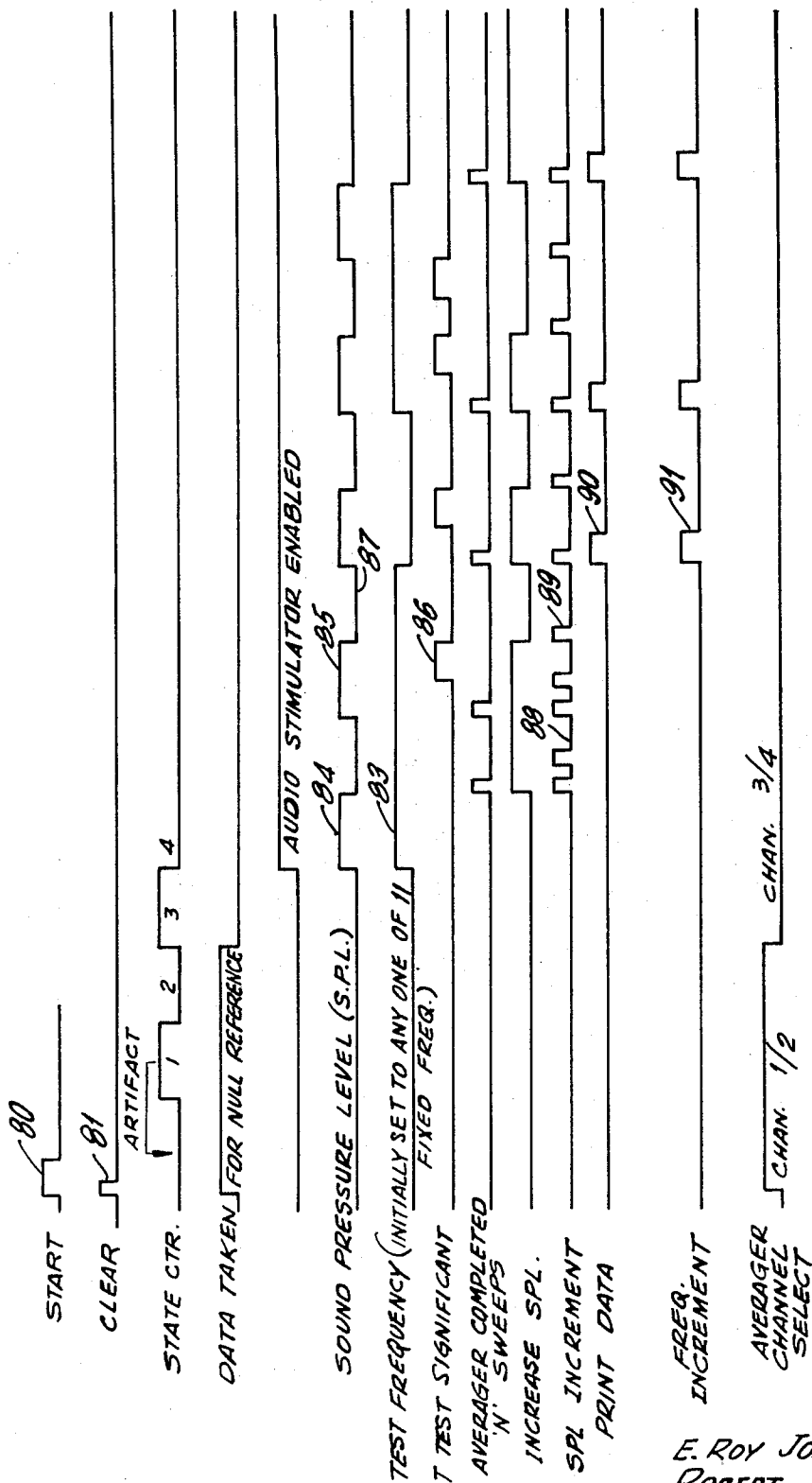


FIG. 7B

INVENTORS
E. ROY JOHN
BY ROBERT LAUPHEIMER

Eliot S. Gerber
ATTORNEY

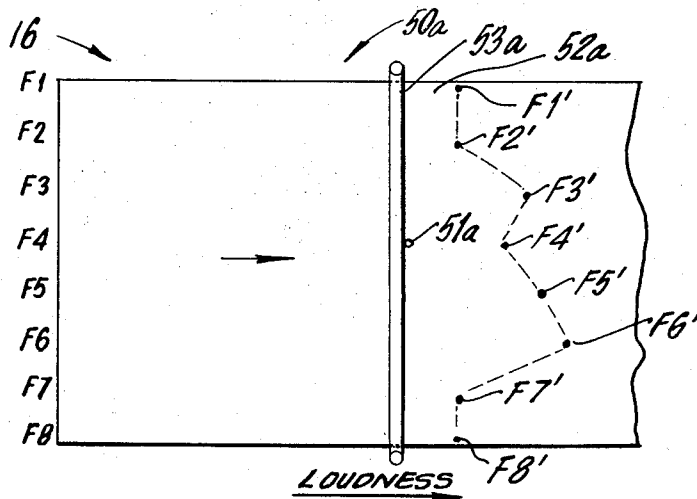


FIG. 8

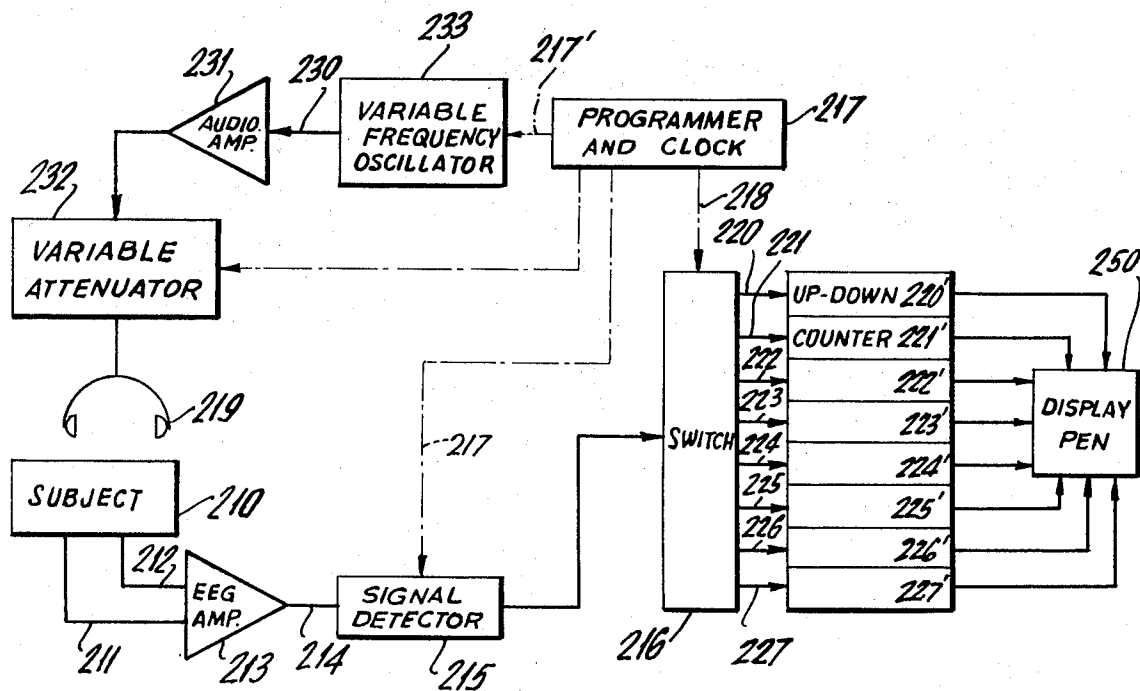


FIG. 9

INVENTORS
 E. ROY JOHN
 ROBERT LAUPHEIMER
 BY
 Eliot S. Gerber
 ATTORNEY

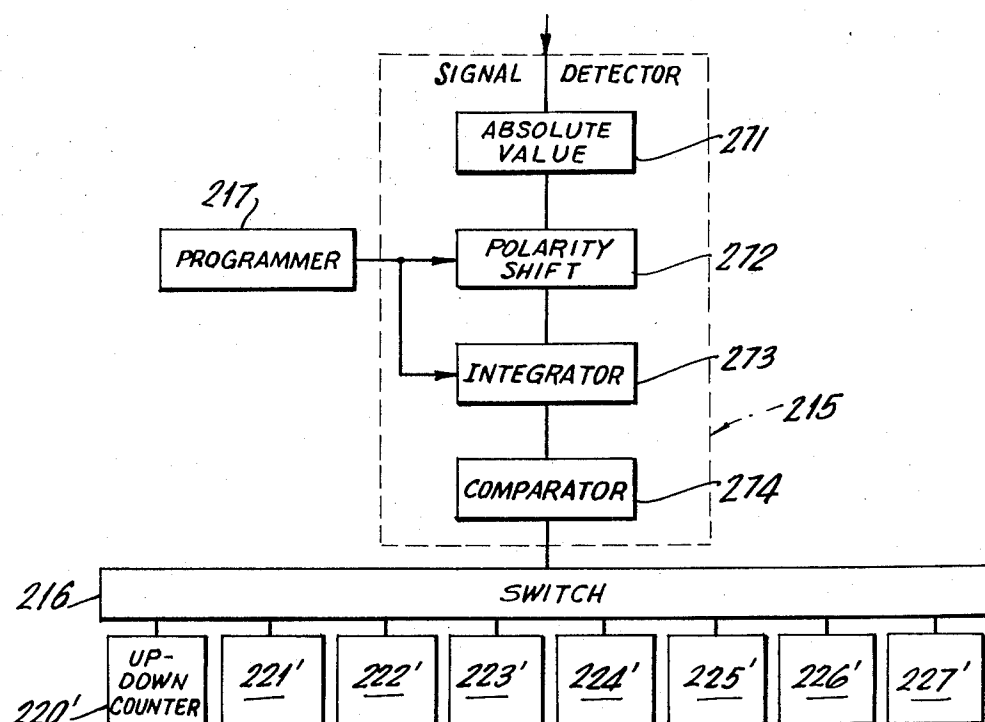


FIG. 10

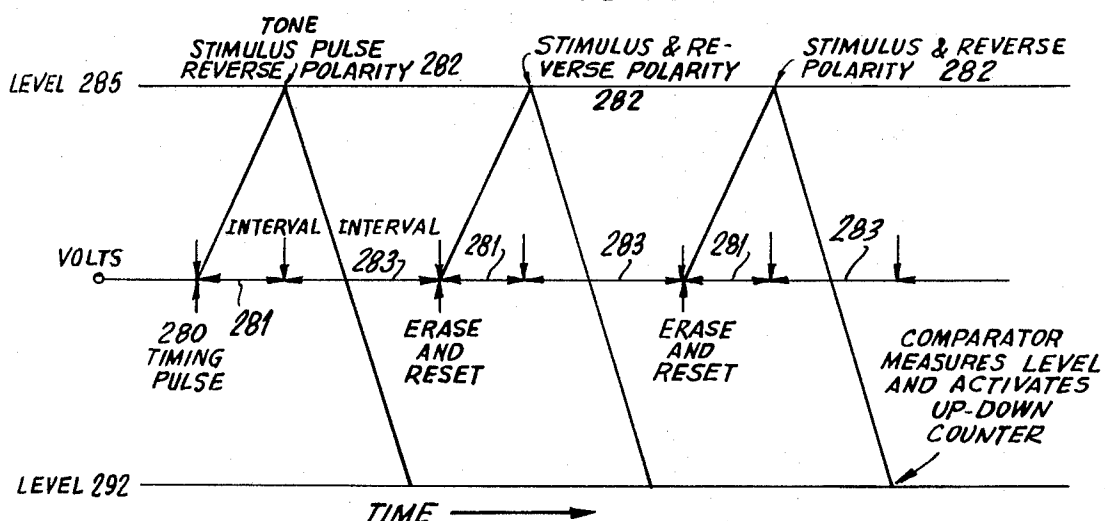


FIG. 11

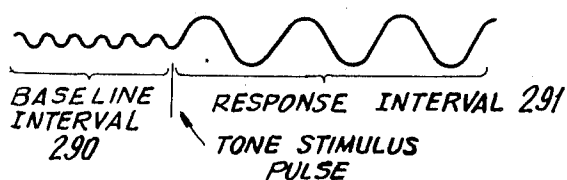


FIG. 12

INVENTORS
E. ROY JOHN
BY ROBERT LAUPHEIMER

Elvitt S. Gerber
ATTORNEY

HEARING TESTING METHOD AND AUDIOMETER

BACKGROUND OF THE INVENTION

The present invention relates to the testing of hearing and more particularly to an audiometer which produces a profile of the subject's hearing ability.

At the present time the usual hearing test involves the services of skilled personnel. A pair of earphones is placed on the subject, i.e., the person to be tested, and eight or more tones at different degrees of loudness are played through the earphones. The technician asks the subject, "Can you hear the tone?" and the subject answers "yes" or "no". A profile is constructed showing the least loudness, at each tone, at which the subject said that he heard the tones.

This conventional procedure has a number of drawbacks. It is relatively expensive as it requires the attention of a skilled technician. It is not an objective test because it depends upon the skill and care of the technician giving the test and the attention and truthfulness of the subject. The test leads to errors as the subject may become bored or fatigued by the repetition of tones. And the test cannot be administered to infants, animals and others unable or unwilling to verbally respond.

