June 5, 1951 H. M. BACH 2,555,390

AUDIOMETER

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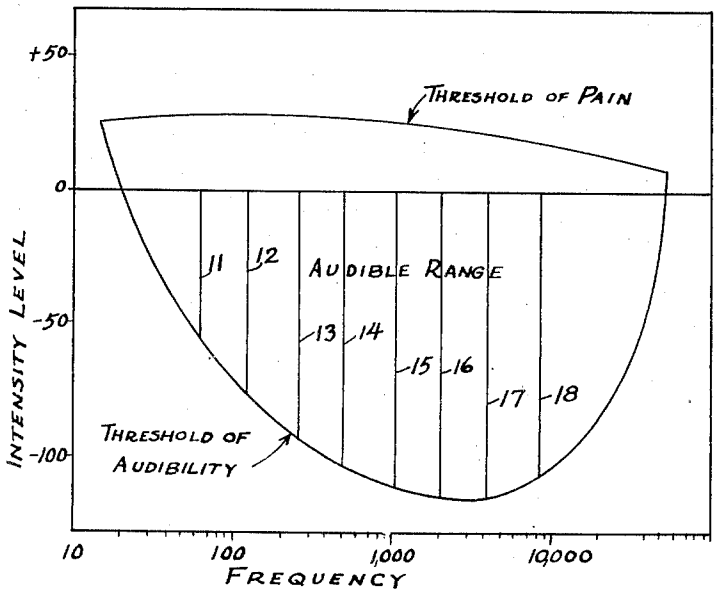



FIG. 1

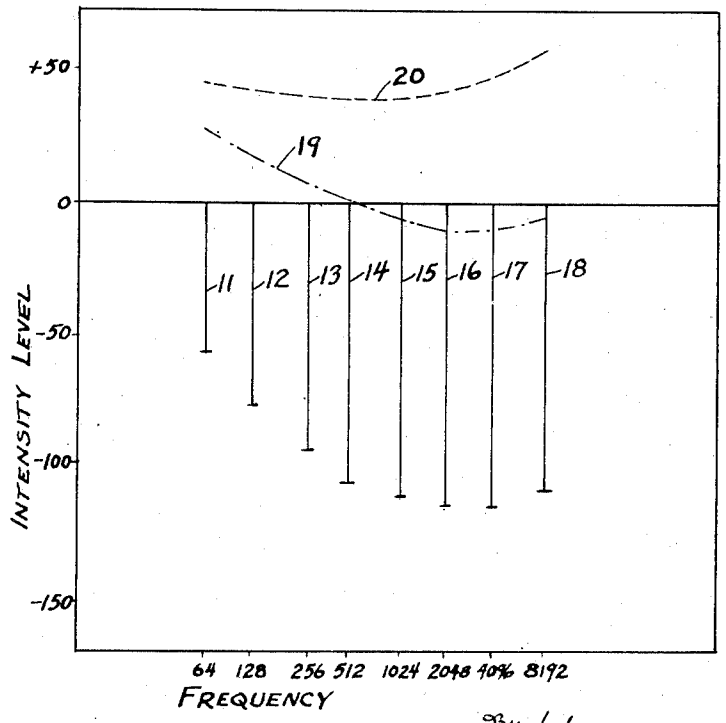



FIG. 2

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AUDIOMETER

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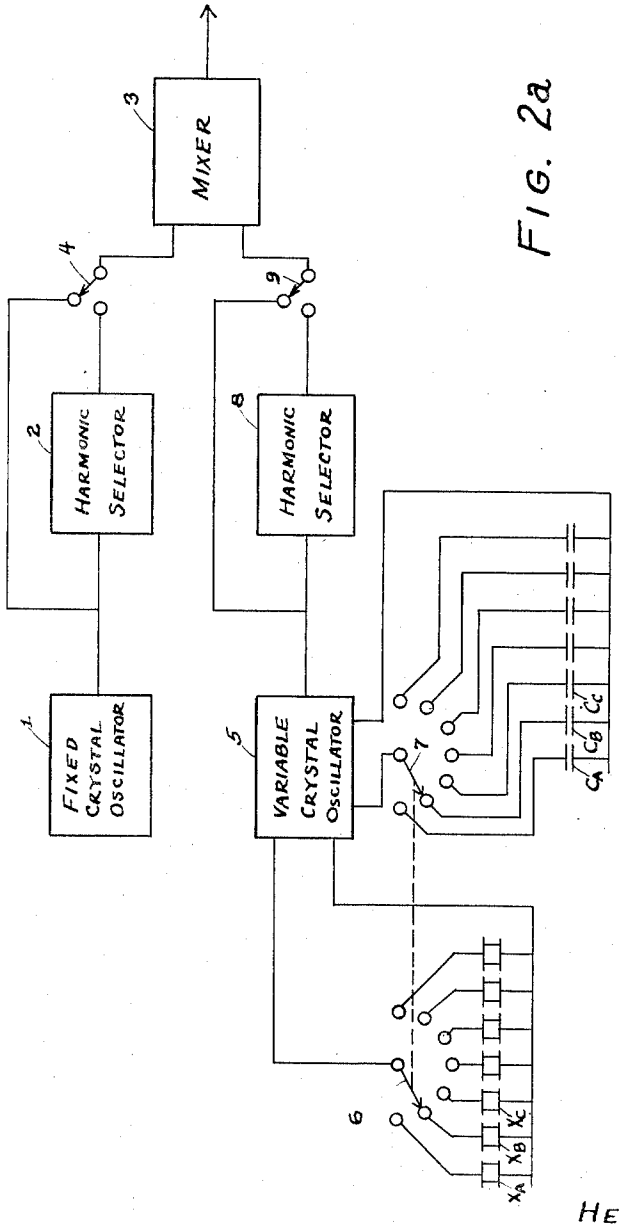



