

[54] **PRECISION AUTOMATIC AUDIOMETER**

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[52] U.S. Cl. .... 179/1 N

[51] Int. Cl. .... H04r 29/00

[58] Field of Search ..... 179/1 N; 181/0.5 G

[56] **References Cited**

**UNITED STATES PATENTS**

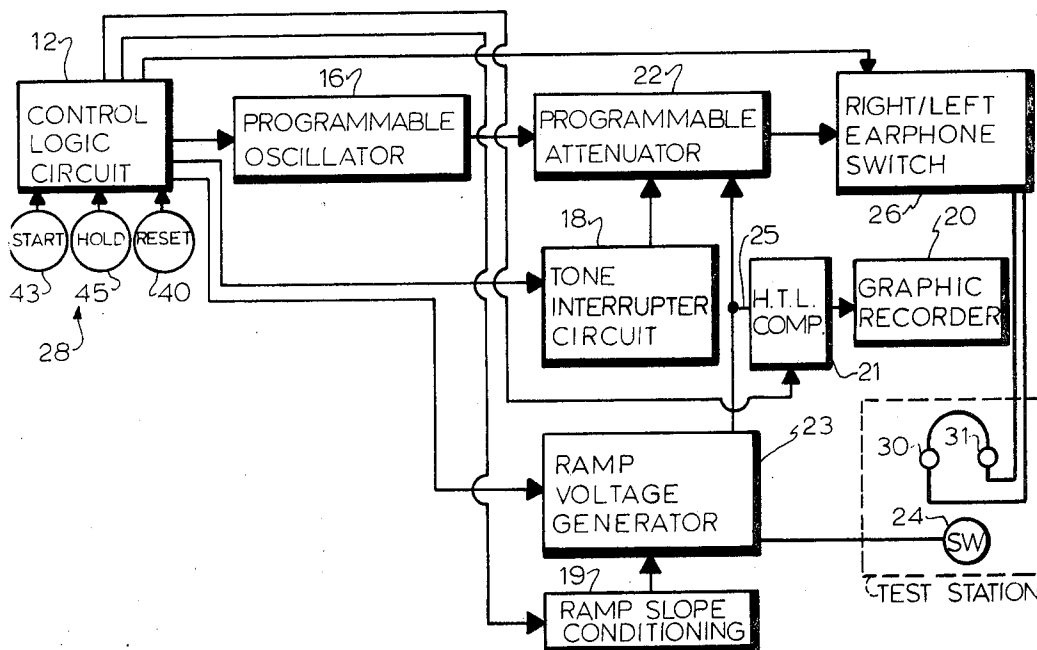
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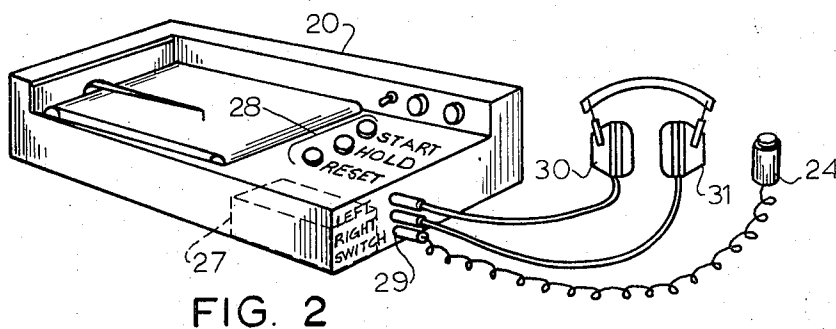
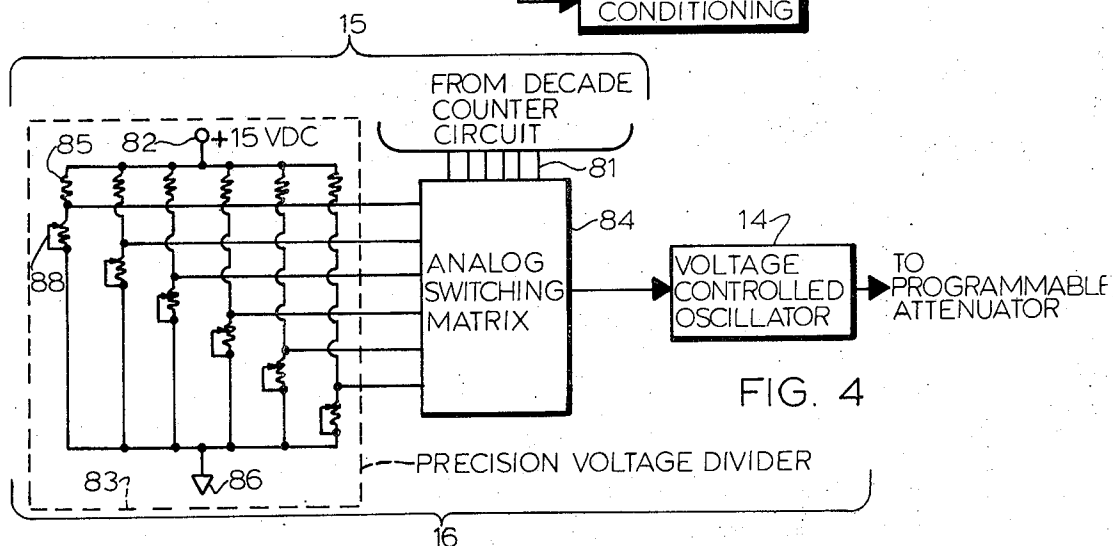
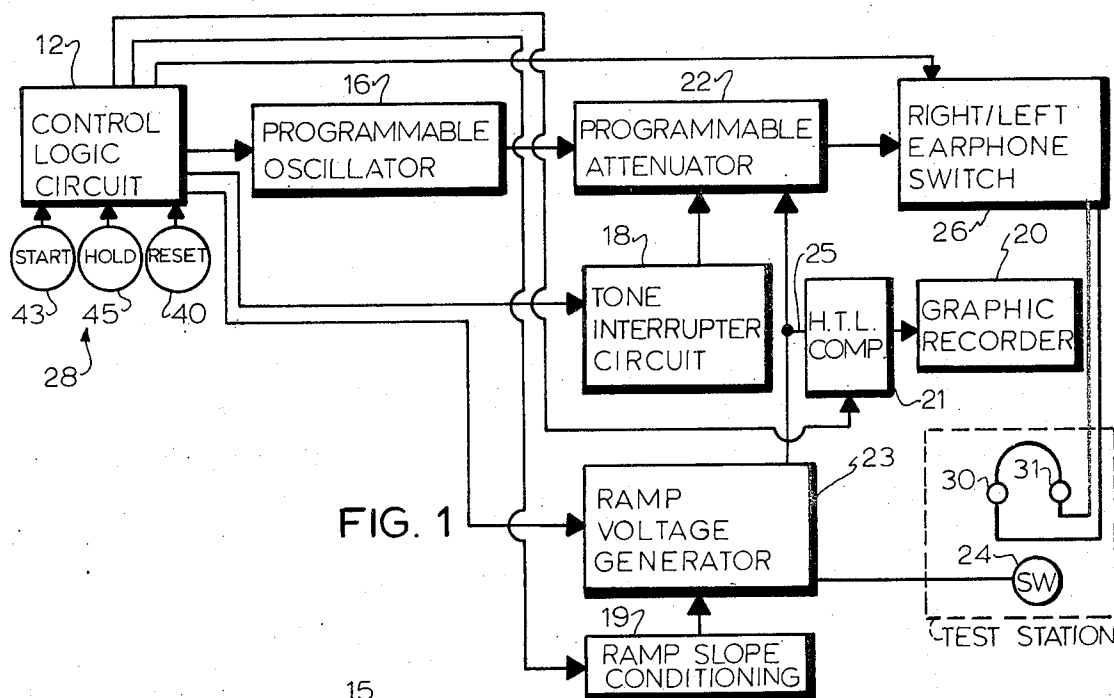
*Primary Examiner*—Kathleen H. Claffy  
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[57] **ABSTRACT**

A precision automatic audiometer adapted to test the hearing of an individual utilizes a voltage programmable oscillator in combination with a preprogrammed logic circuit to generate a predetermined series of hearing test tones into a suitable earphone worn by the individual being tested. A novel solid state voltage proportional attenuator being controlled by examinee manually operated switch means enables an examinee being tested to regulate the level of sound pressure to which he is being exposed, while a chart recording instrument simultaneously graphs the audiogram of his test responses.