OBJECTIVES OF THE INVENTION

It is the objective of the present invention to provide an audiometer and testing method which:

- a. is automatic and does not require the services of skilled personnel to administer the test;
- b. may be administered to infants, animals and others unable to give a verbal reply;
- c. does not depend upon the judgment of the subject to whom the test is given; and
- d. is not boring or fatiguing to the subject.

SUMMARY OF THE INVENTION

A series of preferably eight or more pure tones, i.e., frequencies, are produced, either by a variable frequency oscillator or from a recording on the track of a magnetic tape cassette. Each of the tones is at different levels of loudness or an attenuator is used to vary the loudness. In one embodiment, the tones constitute, or are part of, a musical composition, so that the subject hears a pleasant song. The tones and their amplitude are controlled by a programmer, for example, a digital logic circuit or a track on a tape having control signals in digital form. The tones are played through earphones to the subject and the subject's evoked responsive brainwaves are picked-up by electrodes removably attached to his head.

The brainwaves are amplified by an electroencephalograph (EEG) amplifier and averaged in a signal averaging device. The averaged signals are automatically compared, on a statistical basis, with background noise in a special purpose "t" test computer. The output of the statistical computer, which automatically computes the "t" test, is to a display device. Preferably the display device is a single pen X-Y recorder which produces a visual graph corresponding to a profile of the subject's hearing ability at each of the selected tone frequencies.