**20 Claims, 12 Drawing Figures**





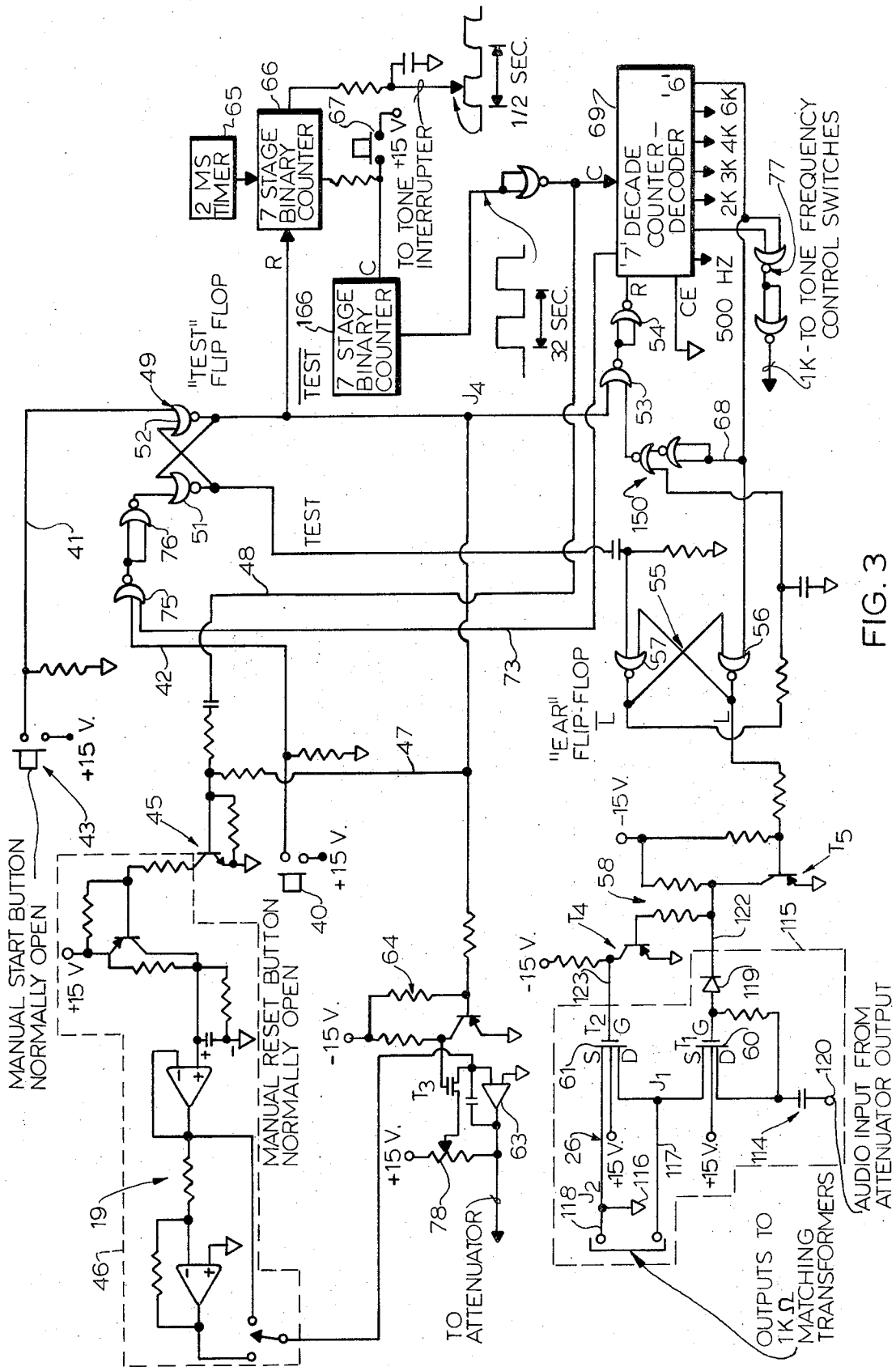


FIG. 3

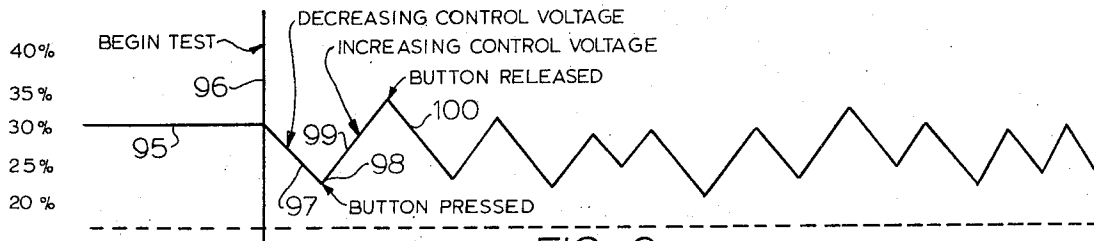


FIG. 6

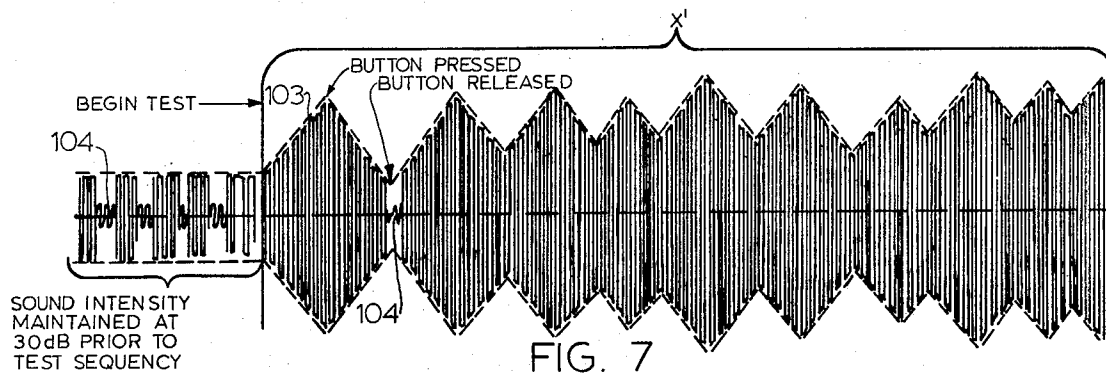


FIG. 7

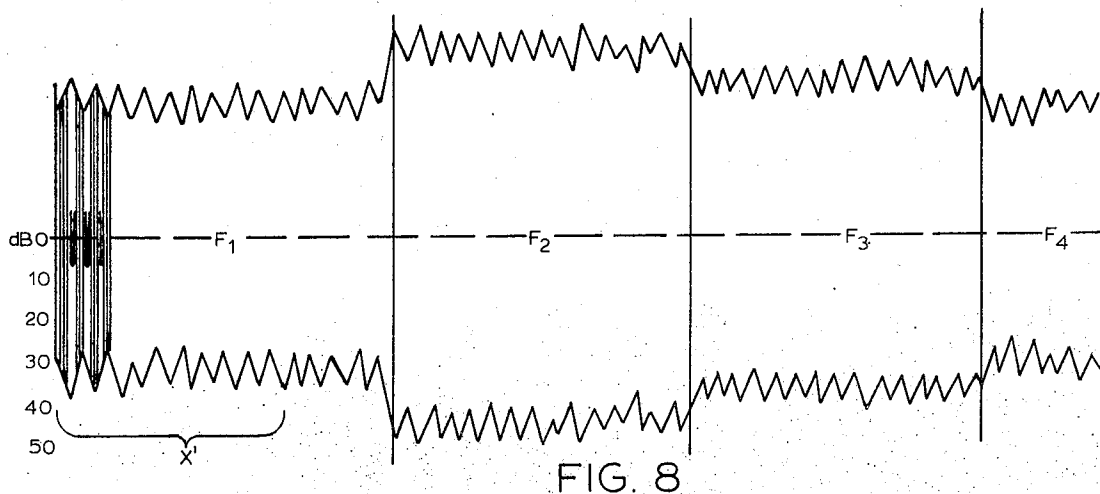


FIG. 8

FIG. 9

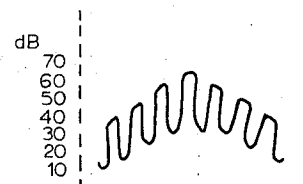
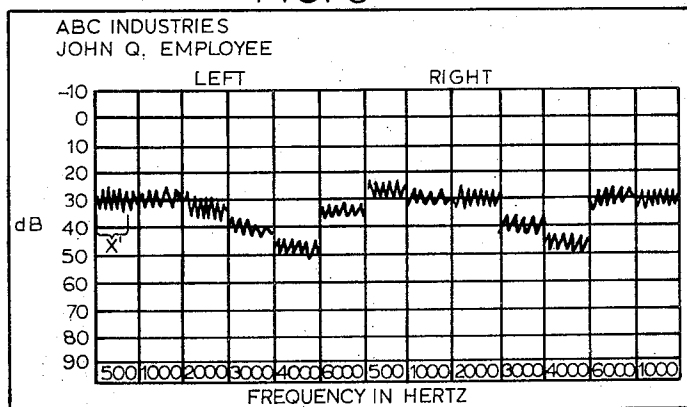
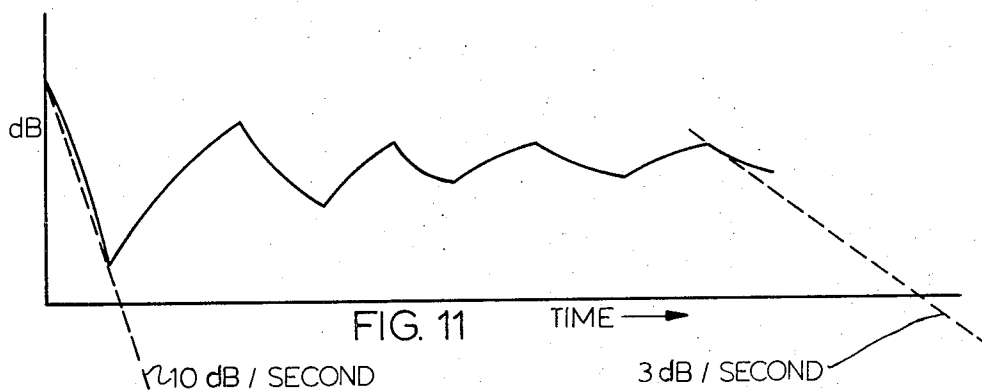
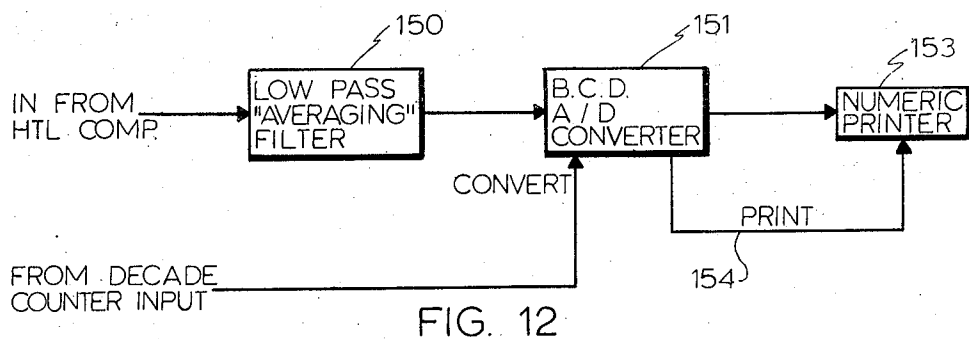
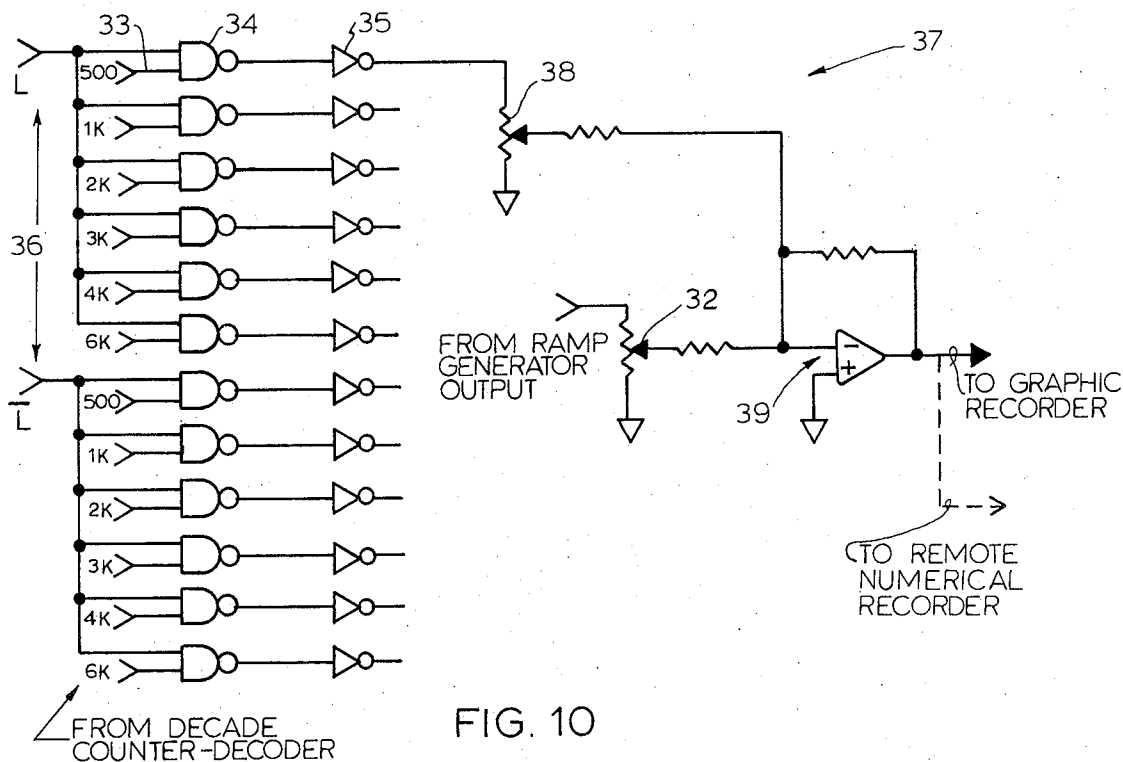


FIG. 5



## PRECISION AUTOMATIC AUDIOMETER

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application relates to copending U.S. Pat. application, Ser. No. 306,351, entitled "Programmable Audio Level Control Useful In Audiometric Apparatus," the specification of which has been herein incorporated by reference, and to copending U.S. Pat. application, Ser. No. 314,816, entitled "Computer Controlled Method and System For Audiometric Screening." The relation between this application and the referred to copending applications is, in a general sense, that U.S. Pat. application Ser. No. 306,351, discloses a specific level control or "attenuation" circuit useful in an audiometer, that this application discloses an audiometer and chart recording system for a test subject using such a level control, and that U.S. Pat. application Ser. No. 314,816 discloses a system using, via long distance communication, e.g., telephone lines, a plurality of geographically widespread audiometers of the type disclosed in this application but modified for control and recording by a central computer whereby a plurality of test subjects at a plurality of geographically remote test sites may be tested simultaneously. Alternately, the computing means may be coupled locally to the audiometer and used on single or plural subjects.

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention

The present invention relates to audiological testing devices and specifically to an automatic audiometer adapted to test the hearing of an individual wherein the individual being tested regulates whether the sound intensity to which he is being exposed automatically increases into or decreases from his range of audibility.

## 2. Description of the Prior Art

Automatic audiometry can be defined as a self-administered hearing test. More accurately, it is a hearing test performed by an instrument designed to present automatically changing tone frequencies while the degree of sound intensity of the signal is controlled by the examinee, the entire test sequence being simultaneously recorded on a synchronously coupled automatic recorder. The earliest automatic audiometer was developed by Bekesy and improved by Reger. Reference is made to George von Bekesy, "A New Audiometer," *Acta Otolaryngologica*, Vol. 35 (1947), pages 411-422, and Scott N. Reger, "A Clinical and Research Version of the Bekesy Audiometer," *Laryngoscope*, Vol. 62 (December, 1952), pages 1,333-1,351. In accordance with the teachings of Bekesy, a motor driven pure tone oscillator is swept from the lowest to the