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 is a block circuit diagram of the instrument of the embodiment of the present invention;

FIG. 2 is a block circuit diagram of the "t" test computer;

FIGS. 3A-6 are circuit diagrams of portions of the "t" test computer;

FIG. 7A is a block circuit diagram of the instrument of FIG. 1 showing the programmer (logic circuit) in greater detail;

FIG. 7B is a timing diagram showing the timing of the various steps of the instrument of FIG. 1;

FIG. 7C is a circuit diagram of the discrete attenuator;

FIG. 7D shows the wave shapes of the tone generated by the instrument of FIG. 1;

FIG. 8 is a top plan view of a suitable pen recorder;

FIG. 9 is a block circuit diagram of the second embodiment of the present invention;

FIG. 10 is a block circuit diagram of the signal detection computer and "up-down" counters used in the embodiment of FIG. 9; and

FIGS. 11 and 12 are diagrams of electrical wave shapes in the circuit of FIG. 10.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As shown in FIG. 1, the first preferred embodiment of the present invention consists of a combination of devices constituting a testing instrument. The subject 10 being tested sits before the testing instrument and wears a pair of earphones 19 and a headband. The headband has a contact electrode 11 which may be wetted with glycerine and touches the subject's forehead. A reference electrode 12 is clipped to the subject's ear lobe.

The electrodes 11 and 12 pick-up the subject's brain waves and communicate them to electroencephalograph (EEG) amplifier 13. The output of the amplifier 13, over line 14, is to the "t" test computer. The output of the computer 15 is to the significance detector 22 (control signals being shown in dot-dash line). The significance detector 22 is connected to the programmer and clock (logic circuit 17) and to the counter 23. The counter is connected to X-Y recorder 16. The programmer and clock 17 controls the frequency of the variable frequency oscillator 18, which supplies pure tones (oscillations) in the audio range. Such tones may be derived from a crystal controlled oscillator. The tones from oscillator 18 are amplified in audio amplifier 20. The output of amplifier 20 is to variable attenuator 21, which variably attenuates the loudness of the tones under the control of programmer 17. The output of attenuator 21 is connected to one earphone of the set of earphones 19. The programmer controls the tones (for example 8-11 selected frequencies generally in the range of 50-10,000 Hz) and the loudness (for example 23 loudness-sound pressure levels).

A suitable circuit for the programmer is shown in FIG. 7A, which shows a digital logic circuit. An alternative to the variable frequency oscillator and digital programmer is to use a magnetic tape read-out, preferably a cassette magnetic tape player having two reading heads. One reading head would read one track of the tape having a musical composition and play it.

Preferably the musical composition is either (a) a song containing 400 notes, each note being a tone of

the selected eight frequencies so that each frequency has 50 notes, or (b) a musical composition in which 400 tones (eight frequencies 50 times each) appears between instrumental portions. The second reading head of the read-out would read a second parallel track on the tape having code signals in digital form. Preferably the second track has, in binary code, the numbers 1-8 corresponding to the eight frequencies, with the numbers preceding its tone by the switching time. The code signals indicate the particular tone and, in addition, may indicate its loudness level.

It should be noted that the instrument tests physiological reaction and does not take account of emotional factors which might cause a person to think that he did not hear a sound, although his brain waves indicate his response to that sound.

The testing method is used as a search for the threshold of the subject's hearing. Each tone is first played at its least loudness and then the loudness level increased. When the threshold level, at each frequency, is reached, i.e., the predetermined "t" test value for that frequency is met, the pen recorder records that event. After each threshold is reached, the test recommences, at the least loud level, at the next frequency.

In operation, for example, the audiometer may look for responses at 11 frequencies in the band 30-20,000 Hz and 23 levels of loudness. The subject's evoked responses to the tones which he hears through the earphones are the X inputs. The subject's background ongoing brain activity is the Y input. The Y input may be obtained either before the test is started or, alternatively, in the intervals between tones, i.e., between evoked responses.

The "t" test is a statistical test for a measure of the significance of the difference between two sample populations. For example, for a sample size of $N = 10$, corresponding to 10 sweeps (10 repetitions of each tone at each loudness level), to obtain a level of significance P of 0.001 (the result occurring by random chance 1 in 1,000) the "t" result must be 4.587. With 25 sweeps and $P = 0.001$ the "t" result is 3.725.

Preferably both the number of sweeps N and the level of significance may be varied by dials on the programmer to set a predetermined "t" test standard. For example, the tester may set the maximum number of sweeps N at 25 and the level of significance P at 0.001. For each tone and loudness level either the "t" test of the evoked response (X values), compared to brain wave ongoing activity background (Y values), will exceed 3.725 (the predetermined "t" standard) or be less than 3.725. If the "t" test evoked response result is larger than the standard, then there is only 1 in 1,000 chances that the result was by accident and consequently the test shows that the subject very likely responded to the tone. Upon such "t" test result, the pen recorder will record the tone and loudness level. As soon as a tone evokes a response, meeting the "t" test predetermined standard, the "t" test computer sends a control signal, over line 15', to programmer 17. The programmer will then automatically start to test for the next frequency, omitting further loudness levels at the frequency at which the response was evoked.

Preferably the "t" test computer will send out its control signal as soon as the predetermined "t" test standard is reached, even though the standard is reached before the maximum set number of sweeps. For example, if N is set at 25 and the P set at 3.725 and the P

value is exceeded on the 11th sweep, a control signal on line 15' will be sent and the remaining 14 sweeps omitted, since a satisfactory set of evoked responses has been obtained. Alternatively, at less cost, the audiometer may be set at the factory to perform a fixed number of sweeps P to obtain a fixed value of "t", thereby setting the level of significance. In this alternative, at each tone and loudness level a "go-no go" signal would be shown, for example, by the pen recorder or by a light.