highest test frequency in a continuous progression. An attenuator or level control comprising, for example, a potentiometer, is driven by a reversible electric motor, the direction of which is determined by a push button switch operated by the examinee. The examinee is instructed to push the button as long as he hears the signal and keep it depressed until it fades from audibility, then to release it immediately. The tone will then fade into audibility again and the earlier process is repeated. The examinee then listens for the test tones through appropriate earphones. Upon his hearing the test tone and depressing the button, the motor causes the attenuator to decrease the in-

tensity of the signal output through the earphones; when the button is released, the motor reverses itself and starts an increase in the intensity of the output signal. An ink writing recorder usually coupled by gears, chains, and the like, to the attenuating and frequency sweeping mechanisms of the audiometer, traces out an audiogram representing the examinee responses to the various test tones presented. Note, for example, U.S. Pat. No. 2,563,384 which teaches an apparatus embodying an automatic audiometer according to Bekesy, synchronously coupled to a drum recording mechanism. As a further reference, a representative automatic audiometer based on the above teachings of Bekesy is manufactured by Grason Stadler, Inc. of West Concord, Massachusetts, and is designated Model E-800. This particular audiometer has found primary application in clinical diagnostic work and research.

An offshoot of the Bekesy clinical and research audiometer is the automatic screening audiometer widely used in industrial and military testing programs. The major difference between the Bekesy automatic and the screening automatic audiometers is that the latter uses discrete frequencies, usually 500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hertz, instead of the continuous frequency sweeping taught by Bekesy. The automatic screening audiometer in operation dwells on each of the above frequencies for approximately 30 seconds, automatically switches to the opposite ear and repeats each of the frequencies. During the 30 second test interval the examinee uses the manual pushbutton to trace his hearing threshold on a suitable chart or drum recording instrument. This type of audiometer is commonly referred to as the Rudmose Recording Audiometer. Reference is made to R. F. McMurray and Wayne Rudmose, "An Automatic Audiometer for Industrial Medicine," *Noise Control*, Vol. 2 (January, 1956), pages 33-36. A representative example of this type of audiometer is sold by Tracor Electronics Company of Austin, Texas, and is designated Model ARJ-4. Several other firms have also recently introduced new industrial automatic recording audiometers; for example, Medical Measurement Instruments, Inc., Model 1,000 and Grason Stadler, Inc., Model 1,703. Reference is also made to U.S. Pat. No. 2,781,416 which teaches an automatic screening audiometer.