The preferred embodiment of the T-test computer is shown in FIG. 2. As shown, the computer has two inputs — an X input on line 100 and a Y input on line 101. The inputs 100 and 101 are to a two-channel sample and hold circuit 102. The purpose of the sample and hold circuit 102 is to sample the two signals X and Y and to hold them so that they become in phase. A suitable sample and hold circuit is shown in FIG. 3A. The output lines 103 and 104 of the sample and hold circuit 102 are each directly connected to one channel of a four-channel average response computer 105. In addition, the outputs 103 and 104 are connected to respective squaring circuits 106 and 107, the details of the squaring circuit being given in connection with FIG. 5. The average response computer 105 gives a value of samples taken periodically in time divided by the number of samples, thereby providing a running average, that is, an average which changes with the additional samples. A suitable average response computer is described in Clynes U.S. Pat. No. 3,087,487. The number of samples N is determined by the operator. The output of the first channel 108 is the average of the sum of the values of X, i.e., the sum of the voltages of each of the samples divided by the number of samples N , which is the mean and may be expressed by the formula: $\sum X/N_x = M_1$. The output of the channel 109 of the average response computer 105 is the sum of the X values squared over the number of samples and may be expressed by the formula: $\sum X^2/N_x$. The output of channel 110 is the sum of the Y values over the number of samples and may be expressed by the formula: $\sum Y/N_y = M_2$ and the output of channel 111 is the sum of the Y values squared over the number of samples and may be expressed by the formula: $\sum Y^2/N_y$.

Each of the channels is connected to a four-channel sample and hold circuit 111'. The only purpose of the sample and hold circuit 111' is to eliminate time skewing errors. An alternative is to have a separate memory for each of the channels, in which case the sample and hold circuit 111' would not be necessary. The circuits of each of the four channels of the sample and hold circuit 111' are the same as the sample and hold circuit shown in FIG. 3A.

The output of channel 108, which is the mean, is then squared in a squaring circuit 112 and similarly the output of channel 110 is squared in a squaring circuit 113. Each of the squaring circuits is the same as shown in FIG. 5. The output of the squaring circuit and the output of channel 109 are then combined in a differential amplifier 114. Similarly the outputs of the squaring circuit 113 and channel 110 are combined in differential amplifier 115. The detailed circuit of a suitable differential amplifier is shown in FIG. 4A. The formula for the computation which occurs in the differential amplifier 114 is:

$$(\sum X^2/N_x) - (\sum X/N_x)^2 = \sigma_x^2$$

and the formula for the mathematical computation which occurs in the differential amplifier 115 is

$$(\Sigma Y^2/N_y) - (\Sigma Y/N_y)^2 = \sigma_y^2$$

The outputs of the differential amplifiers are connected to the respective divide circuits 116 and 117, the details of which are shown in FIG. 5. The divide circuit 116 divides the variance σ_x^2 by the number of samples. The output of the divide circuits 116 and 117 are connected to summing amplifier (adder) 118 which performs the following mathematical computation: $(\sigma_x^2/N_x) + (\sigma_y^2/N_y)$, a suitable circuit being shown in FIG. 4B. The output of the summing amplifier 118 is to a square root circuit 119, the details of which are given in FIG. 5. The output of the square root circuit is to the divide circuit 120, a suitable divide circuit being shown in FIG. 5. The second input to the divide circuit is from a differential amplifier 121 which may be of the type shown in FIG. 4A. The differential amplifier 121 provides the difference between the two means, that is, it accomplishes the mathematical computation as follows:

$$(\Sigma x/N_x) - (\Sigma y/N_y)$$

The output of the divide circuit 120 is to the absolute value circuit 122, shown in FIG. 6, which provides the final result of the "t" test.

All of the computations necessary for the "t" test have been provided by the circuit of FIG. 2 and the "t" test result is taken at the output 123. The "t" test computation performed by the circuit of FIG. 2 is as follows:

$$t = \frac{\frac{\Sigma x}{N_x} - \frac{\Sigma y}{N_y}}{\sqrt{\frac{\sigma_x^2}{N_x} + \frac{\sigma_y^2}{N_y}}}$$

A suitable squaring circuit, as shown in FIG. 3B, uses three integrated circuits. The integrated circuits 150 and 151 are operational amplifiers and may be of the type Motorola No. MC 1556-G. That integrated circuit is a compensated and monolithic operational amplifier. The integrated circuit 152 is a multiplier which, suitably, may be Motorola Type 1594-L. The multiplier, as its two inputs 153 and 154 derived from a common line 155 which is the output of the operational amplifier 150, and acts to square the input from line 155; that is, its inputs are tied together. A suitable integrated circuit is a monolithic four-quadrant multiplier where the output voltages are a linear product of two input voltages. The Motorola 1594-L is a variable transconductance multiplier with internal level shift circuitry and voltage regulation. The scale factor is adjustable and preferably is set to be 1/10 of input. An operational amplifier 151 is used to complete the multiplier connections from the integrated circuit 152. Its output 156 provides a square of the input at 157. This type of multiplier connection is described in further detail in the specification sheet dated October 1970 DS-9163 from Motorola of Phoenix, Arizona, of their 1594-L integrated circuit.

A suitable sample and hold circuit is shown in FIG. 3A. It uses an operational amplifier 140. Preferably operational amplifier 140 is an integrated circuit, for example, of the type Motorola No. 1456G, described above.