While the above mentioned prior art has in every case constituted major advances in the field of audiology, those skilled in the art have noted certain deficiencies over the years. The most commonly noted deficiency is the extraneous noise generated by the use of motors, gear drives, chain links, stepping switches, solenoids, and relays. Such devices are not only subject to wear and misalignment, but also are a source of acoustic noise, constituting a deterrent to the accurate determination of hearing thresholds. Additional and separate rooms of soundproof construction, costing approximately \$100 per square foot, are usually required for containing the above stated audiometers. Since the examinee is the operator of an automatic audiometer, however, it is desirable to have a silent audiometer capable of being left near the subject, or in any case, within the same room.

As an added disadvantage, audiometers of the prior art have employed vacuum tubes with their attendant failures and heat emission, often have weighed in excess of 100 pounds, and have occupied considerable table or console space. While newer updated versions

of audiometers are lighter due to the partial utilization of semiconductor electronic components they still require approximately the same surface area for housing. Even those audiometers employing transistor construction, however, utilize numerous relays for switching, along with other electromechanical components. All existing automatic audiometers of the prior art have varying amounts of acoustic noise when received as new before wear on gear trains or motors occurs.

Even further disadvantages have been cited by those skilled in the art regarding calibration of conventional audiometers. In most cases mechanical as well as electronic calibration parameters are involved and there is present the need to align the two with respect to each other. Calibration components are furthermore typically inaccessible when the conventional audiometer is in its normal operating mode. Even when access to calibration components is possible, components are not usually adjustable and must be desoldered and exchanged for other values.

Other audiometers of the prior art have employed photocells and appropriate variable light sources or field effect transistors, to induce variance in sound attenuation without requiring the use of the conventional potentiometric attenuators, but even these electronic components have not been wholly satisfactory in that they have introduced signal distortion and nonlinearity at some degrees of attenuation. Reference is made with this respect to "Description of the Prior Art" in previously referred to copending U.S. Pat. application Ser. No. 306,351, entitled "Programmable Audio Level Control Useful In Audiometric Apparatus."

The inherent deficiencies of conventional automatic audiometers in the prior art have generated a need for an automatic audiometer having improved, more accurate performance, better reliability, having no moving component parts, and which is extremely quiet in operation. Such an audiometer could now be placed in the immediate proximity of an examinee and by the elimination of massive conventional electromechanical components, could be enclosed in a small lightweight portable housing such as a portion of a chart recording instrument thereby occupying a minimum amount of table or console space.

Other prior art to be considered includes U.S. Pat. Nos. 2,537,911; 2,781,416; 3,007,002; and 3,392,241.

### SUMMARY OF THE INVENTION

This invention is directed to an automatic screening audiometer adapted to administer a hearing test to an examinee wherein the examinee listens to a predetermined sequence of test frequencies through suitable earphone transducers, one ear at a time, and controls the sound intensity of the various test tones being presented by a manually operable switch. A pre-programmed logic circuit is adapted to control the sequence of test frequencies presented by precisely regulating the amount of voltage being supplied a voltage controller oscillator. A voltage proportional attenuator circuit receives the controlled frequency signals and is adapted to provide voltage proportional control over signal amplitude. Prior to the administration of a hearing test, the examinee is instructed to press his switch upon hearing the test tone and to release the switch when the tone is no longer heard. A solid state ramp generator controlled by this switch is adapted to supply

either an increasing or decreasing control voltage to the voltage proportional solid state attenuator, whereby depression of an examinee-operated switch causes the sound intensity to which that respective examinee is being exposed to be automatically decreased by the attenuator, while release of the switch causes the sound intensity to be automatically increased. In one embodiment the ramp voltage is characterized by a substantially linear ascending and descending wave, while in another embodiment a ramp voltage slope conditioning circuit causes the instantaneous ramp voltage slope to continuously change from a relatively steep slope at the onset of each tone presentation, to a relatively gradual slope at the conclusion of the tone enabling a test subject to rapidly approach his hearing threshold early in each tone frequency presentation, and to accurately approximate his threshold during the remainder of each tone presentation. A tone pulsing circuit connected to the attenuator is adapted to regularly pulse the signal an examinee is hearing. During a hearing test, the examinee responses are monitored by means of the control voltage emanating from the ramp generator and in the embodiment described, and which control voltage is continuously recorded on a chart recording instrument provided for the individual being tested. Hearing threshold level compensation circuitry is voltage provided and acts on the voltage applied to the recording device to correct for earphone deficiencies and the Fletcher-Munson curve. Due to the extreme simplicity and smallness of the solid state circuitry utilized, a small portion of most chart recording instruments provides adequate space to house the entire invention circuitry. An alternate printer readout is disclosed.

### DESCRIPTION OF THE DRAWINGS

FIG. 1 is a generalized block diagram of the preferred embodiment invention circuitry.

FIG. 2 is a perspective view of a typical chart recording instrument, a portion of which represented by dashed lines is used to house the invention circuitry.

FIG. 3 is a somewhat schematic diagram of a control logic circuit according to the invention and whereas R designates reset, C designates clock, and CE designates clock enable.

FIG. 4 is a generalized block diagram showing the constituent circuits of a programmable oscillator according to the invention.

FIG. 5 is a generalized wave form representing the combination of a modified square wave and an ascending-descending linear ramp voltage being input into the attenuator used by the invention.

FIG. 6 is a generalized waveform of a typical envelope of ramp voltage generated during a test tone presentation.

FIG. 7 is a generalized waveform showing the proportional output sound pressure envelope corresponding to the application of a ramp voltage pattern shown in FIG. 6.

FIG. 8 is a generalized waveform showing typical sound pressure envelope patterns for different selected test frequencies.

FIG. 9 shows an audiogram according to the invention derived by causing a strip chart recorder to plot envelopes such as that of FIG. 6 corresponding to an audiometric test.

FIG. 10 is a somewhat schematic diagram of a hearing threshold level compensation circuit employed in the instant invention.

FIG. 11 is a generalized waveform of the control voltage in the form of being programmably controlled such that the instantaneous slope varied from a steep to a gradual rate at a predetermined rate.

FIG. 12 is a schematic block diagram of a circuit enabling use of a printer readout.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, the audiological testing apparatus of the preferred embodiment is directed to an electronic circuit comprising a programmable oscillator 16 adapted to programmably generate pure tone audio signals of different selected frequencies in response to different pre-selected input voltages; a tone interrupter 18 of the type previously disclosed in copending U.S. Pat. application Ser. No. 306,351, adapted to pulse the signals in rapid succession and at regular intervals; an analog programmable attenuator 22 of the type also previously disclosed in copending U.S. Pat. application Ser. No. 306,351, adapted to automatically increase or decrease the amplitude of the input audio signals in a smooth progression depending on the quantity of control voltage being added to the attenuator by a ramp voltage generator 23; an examinee operable switch 24 adapted to regulate whether the ramp voltage being added to the attenuating device is caused to increase or decrease in a smooth progression; a solid state right/left earphone switch 26 adapted to regulate whether audio signals pass into the right or left earphones; appropriate earphone transducers 30, 31 for producing audible tones from input audio signals; a control logic circuit 12 adapted to cause a predetermined test sequence of audio signal frequencies to be generated by programmable oscillator 16, to cause the signal to change from the first ear being tested to the opposite ear at a predetermined time, and a chart recording instrument 20 adapted to record the ramp voltage wave being generated during the hearing test as a linearly proportional representation of the hearing threshold level to which the individual has been exposed during the test.

In one embodiment of the invention a ramp slope conditioning circuit 19 is adapted to continuously vary the instantaneous ramp voltage slope from a predetermined steep slope at the onset of a tone presentation to a gradual slope at the conclusion of a tone presentation as shown in FIG. 11. By "instantaneous slope" is meant the slope at any instant of time. "Steep" and "gradual" are intended to mean approaching vertical and approaching horizontal, respectively. Varying the ramp voltage slope in this manner enables an examinee to rapidly approach his hearing threshold early in a given test tone presentation and to accurately approximate his threshold during the remainder of the tone presentation and without the handicap of acoustic noise producing cams, relays and the like. Such ramp slope conditioning circuit shown in dashed lines 46 of FIG. 3 of this application and the advantages thereof may be better understood by referring to the above cited copending U.S. Pat. application Ser. No. 306,351, entitled "Programmable Audio Level Control Useful in Audiometric Apparatus," and specifically FIGS. 9 and 10 and related description of that application. In a more sim-

plified embodiment, however, the ramp voltage is characterized by a substantially linear increasing and decreasing wave as shown in FIG. 6 of this application. Thus, the term "ramp generator" is intended to include both strictly linear ramp generators as well as non-linear ramp generators capable of generating non-linear and controlled slope ramps.

Referring now to FIG. 2, in a preferred embodiment a chart recording instrument 20 is adapted to house the invention circuitry in an interior portion thereof, indicated by dashed lines 27, and is adapted to include appropriate switches 28 designated "start," "hold" and "reset" for manual use by a supervisor in regulating the test sequence. Earphones 30, 31 and switch 24 are adapted to be connected to the invention circuitry via appropriate panel jacks 29.

A better understanding of the functional operation of the present invention apparatus may be had by first observing how a typical hearing test of one individual is conducted. Therefore, before explaining the details of the circuitry and describing the operation in full, the simplified description of a typical test sequence which follows is believed helpful. During a hearing test, a series of auditory test tones having different selected frequencies are presented to an examinee first through a left earphone 30, then the series is repeated through a right earphone 31. The examinee is instructed to depress switch 24 when he first hears the tone, a point just above his hearing threshold due to his reaction time. At the outset of the test, the first tone is adapted to automatically rise in intensity. Once the examinee hears the tone, he presses switch 24 causing the intensity to automatically decrease. The tone intensity diminishes until he can no longer hear it. At this point, he has been previously instructed to release the switch, causing the test tone to begin rising in intensity again. Due to his reaction time, the point at which an examinee releases the switch is typically just below his hearing threshold. The examinee proceeds to regulate the sound intensity in a like manner for a predetermined length of time at each test frequency. The hearing test sequence may comprise, for example, test frequencies at 500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hertz, each held for 30 seconds in a first, then an opposite earphone. Examinee responses in pressing or releasing switch 24 with respect to sound intensity, or sound pressure level in decibels (dB), are graphed by chart recorder 20 during the hearing test. The resulting audiogram serves as a permanent record of an examinee's hearing threshold level in each ear for each of the tone frequencies presented.

Continuing with the description, and referring again to FIG. 1, the control logic circuit 12, according to the instant invention, utilizes design concepts considered well-known in the art of digital logic circuitry, and is constructed almost exclusively using COS/MOS logic elements of the CD 4,000 series, available for example from Radio Corporation of America Solid State Division, Somerville, New Jersey. In addition, discrete bipolar, MOS, and FET transistors are utilized for analog switching, digital level shifting, and interfacing.

While the logic circuitry of the present invention control logic circuit is believed to be constructed within the skill of the art, a better understanding of the invention may be had by describing in detail a portion of the logic circuit which is adapted to control, for ex-

ample, the sequence of test frequencies presented during the administration of a hearing test.

Referring to FIG. 3, in order to initiate a test procedure, a supervisor manually presses the start button 43 which has the effect of supplying 15 volts into the logic circuitry raising digital line 41 to a logic level of 1. The resulting level 1 signal now enters a flip-flop 49 comprising cross-connected COS/MOS NOR gates and designated "TEST" in a level 1 state setting the flip-flop and consequently causing NOR gate 51 to output a level 1 signal. The resultant signal next enters a flip-flop 55 designated "EAR" in a level 1 state causing NOR gate 56 to emit a level 1 signal through a positive to negative voltage converter circuit 58 to a left series earphone transistor switch 60, thereby causing the left earphone being employed to be connected with the audio input at 120 (FIG. 3). Note that only the left earphone switch has been shown for purposes of simplifying the drawing and that in actuality similar circuitry is employed to switch the right earphone on and off. This is accomplished by causing a gate voltage of zero volts to be applied to the left shunt earphone transistor switch 61 and a gate voltage of -15 volts to be applied to the left earphone series switch 60, due to the logic level of 1 emanating from NOR gate 56. Simultaneously the right earphone shunt switch (not shown) is closed effectively shunting stray signals to ground. This enables the present invention circuitry to prevent signal cross talk between earphones due to induction, etc., since any unwanted extraneous signals passing into the opposite earphone are brought immediately to ground.

Initiating the "TEST" procedure also has the effect of beginning the pulse train in a timing circuit 65 and of beginning the sequential stepping between different stages of a decade counter 69, each stage corresponding to a separate predetermined voltage controlled frequency. A digital timer 65 delivers a pulse train at the rate of one pulse every 2 milliseconds into binary counters 66 and 166 which are adapted to emit a square wave pulse at 0.5 second intervals to tone interrupter circuit 18, shown in FIG. 1 and which emit a square wave pulse every 32 seconds into decade counter-decoder 69. When a "TEST" instruction is present, NOR gate 52 of "TEST" flip-flop 49 outputs a level 0 signal to NOR gate 53. At this phase of the test the other input of gate 53 is at a logic 0 resulting in a logic 1 output. This passes through NOT gate 54 and into decade counter 69 causing it to begin stepping from a first through subsequent steps corresponding to the various frequencies indicated. In addition, the output level 0 state from NOR gate 52 causes binary counters 66 and 166 to begin counting the above mentioned 32 second square wave interval.

Next will be described the "RESET" procedure which resets the binary counters 66 and 166 controlling the tone interrupter 18, as well as the decade counter-decoder 69 controlling the sequential stepping of test frequencies. By pressing the reset button 40 a supervisor causes 15 volts D.C. to be connected to digital line 42. The resulting level 1 signal now enters NOR gate 75 and is output in a level 0 state. The signal now enters NOT gate 76 and is output in a level 1 state before entering "TEST" flip-flop 49. The resultant level 1 signal being input into NOR gate 51 causes the opposite NOR gate 52 to output a level 1 signal into binary counters 66 and 166, causing them to become initialized. In addition, the above level 1 signal being input into NOR

gate 53 is output as level 0 into NOT gate 54, and is output as level 1 and is fed into decade counter decoder 69, causing it also to be initialized.

In addition to the foregoing, a "RESET" instruction is also adapted to cause programmable attenuator 22 (FIG. 1) to maintain a level corresponding to 30 dB sound pressure level intensity prior to the commencement of a test sequence. This is accomplished as a logic level of 1 emanating from NOR gate 52 as a "RESET" or "TEST" instruction enters a transistor switching circuit 64 adapted to de-energize transistor  $T_3$  via junction  $J_4$  when a level 1 signal is present, thereby causing a ramp-generating integrator 63 to be held at a voltage level corresponding to 30 dB sound pressure. This voltage level may be slightly adjusted by moving trimming potentiometer 78. It is important to note that in the instant invention an operational amplifier 63 adapted for integrating purposes is utilized as a ramp voltage generator (23 in FIG. 1) adapted to supply ramp control voltage to programmable attenuator 22. The 30 dB corresponding voltage level is maintained as long as a logic level 1 signal is present as in the case of a "RESET" instruction. When in the case of a "TEST" instruction, a level 0 signal is present, transistor switching circuit 64 is adapted to turn  $T_3$  on thereby transferring control of integrator 63 to examinee operated switch 24 (see FIG. 1).

An important feature to note in FIG. 3 is "HOLD" switch 67 between counter 66 to counter 166 and which is adapted to be normally open as shown in FIG. 3. In the event that a supervisor wishes to temporarily interrupt the test sequence yet not completely reset the test sequence, actuation of hold switch 67 will momentarily stop counter 166 by preventing the transmission of pulses from counter 66 to 166. Counter 66 continues to count, operating the tone interruptor as before, but the test sequence will not continue until the hold button 67 is released.

During the test sequence, six stages of decade counter 69 corresponding to the six test frequencies of 500, 1,000, 2,000, 3,000, 4,000, and 6,000 Hertz are sequentially energized for 32 seconds each. When the step '6' is reached, a level 1 signal emanates from decade counter-decoder 69 resetting "ear" flip-flop 55 to the right ear position while simultaneously grounding the left earphone. At this time, a level 1 signal passes through feedback loop 68 into decade counter-decoder 69 which resets it and starts the test sequence for testing the right ear. Once the step '6' has again been reached, NOR gate 150 is disabled by reason of the condition  $\bar{L} = 1$ , the number 1 position frequency of 1,000 Hertz is repeated in the right ear as a comparison measure to check those persons attempting to cheat. A NOR-NOT gate combination 77 is provided for this additional step. Following the additional frequency step, output '7' goes momentarily to causing a feedback line 73 communicating between decade counter 69 and NOR gate 75 to assume a level 1 state thereby automatically initiating a complete "RESET" procedure and automatically readying the circuitry for the next test.

Also shown in FIG. 3, a ramp slope conditioning circuit 19 previously described is adapted for use in the instant invention logic circuit through the addition of a switching transistor 45, and appropriate resistive and capacitive interfacing. During operation, line 47 which communicates with a TEST digital line, enables circuit 19 to be initialized at the same time that the logic cir-

cuit is automatically or manually reset. Line 48 which communicates with the timing input of decade counter-decoder 69 enables circuit 19 to be initialized whenever decade counter-decoder 69 steps to the next sequential frequency including the change of earphone. When the test frequency proceeds and the TEST line assumes a low or 0 state circuit 19 is freed to begin integrating an exponentially decaying voltage to control the instantaneous slope of the control voltage. In this manner ramp slope conditioning circuit 19 is adapted to be initialized during each change of frequency, change of earphone, and simultaneous with resetting of the logic circuit prior to a new test.