A suitable differential amplifier circuit is shown in FIG. 4A. It uses an operational amplifier 160 having two inputs 161 and 162. Preferably the operational amplifier 160 is an integrated circuit. A suitable integrated circuit is Motorola No. MC 1456G described in the specification sheet DS9147R1 dated April 1970 as being epitaxial passivated and monolithic. It has a power supply voltage of +18V dc and -18V dc, a power bandwidth of 40K Hz and power consumption of 45m W max.

The summing amplifier of FIG. 4B also uses an operational amplifier 165. The two inputs to be added are connected to one input of the amplifier 165. A suitable operational amplifier is the integrated circuit Motorola No. 1456G described above.

A suitable divider circuit is shown in FIG. 5. It uses a linear multiplier 170 and an operational amplifier 171. Preferably the multiplier 170 and the amplifier 171 are integrated circuits. A suitable integrated circuit for the multiplier 170 is Motorola No. 1594, described above, and for the amplifier Motorola No. 1456G, also described above. The inputs are 172 and 173 and the output at 174.

A suitable square root circuit is shown in FIG. 5. The square root circuit is a special case of a divider in which the two inputs to the multiplier are connected together. Consequently the input line 173 and the input line 172 are connected together to form a common input line 175, shown in dashed line and the ground.

A suitable absolute value circuit is shown in FIG. 6. It uses two operational amplifiers 176 and 177. Preferably they are integrated circuits and may be of the type Motorola No. 1456G described above. The input 178 is to the minus input of amplifier 176 and the output 179 is from amplifier 177. The purpose of the circuit of FIG. 6 is to provide a positive quantity if the X or the Y terms are larger, the absolute value being the value regardless of the plus or minus sign of the quantity.

FIG. 7A is similar to FIG. 1 but shows the programmer 17 in greater detail. As shown in FIG. 7A the electrodes from the subject 10 are connected to the EEG amplifier 14 and the amplifier 14 is connected to the "t" test computer 15. The results of the "t" test computation go to the significance detector 22. The probability level is manually set in the significance detector by means of dial 50. When the "t" test is determined to be significant, in accordance with the selected and dialed probability level, a signal is communicated, over line 51, to the sound pressure level (SPL) logic circuit 52. The logic circuit 52 will indicate to the sound pressure level counter 53 whether the sound level is to be increased or decreased. The counter 53 is connected, by five lines (for 5 bits) to the level decoder 54. The decoder over six lines 55 (only one of which is shown) provides a control signal to the variable attenuator 21.

The audiometer is started, by means of switch 56, which is connected to the state counter 57. The state counter 57 is connected, by line 57a, to the EEG amplifier 14. If an artifact occurs, for example, an eye movement, the overly large voltage amplitude of the artifact will re-start the state counter. The state counter 57 is connected to the timing and clock circuit 58. The timing and clock circuit, in turn, is connected to the frequency counter 59. The frequency counter 59 is controlled by 11 push-buttons 60 which manually set the frequency at which the test is to start. For example, the frequencies may range from 125 Hz to 8,000 Hz. How-

ever, it may be desired to start the test not at 125 Hz, but at 2,000 Hz. There are preferably 11 push-buttons provided for the 11 frequencies.

The frequency counter 59 is connected to the decoder 60a by means of four lines, i.e., a four-bit counter. The decoder is connected by 8 lines, only one of which is shown, to the variable frequency oscillator 18. The variable frequency oscillator 18 receives a digital control signal and produces the desired frequency. Preferably the digitally controlled variable frequency oscillator 18 may consist of eight input lines each one of which is connected to a field effect transistor. The transistors are connected to a common line which is one input of an operational amplifier integrator. The output from the integrator is connected to an input comparator whose output is connected to a voltage reference clamp. The output of the integrator is in the form of a triangular wave and its frequency depends upon which of the field effect transistors are turned on. The output from the integrator is connected to a sine converter which converts the triangular shaped waves into sine waves.

An output from the frequency counter 59 is to the digital-to-analog converter 61 whose output provides the information of the X axis of the X-Y pen recorder 16. Similarly, the sound pressure level counter 53 is connected to the digital-to-analog converter 62 which provides the information for the Y axis.

FIG. 7A also shows a masking source circuit 63 which is controlled from the decoder 60a and whose output is to one of the earphones 19. The masking source is operated only when a tone is produced. It provides random noise to the ear which is not being tested. Such masking noise helps prevent an evoked response due to the ear which is not being tested picking up the test tone.

As shown in FIG. 7C a digital control attenuator consists of a series of resistances. The switches 70, 71, 72 of which, for example, there may be 10 or more, are relay closure contacts. When those contacts are closed, the particular resistances are placed in the circuit between V_{in} and V_{out} to attenuate the tones. It has been found that a rapid rise and fall of the tone sounds like a click noise and should be avoided. To avoid such "click sounds" preferably the variable frequency oscillator 18 is not directly connected to the attenuator but rather the tones shaped first through a wave-shaping circuit 75. The wave-shaping circuit 75 is preferably a trapezoidal generator which is connected to a modulator. The tones from oscillator 18 are connected to the input of the modulator and are modulated by the trapezoidal generator. Consequently, at the output of the modulator the tones are a sine wave in the form of a trapezoidal envelope, as shown in FIG. 7D. The period D, which is the duration of each tone, may be set by the front panel of the device and, in the case of a trapezoidal shape envelope, is at the half points of the trapezoid. The time T, i.e., the time from one tone to another, is set by the front panel, as is the duration D of each tone. Alternatively, the time D may be fixed within the device and the time T may be random to avoid habituation.