An appropriate power supply of +15, 0, and -15 volts D.C. may be utilized to energize the various logic and other solid state components.

Continuing with the description, referring now to FIG. 4, a programmable oscillator 16, according to the invention, is adapted to produce different selected precise frequencies in response to pre-programmed logic instructions emanating from decade counterdecoder 69 (see FIG. 3) through appropriate input terminals 81 and utilizes an appropriate voltage supply 82, and a precision voltage divider circuit represented by dashed lines 83, in conjunction with a 6-input analog switching matrix 84 adapted to select the different precise voltages. The various voltages next enter a voltage controlled oscillator 14 which produces a frequency based on the voltage applied. A precision voltage divider 83, best suited to the invention, comprises a plurality of resistive elements 85 having adjustable different resistive values connected in parallel between said voltage supply 82 which may be 15 volts D. C. and an appropriate ground 86. In a preferred embodiment, as previously mentioned, so-called trimming potentiometers 88 are utilized to precisely set the different voltages, such that voltage controlled oscillator 14 generates the desired corresponding frequencies. The use of trimming potentiometers also facilitates easy frequency calibration of the invention apparatus during normal use. During a normal test sequence appropriate signals sequentially emanating from the various positions of decade counter-decoder 69 (see FIG. 3) cause switching matrix 84 to sequentially emit a first, then subsequent voltages, into voltage controlled oscillator 14 for a period of 32 seconds each, thereby causing to be generated a series of test tones having different corresponding frequencies occurring in pre-programmed sequence.

As mentioned above, the different voltages produced in programmable voltage source 15 are fed into voltage controlled oscillator 14 and are used to generate corresponding different frequencies. A voltage controlled oscillator suited to the invention circuit is available from Wavetek, San Diego, California, as Model Numbers 120-021 and 120-022 combined. Alternately, a plurality of pure tone audio oscillators having different selected frequencies and a suitable programmable tone switching matrix may be used to programmably generate the various different audio frequencies presented during a hearing test.

Signals having controlled frequency next enter a tone interrupter circuit 18 adapted to pulse the signal. This circuit element while admittedly quite old in the art is employed in the instant invention because it has been found experimentally that a typical examinee is able to more closely discern a pulsating signal, that is, one whose tone is intermittently on and off, when the tone

intensity is very close to his hearing threshold, than he would a continuous tone. Furthermore, improved tonal pulsing means have been disclosed in previously referred to copending U.S. Pat. application Ser. No. 306,351. Tone interruption may be accomplished, for example, through a square wave conditioning circuit operating on a one-half second square wave as more fully set forth in U.S. Pat. application Ser. No. 306,351. The signal pulses emanating from tone interrupter 18 are adapted to pulsingly drive attenuator 22 (see FIG. 1) at 0.5 second intervals. The resulting tonal pulsations emanating from the output of attenuator 22 are graphically represented in FIG. 5 and generally comprise 0.25 second tone pulses of 40 dB sound intensity reduction at 0.5 second intervals of a given tone frequency. For a more detailed explanation of tonal interruption and the novel manner in which it is accomplished, reference is made to the above cited copending application which embodies the attenuator utilized by the present invention.

Referring again to FIG. 1, the resultant signal pulses now enter programmable attenuator 22 which is of the type disclosed in previously referred to copending U.S. Pat. application Ser. No. 306,351, the specification and drawings of which have herein been incorporated by reference. An "attenuator" as used in connection with the instant invention, is a device acting only upon the amplitude component of a given signal and which is capable of reducing or attenuating the amplitude of the given signal by a predetermined amount from a fixed maximum amplitude. An attenuator by mathematical definition may have either positive or negative attenuating characteristics, however, and thus a "negative attenuating device" is one which produces signal amplitude gain from a fixed minimum. It is in this latter "negative attenuating" sense that the term "attenuator" is used in describing the overall function of programmable attenuator 22 in the invention audiometer. A programmable attenuator 22, according to the invention, is adapted to vary only the amplitude component of the input signal pulses through the use of solid state logging and exponentiating components, and in inverse proportion to the addition of a continuously variable control voltage originating in ramp voltage generator 23. The amount of control voltage applied to programmable attenuator 22 is therefore inversely related to the signal amplitude being output from said attenuator. It is now possible to employ the variance in input control voltage as a proportional measure of the sound intensity to which each examinee is being exposed. A signal output 25 communicating between ramp generator 23 and graphic recorder 20 is therefore adapted to enable measurement of the quantity of control voltage being supplied the attenuator. In the present invention an examinee-operated switch 24 connected to ramp generator 23 is adapted to enable the examinee to govern whether the ramp voltage being generated is caused to increase or decrease in magnitude. A hand-held switch suited to the invention is manufactured by any of a number of well-known switch manufacturers in the form shown in the drawings. Numerous other substitute switches equally suitable will appear to those skilled in the art. Such a switch should preferably be comfortable for the examinee to grip, easy to press, and acoustically silent in operation. A switch characterized by a "click" during operation would not be suitable. Alternately, a foot operated switch having silent operating character-

istics may be utilized for persons having impaired finger movements.

Referring next to FIG. 6, which graphically represents percent control voltage of an individual attenuator with respect to time, as previously mentioned, the control voltage is maintained at a level 95 corresponding to 30 dB sound intensity prior to the beginning 96 of the hearing test sequence. Once the test sequence is begun, and a first frequency is being produced, the attenuator is automatically released to begin raising the audio signal intensity and, as previously mentioned, control of the intensity is then transferred to an examinee operated switch 24. Note that in FIG. 6 the ramp voltage is characterized by a substantially linear increasing and decreasing wave while in another embodiment the wave increases and decreases in a nonlinear fashion effected by previously mentioned slope control circuitry.

The initial drop in control voltage  $V_c$  being fed to this attenuator is represented by straight line 97. As soon as the examinee hears the tonal pulsations and presses the control switch, at point 98, the control voltage curve begins an upward cycle, indicated by straight line 99. Likewise, when the tonal pulsations fade from audibility and an examinee appropriately releases his switch, represented by point 100, the control voltage  $V_c$  will begin a falling cycle again. Referring now to FIG. 7, which represents the actual tonal pulsation sound pressure level in dB to which an examinee is exposed consistent with the wave pattern of  $V_c$  in FIG. 6, it is of importance to note that the sound intensity wave envelope outer edge, represented by dashed line 103, closely approximates the inverse of the waveform of control voltage shown in FIG. 6. That is, the control voltage  $V_c$  being governed by an examinee, inversely determines the sound intensity level in decibels to which the examinee is being exposed. According to the invention during a tonal interruption the signal amplitude will diminish approximately 40 dB as indicated by less intense signal areas 104. Referring to FIG. 8, which represents the sound intensity envelope measured in dB over a portion of a typical test sequence, and which  $X'$  of FIG. 7 is shown to approximate scale,  $F_1$ ,  $F_2$ ,  $F_3$  and  $F_4$  represent different successive test frequencies of the pre-programmed automatic test sequence, each held for a duration of 32 seconds. Finally, FIG. 9 shows the result of a complete typical hearing test measured on a chart recorder according to the invention, a portion of which has been derived from the control voltage envelope in FIG. 6 and which is consistent with  $X'$  in FIG. 7. Note that 13 recording measurements are based on the control voltage applied to attenuator 22.

Referring again to FIG. 1, tonal pulses now emanating from analog programmable attenuator 22, having controlled amplitude and frequency characteristics next enter right/left earphone switch 26, one-half of which is shown within dashed lines 115 in FIG. 3, and which comprises a pair of MOS-FET switching transistors  $T_1$  and  $T_2$  (for example, Hughes model HDGP1001) each having a substrate connected to a 15 volt power supply, and both being connected in series through high pass filter means 114 with attenuator output 120 and being further connected in series with a suitable ground 116. The drain (D) terminal of transistor  $T_1$  is connected through resistor-capacitor filter means 114 to attenuator output 120. The source terminal (S) of transistor  $T_1$  is connected to the drain terminal

(D) of transistor  $T_2$ . A lead 117 communicates between a 1,000 ohm left earphone matching transformer (not shown) and junction  $J_1$ .  $T_1$  and  $T_2$  thus form a series-shunt switch well adapted to switching the left earphone signal on and off over a very wide dynamic range. A suitable ground 116 is located at junction  $J_2$ . A first digital line 122 which emanates from control logic circuit 12 communicates via diode 119 with the gate (G) of transistor  $T_1$  and carries appropriate signals to activate transistor  $T_1$ , and which is adapted in one mode of operation to enable test signals to flow into a left earphone transducer (not shown). A second digital line 123 is appropriately connected to the gate (G) of transistor  $T_2$  and is adapted to carry signals complementary to that of digital line 122, and which is also adapted in another mode of operation to shunt the left earphone signals to ground 116 when the right earphone transducer is activated. It is important to note that the operating characteristics of  $T_1$  and  $T_2$  are such that a negative digital signal which may be characterized as level 1 energizing the gate (G) will cause electrical conduction between the source (S) and drain (D); whereas when a voltage of zero is present at the gate, electrical conduction between source and drain is effectively prevented. Transistors  $T_4$  and  $T_5$  cooperate to provide the appropriate voltage input levels for transistors  $T_1$  and  $T_2$ . Due to the action of "EAR" flip-flop 55 of alternating opposite digital levels in output lines L and  $\bar{L}$ , whenever an audio test signal is adapted to be produced in one earphone, the opposite earphone is effectively prevented from conducting a signal. In addition, the output matching transformer (not shown) opposite the one transforming audio test signals will always be grounded due to the transistor source connection with ground 116, thereby preventing induction. Thus, signal cross talk between earphones is effectively prevented.

Referring again to FIG. 1, earphones 30 and 31 in the preferred invention embodiment include circumaural noise reducing earcups having calibrated earphone transducer inserts. A suitable pair of noise excluding earphone enclosures is manufactured by Hearing Conservation, Ltd., of Wembly, England, and is designated Amplivox "Audiocups," which permit the use of standard TDH-49 earphones utilizing the MX-41/AR cushions. The utilization of noise excluding, yet calibratable, earphones provides the instant invention with the advantage of being able to conduct a hearing test in many instances in simple, quiet surroundings rather than in specially fabricate soundproof booths, while at the same time maintaining accurate calibration between the earphones and the preferred embodiment automatic audiometer.

According to the present invention, previously mentioned, ramp generator 23 which may suitably be an integrating operational amplifier (see 63, FIG. 3) is adapted to generate an ascending-descending ramp voltage into programmable attenuator 22. In order to enable measurement of the amounts of ramp voltage being applied to programmable attenuator 22, an output lead 25 is adapted to communicate between the output of ramp voltage generator 23 via appropriate hearing threshold level compensation circuitry 21 to a chart recording instrument 20. A chart recording instrument suited to the preferred invention embodiment is obtainable from any of a number of well-known manufacturers of such instruments. A hearing threshold

level compensation circuit suited to the instant invention and adapted to correct the earphone deficiencies and the Fletcher-Munson curve is shown in FIG. 10. Such compensation circuit is preferably solid state and may comprise switching matrix including a plurality of NAND gates 34 and inverting amplifiers 35 arranged as shown, being adapted to be selectively energized by control logic circuit 12 according to the instant tone frequency corresponding to inputs 33, and either right or left ear being tested corresponding to inputs 36 designated L and  $\bar{L}$ . Two inputs simultaneously present at any of the NAND gates 34 will energize the respective compensation circuit 37 which includes voltage adjustment means 38 and amplification means 39. As is apparent, minute voltages may be easily added or deleted as required from the ramp generator output 25 going to recorder 20 to compensate for earphone deficiencies and the Fletcher-Munson curve at each test frequency and for right and left earphones. Voltage adjustment means 32 enables scaling of graphic recorder 20.

### OPERATION

In preparation for a hearing test the supervisor places the earphones 30, 31 in position over the ears of the examinee, and instructs the examinee to grasp his control switch 24 in one hand, and to listen for the test tone which will indicate that the test sequence is about to commence. The supervisor will then press the "start" button 43. This action transfers control of the attenuators from a 30 dB holding level to control by the ramp voltage controlling examinee switch. In addition, all counting devices are simultaneously started, chart recorder 20 is caused to begin sampling and graphing the ramp control voltage, and a first test frequency of 500 Hertz is caused to be pulsingly generated in the left earphone 30.

As previously mentioned, a series of six different test frequencies comprising, for example, 500 Hz, 1,000 Hz, 2,000 Hz, 3,000 Hz, 4,000 Hz and 6,000 Hz are sequentially produced in the left ear-phone at 32 second intervals each, then the sequence is repeated in the right earphone and an additional 1,000 Hz signal is produced following the 6,000 right ear test frequency, to serve as a comparison check on a person attempting to cheat. During the presentation of the test sequence the examinee responds to the test tones by pressing control switch 24 when the tone is audible and releasing the control switch when it is inaudible. At any point during the test sequence a supervisor may temporarily stop the progress of a hearing test in the event of malfunction, unexpected excessive noise, etc., by operation of hold switch 67 (see FIG. 3). Once the test sequence has ended the circuit will automatically reset itself for the next test.

As an auxiliary portion of the hearing test sequence, the present invention contemplates the short presentation of an instruction lecture or use of a training device, teaching the correct operation of the invention apparatus to, say, a group of examinees prior to the administration of individual hearing test. The utilization of such a presentation and or training device appears to effectively avoid misunderstanding during the actual hearing test which would normally delay the test or yield faulty results.

Based on the foregoing description, it is apparent that the present invention provides both a simple and effective means to test the hearing of an individual, and to

transform the test data into graphic results. Furthermore, due to the elimination of moving parts, i.e., electromechanical potentiometers, relays, rheostats, and the like, administration of a typical hearing test proceeds in the absence of system-generated acoustic noise, such that only the clear test tones are heard by the examinee. It is now possible to utilize the highly accurate attenuator control voltage as a measure of sound pressure. Based on the above, it is readily apparent that the present invention therefore has the capacity for producing a substantially high degree of hearing test scoring accuracy by measurement of an amplitude determinant voltage quantity and by full use of solid state components, while at the same time providing a quick and easily conducted hearing test. The invention apparatus has the added advantage of being readily made portable and adapted for installation in a chart recording instrument, and of being readily adjustable whenever calibration is necessary.

The preferred attenuator or level control circuit for the audiometer invention of this application is that set forth in copending U.S. Pat. application, Ser. No. 306,351, entitled "Programmable Audio Level Control Useful In Audiometric Apparatus," and which, as previously mentioned, is incorporated herein by reference. Such a level control first computes the logarithm of the tone signal, then combines such logarithm and the control voltage wave and then exponentiates the result sum which becomes the test signal fed to the earphones. Reference should be made to the mentioned U.S. Pat. application, Ser. No. 306,351, for a more complete explanation of such a level control and for an appreciation of how it relates to this invention.

In an alternate embodiment of the invention shown in FIG. 12 a numeric printer is adapted to print the test results on a prepared form having additional space for patient name, identifiers and other significant medical data. For this purpose a low pass "averaging" analog filter 150 is adapted to compute the mean of a predetermined portion of the envelope output from the ramp generator 23 through the HTL compensator 211. Filter 150 has suitable time constants which adapt it to smooth the envelope and derive its mean value, equivalent to computing a numeric average. Filter 150 is constructed according to techniques well-known to the art and can take the form of the familiar third order "Butterworth" filter as shown for example on page 75 in *Application Manual for Computing Amplifiers* published by Nimrod Press, Inc., Boston, Massachusetts. At the end of each test tone, the filter 150 will contain the average of the envelope corresponding to the hearing threshold of the subject at the tone frequency involved. As the tone terminates the 32 second input to counter 69, FIG. 3, assumes a logic 7 level causing A-D converter 151 to immediately convert the filter output to Binary Coded Decimal (BCD) format, adapted to the input requirements of numeric printer 153. When the conversion is complete, line 154 assumes a logic 1 level signaling printer 153 to print the data present at its input, i.e., the hearing threshold level in dB, on a suitable score sheet form. Thus, the audiogram may be made available directly in numeric form as decimal numbers with no manual envelope averaging required by the user. Such a format will enable quick quantitative comparisons with previous similar audiograms for the purpose of detecting gradual hearing threshold changes. It should also be recognized that the output from A-D

converter 151 is computer intelligible. Since suitable BCD analog to digital converters and compatible numeric printers are available from a number of vendors, the same are not further described.

What is claimed is:

1. An audiometer apparatus comprising, in combination:

- a. an audiometric patient test station having right and left earphones and a two position patient actuated switch;
- b. programmably controllable right-left earphone switching means connected to receive an audio signal and selectively direct the same to the right or left earphone at said station;
- c. a programmably controllable signal source adapted to provide in some predetermined order a series of continuous tone signals arranged in a fixed repeatable sequence, each tone signal in the series being of a selected audio frequency, amplitude and period of duration;
- d. a programmably controllable continuous control voltage source productive of a ramp voltage wave controllable as to ascending and descending direction and representing a control voltage having maximum and minimum values when moved without interruption in either direction, said control voltage source being connected to said two position switch and being adapted such that the direction of said ramp voltage wave may be interrupted and reversed in direction by the position of said two position switch and the magnitude of the ramp voltage wave may be regulated in coordination with desired maximum and minimum audio thresholds in said earphones;
- e. programmably controllable circuit attenuator means connected to said signal source to receive said tone signals and to said control voltage source to receive said ramp voltage wave, said attenuator means being adapted to generate therefrom an audio output test signal having precisely controlled gain qualities in linear proportion to said control voltage and at the selected said frequency, said earphone switching means being connected to receive said test signal;
- f. preprogrammed control logic circuit means connected to programmably control said signal source, voltage source and earphone switching means whereby upon actuation thereof said signal and voltage source are energized to produce said tone signals and voltage wave wherein said patient hears first in one said earphone and then the other said series of signals and during the hearing of each tone signal in each respective earphone the subject is enabled to move said two position switch to a first position when said tone signal is first heard and to a second position when said tone signal is lost to hearing and by so positioning said two position switch said subject being able to control both the direction of said voltage wave and the maximum or minimum level achieved in each direction; and
- g. recording means connected to said voltage source and adapted to develop and record a printout for said patient in a form directly corresponding to the earphone levels heard as determined by when and at what amplification levels the patient operates said two position switch in respect to said tone signals as an indication of the patient's hearing loss.