FIG. 7B illustrates the operation of the circuit of FIG. 7A. When the start button 56 is pushed, it provides a control signal 80 which starts the operation. At first the "t" test computer 15 takes data for the null reference, that is, it takes data for the X input of the "t" test. This

data is gathered before tones are sent to the earphones 19 and is the subject's background ongoing brain activity. At the conclusion of the null reference, the audio stimulator (oscillator 18) is enabled and will start to provide a sequence of sounds. The desired frequency, which may be initially set to one of 11 frequencies in the example shown in FIG. 7B, is started at 125 Hz, as shown by the line 83. The sound pressure level, which is digitally set at the variable attenuator 21 is first set for 10 db at 84. It is then raised to 20 db at 85. It will be noted at 20 db that there is a "t" test significance response 86. Consequently, the SPL logic 52 provides a control signal, which is a decreasing control signal, to the counter 53 and the signal is then attenuated at 87 to 15 db. As shown on line 88 the circuit is set to give two sound pressure level increments when there is not a significance according to the "t" test. If there is such a "t" test significant response, however, as shown by the signal 89, there is only a one-level change. At 90 there is a "t" test significant response (at 125 Hz, 20 db) and a print-out signal 91 occurs.

A suitable pen recorder is shown in FIG. 8. The display pen 50a consists of a single stylus 51a which is positioned over a movable broad band of recording paper 52a. The stylus 51a is supported on a slide 53a transverse to the direction of movement of the paper 52a.

The display pen marks the paper 52 at the threshold of auditory evoked response at each frequency F1-F8 a profile of the subject's hearing. This series of eight dots F1-F8 may be connected later manually, as shown by the dashed lines, to produce a line display showing.

FIG. 9 shows the second preferred embodiment of the present invention. The subject 210 being tested sits before the testing instrument and wears a pair of earphones 219 and a headband. The headband has a contact electrode 211 which may be wetted with an electrolyte and touches the subject's forehead. A reference electrode 212 is clipped to the subject's ear lobe. The electrodes 211 and 212 pick-up the subject's brain waves and communicate them to electroencephalograph (EEG) amplifier 213. The output of the amplifier 213, over line 214, is to the signal detector 215 (described below). The detector 215 is connected to switch 216, an electro-mechanical switch, or preferably a solid state electronic switch, which connects the input from detector 215 to alternatively any one of the output lines 220-227 the selection of the lines 220-227 being under control of control signals received over line 218 from the programmer 217. A suitable circuit for the programmer is shown in FIG. 7A, which shows a digital logic circuit.

The programmer and clock 217 provides control signals, over line 217', to a variable frequency oscillator 233, of the type described above. The oscillator 233 is connected to audio amplifier 231, which is connected to variable attenuator 232, of the type described above. The attenuator 232 is connected to provide tones to the earphones 219. The programmer, over line 218, controls switch 216 so that the brain wave response at each tone appears on only one output line 220-227.

The brain wave responses on each line 220-227 go to up-down counters 220'-227' which are averaging memory sections. The peak amplitude of brain wave responses at each tone and at each tone level of loudness are averaged. For example, the oscillator provides each of eight tones, at their least loudness level, 25

times, i.e., 25 notes of each tone. The peak amplitudes of the brain wave responses are averaged as a technique to eliminate noise, such as muscle artifact. If the averaged amplitudes are zero at each loudness level at each frequency, then the subject did not respond and therefore did not hear the tones. If there is a positive average, i.e., an up or a down count, at one tone, then the subject heard that tone.

Each of the up-down counters 220'-227' is connected by a line 240-247 to a recording display 250 of the type described above.

The testing method is used as a search for the threshold of the subject's hearing. Each tone is first played at its least loudness and then the loudness level increased. When the threshold level, at each frequency, is reached, i.e., the predetermined and pre-set average value for that frequency is met, the pen recorder records that event. After each threshold is reached, the test recommences, at the least loud level, at the next frequency.

The circuit for the signal detector 215 is shown in FIG. 10. It includes an absolute value circuit 271, for example a bridge rectifier having four diodes, which first produces an absolute value, that is, it produces a unipolar output voltage which is independent of the incoming polarity. The outgoing polarity, positive or negative, is then controlled by a polarity reversing switch circuit 272. The polarity reversing circuit 272 is connected to an integrator 273, such as an operational amplifier. The integrator 273 is connected to a comparator 274.

The polarity reversing circuit 272 and the integrator 273 are connected to the programmer 217" whose clock provides time pulses. Every pulse from the clock reverses the polarity switch 272. In addition, every other pulse erases and resets the integrator 273. In addition, the time pulses are simultaneous with the tones, the moment of occurrence of such tones being designated by the term "tone stimulus pulse" in FIGS. 11 and 12.

The computing cycle is initiated by pulse 280 from the programmer 217. Pulse 280 resets the polarity switch 272, erases the integrator 273 and begins the baseline sampling interval 281 lasting 250 milliseconds. Pulse 282 from programmer 217 reverses the polarity switch. A note is heard by the subject as a stimulus and briefly interrupts the computing cycle to protect against artefact, after which the evoked response sampling interval 283 begins and lasts for 250 seconds. Thus, the integrated activity accumulated during the period of evoked response to the note stimulus is subtracted by the comparator 274, from the integrated baseline activity preceding delivery of the note stimulus.

For example, if the integrator output during interval 281 is a rising positive waveform, the polarity shift occasioned by pulse 282 will cause a descending negative waveform of equal duration 283. The signals shown in FIG. 11 are taken at the output of the integrator 273. If there is only noise and no signal, as seen in baseline interval 280 of FIG. 11 then the rising level during baseline interval 280 will go to a certain level 285 of FIG. 11. On the other hand, if there is both noise and signal present (as shown by response interval 291 of FIG. 12), then the descending voltage during interval 283 will cross the zero value of the integrator and to the level 292.

If the signal plus the noise is greater than the noise, the lower level 292 of the descending voltage slope will be below a predetermined voltage level and there will be a plus-one count registered in one of the up-down counters 220'-227'. Conversely, if the signal plus the noise is less than the noise, then the lower end will be above the predetermined voltage level and a minus-one will be registered in one of the up-down counters 220'-227'. If only noise is present, then the run-up and the run-down should average to zero, or about zero, in the counter corresponding to the tone. If there is a signal, in addition to the noise, then there will be a positive average or a negative average, the negative average corresponding to systematic inhibition of the noise. The up-down counters 220'-227', consequently, only determine the presence, or absence, of a signal (a brain wave response) at each of the tone frequencies, but does not give any information regarding its wave shape or amplitude.

Modifications may be made in the present invention within the scope of the subjoined claims. For example, (a) the variable frequency oscillator may be replaced by separate tuned oscillators; (b) the programmer may be other than a logic circuit or a program track on the magnetic tape, for example, it may be a mini-computer or a punched paper tape reader; and (c) the recording pen may be replaced by a bank array of signal lights, for example, 56 lights for 8 frequencies and seven loudness levels.

We claim:

1. An instrument for the testing of the hearing of a subject, including means to make audible to the subject a series of tones at selected frequencies and loudness levels; a contact adapted to be worn by the subject to detect his brain waves; an electroencephalograph amplifier having an input and output whose input is connected to said contact; a signal detector having an input and an output and whose input is connected to said amplifier output, said signal detector comprising an absolute value circuit having its input connected to the input of said signal detector; a polarity shifting circuit whose input is connected to the output of said absolute value circuit, an integrator whose input is connected to the output of said shifting circuit, and a comparator whose input is connected to said integrator and whose output is connected to the output of said signal detector; a single-input multi-output switch whose input is connected to said signal detector output; a plurality of memory section counters connected to said switch outputs; a display device connected to said memory sections; and a programmer connected to said tone means and to said switch to direct the evoked responses at each tone to one of the memory sections.

2. An instrument as in claim 1 wherein said tone means includes a variable frequency oscillator whose frequency is controlled by said programmer and a variable attenuator controlled by said programmer, said oscillator and said attenuator both being connected to said programmer.

3. An instrument as in claim 1 wherein said memory sections are up-down counters.

4. The method of testing the ability of a subject to hear tones, consisting of playing for the subject a recording of a musical composition which includes the tones selected to be tested at selected levels of loudness, obtaining and amplifying the brain waves of the subject during said playing, averaging the subject's am-

plified brain waves with the brain wave response at each said tone being averaged with responses at the same tone and loudness, and displaying the subject's averaged response at the said tones and loudness levels.

5 5. An instrument for the testing of the hearing of a subject, said instrument including means to make audible a series of tones at selected frequencies and at selected loudness levels; a contact adapted to be worn by the subject to detect his brain waves; an electroencephalograph amplifier having an input and an output
10 whose input is connected to said contact; a "t" test computer whose input is connected to the output of said amplifier, said computer having, connected in sequence, a first set of squaring circuits, an averaging circuit, a second set of squaring circuits, differential circuits, a first set of divider circuits, a summing circuit
15 and a square root circuit and also having a differential circuit whose input is connected to the averaging circuit, a second dividing circuit whose input is connected to the outputs of the differential circuit and the square root circuit, and an absolute value circuit whose input
20 is connected to said dividing circuit; and display means connected in series with said computer to display the hearing test results.

6. The instrument of claim 5 and also including a programmer connected to and controlling said tone means and a significance detector whose input is connected to the output of said absolute value circuit, said programmer being connected to the output of said significance detector to receive control signals controlling its program.

7. The instrument of claim 6 wherein said tone means includes a variable frequency oscillator and a variable attenuator and wherein said programmer is connected to and controls said oscillator and said attenuator.

8. The instrument of claim 5 wherein said display device is an X-Y pen recorder adapted to produce a profile of the subject's hearing.

9. The instrument of claim 5 and including a significance detector to set the "t" test standard value connected to said computer and said programmer, upon attainment of which standard "t" value a control signal is provided by said significance detector to said programmer.

10. An instrument as in claim 5 wherein the said averaging circuit of said "t" test computer is a four-channel average response computer.

* * * * *

25

30

35

40

45

50

55

60

65