2. An audiometer as claimed in claim 1 including a tone interrupter circuit means connected to interrupt and convert said continuous tone signals into pulse form.

3. An audiometer as claimed in claim 1 wherein said control logic circuit includes manually operated reset circuitry means adapted to cause said tone signal sequence to be reset to a predetermined starting frequency.

4. In an audiometer as claimed in claim 1 wherein said right-left earphone switching means, said signal source, said voltage source, said attenuator means and said logic circuit means comprise solid state components thereby adapting the same to function without mechanical motion.

5. In an audiometer as claimed in claim 1 wherein said signal source comprises a voltage controlled oscillator and said logic circuit means precisely controls the amount of voltage supplied said oscillator to control said tone signal frequency.

6. In an audiometer as claimed in claim 1 wherein said circuit attenuator means incorporates circuitry for computing a signal representing the logarithm of said tone signal, for combining such logarithm signal and said ramp voltage wave, to produce the antilog of such combination and from such antilog to produce said test signal.

7. In an audiometer as claimed in claim 1 including manually actuated holding circuitry means adapted when actuated to cause said logic circuit means to stop and hold said tone signal sequence at the then programmed frequency.

8. In an audiometer as claimed in claim 1 wherein said logic circuit means is programmed to cause said tone signal sequence to be heard first in one of said earphones and then in the other of said earphones and with a redundant test tone in the latter.

9. In an audiometer as claimed in claim 1 wherein said logic circuit means includes cross talk circuit means connected to said earphones and adapted to selectively prevent one of said earphones from conducting a signal when the other of said earphones is being utilized for testing.

10. In an audiometer as claimed in claim 1 including ramp voltage wave conditioning circuit means adapted to cause the instantaneous slope of said ramp voltage wave to be steep at the onset of each said tone signal presentation and to continuously decrease said ramp voltage slope to a relatively gradual slope at the conclusion of each said tone signal.

11. In an audiometer as claimed in claim 1 wherein said printout is in the nature of a voltage envelope and said recording means is a strip chart recorder adapted to print said envelope.

12. In an audiometer as claimed in claim 1 wherein said printout is in the form of numeric data and said recording means is a printer adapted to print such numeric data.

13. In an audiometer as claimed in claim 1 including hearing threshold level compensation circuit means connected to receive the output of said voltage source and to electrically compensate said voltage source for normal ear efficiencies and earphone deficiencies to provide an electrical output corrected for both.

14. In an audiometer system, the method of generating and recording audiometric data for a patient, comprising the steps:

- a. establishing for the patient an audiometric patient test station having right and left earphones and a two position patient actuated switch;
- b. directing to the station under logic circuit program control and in some predetermined order a series of continuous tone signals arranged in a fixed repeatable sequence, each tone signal in the series being of a selected audio frequency, amplitude and period of duration;
- c. establishing for the station a programmably controllable continuous control voltage source productive of a ramp voltage wave controllable as to ascending and descending direction and representing a control voltage having maximum and minimum values when moved without interruption in either direction and connecting said control voltage source to the said two position switch such that the direction of said ramp voltage wave may be interrupted and reversed in direction by the position of said two position switch at the test station and the magnitude of the ramp voltage wave may be regulated in coordination with the patient's thresholds in said earphones;
- d. connecting a programmably controllable circuit attenuator means for the test station to said signal source to receive said tone signals and to said control voltage source to receive said ramp voltage wave and generating for the test station an audio output test signal having precisely controlled gain qualities in linear proportion to said control voltage and at the selected said frequency;
- e. directing said test signal for the test station through programmably controllable right-left earphone switching means and programmably controlling said signal source, voltage source and earphone switching means for the test station with said logic circuit whereby upon local manual actuation of the test station, said signal and voltage sources for the test station produce said tone signals and voltage wave and said earphone switching means switches under said logic circuit supervision wherein said patient at each such test station hears first in one said earphone and then in the other said series of signals and during the hearing of each tone signal in each respective earphone the patient is enabled to move said two position switch to a first position when said tone signal is first heard and to a second position when said tone signal is lost to hearing and by so positioning said two position switch said patient is able to control both the direction of said voltage wave and the level achieved in each direction;
- g. developing with voltage developing means connected to each respective said voltage source a voltage envelope for the patient which envelope directly corresponds to the earphone levels heard as determined by when and at what audio levels the said patient operates said two position switch; and
- h. recording said envelope for the said patient in correspondence with the earphone levels heard by the patient as determined by when and at what amplification levels the patient operates said two position switch in respect to said tone signals as an indication of the patient's hearing loss.

15. The method of claim 14 including the step of generating said tone signals in pulse form.

16. The method of claim 15 including the step of changing the instantaneous slope of ramp voltage during each tone signal presentation from a relatively steep slope at the onset of each said tone signal and continuously decreasing said slope to a relatively gradual slope at the conclusion of each said tone signal presentation.

17. The method of claim 14 wherein said recording comprises chart strip recording.

18. The method of claim 14 wherein said recording comprises electrically converting said envelope to numeric data and recording as a numeric printout.

19. The method of claim 14 including the step of electrically compensating the output of said voltage source for normal ear efficiencies and earphone deficiencies.

20. An audiometer apparatus comprising, in combination;

- a. an audiometric patient test station having right and left earphones and a two position patient actuated switch;
- b. programmably controllable solid state right-left earphone switching means connected to receive an audio signal and selectively direct the same to the right or left earphone at said station;
- c. a programmably controllable solid state voltage controlled oscillator signal source adapted to provide in some predetermined order a series of continuous tone signals arranged in a fixed repeatable sequence, each tone signal in the series being of a selected audio frequency, amplitude and period of duration;
- d. a programmably controllable continuous control solid state voltage source productive of a ramp voltage wave controllable as to ascending and descending direction and representing a control voltage having maximum and minimum values when moved without interruption in either direction, said control voltage source being connected to said two position switch and being adapted such that the direction of said ramp voltage wave may be interrupted and reversed in direction by the position of said two position switch and the magnitude of the ramp voltage wave may be regulated in coordination with desired maximum and minimum audio thresholds in said earphones;
- e. programmably controllable solid state circuit attenuator means connected to said signal source to receive said tone signals and to said control voltage source to receive said ramp voltage wave, said attenuator means being adapted to generate therefrom an audio output test signal having precisely controlled gain qualities in linear proportion to said control voltage and at the selected said frequency, said circuit attenuator means incorporating circuitry for computing a signal representing the logarithm of said tone signal, for combining such logarithm signal and said ramp voltage wave, to produce the antilog of such combination and from such antilog to produce said test signal, said earphone switching means being connected to receive said test signal;
- f. preprogrammed control solid state logic circuit means connected to programmably control said signal source by precisely controlling the voltage supplied said oscillator to control said tone signal frequency, voltage source and earphone switching means whereby upon actuation thereof said signal and voltage source are energized under program

19

control to produce said tone signals and voltage wave wherein said patient hears first in one said earphone and then the other, said series of signals and during the hearing of each tone signal in each respective earphone the subject is enabled to move 5  
said two position switch to a first position when said tone signal is first heard and to a second position when said tone signal is lost to hearing and by so positioning said two position switch said subject being able to control both the direction of said voltage wave and the maximum or minimum level achieved in each direction, said control logic circuit including manually operated reset circuitry means adapted to cause said tone signal sequence to be reset to a predetermined starting frequency, 15  
and including cross talk circuit means connected to said earphones and adapted to selectively prevent one of said earphones from conducting a signal when the other of said earphones is being utilized for testing. 20  
g. tone interrupter circuit means connected to inter-

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rupt and convert said continuous tone signals into pulse form;  
h. manually actuated holding circuitry means adapted when actuated to cause said logic circuit means to stop and hold said tone signal sequence at the then programmed frequency;  
i. hearing threshold level compensation circuit means connected to receive the output of said voltage source and to electrically compensate said voltage source for normal ear efficiencies and earphone deficiencies to provide an electrical output corrected for both; and  
j. recording means connected to said voltage source and adapted to develop and record a voltage envelope for said patient directly corresponding to the earphone levels heard as determined by when and at what amplification levels the patient operates said two position switch in respect to said tone signals as an indication of the patient's hearing loss.

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