FIG. 2a

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AUDIOMETER

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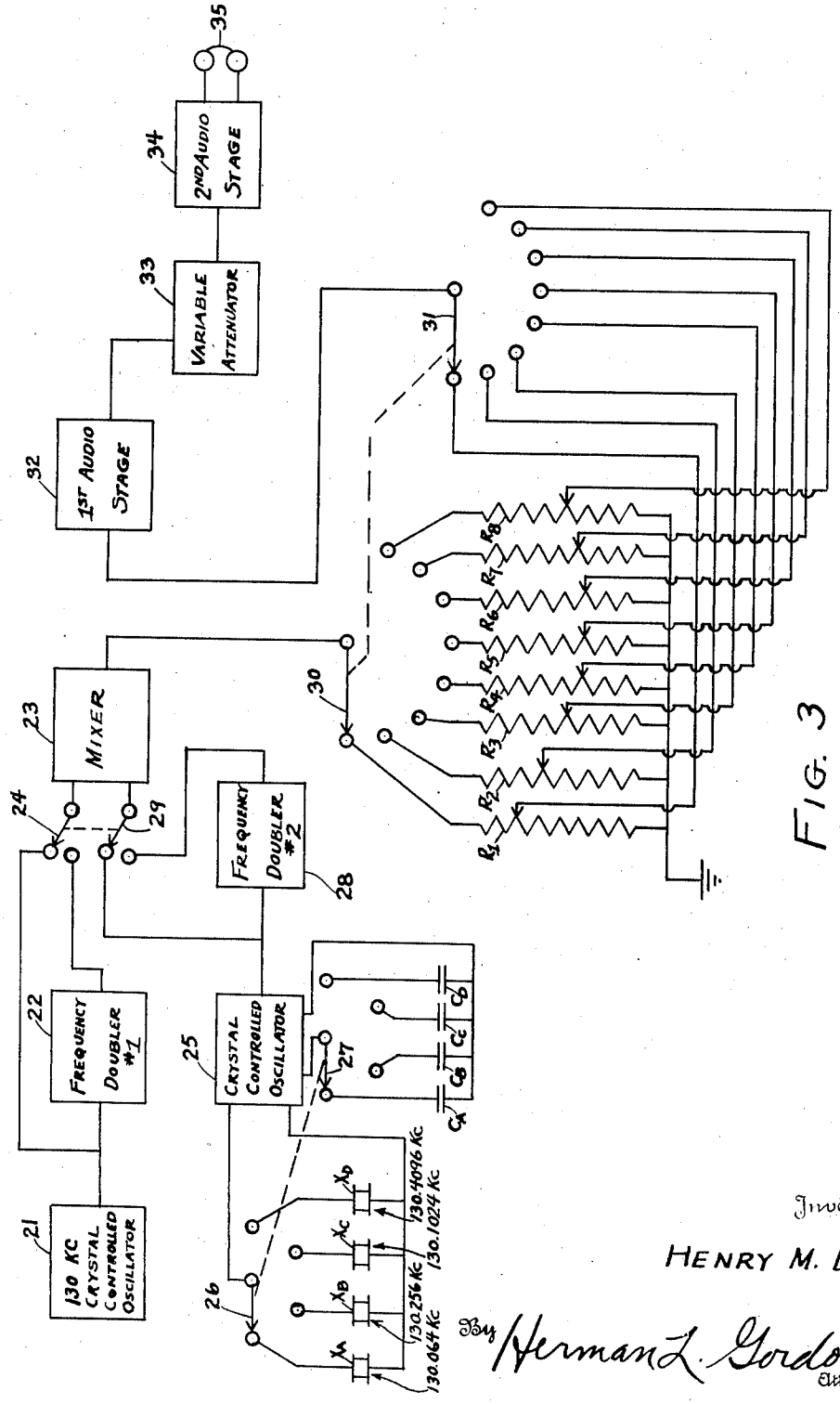



FIG. 3

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AUDIOMETER

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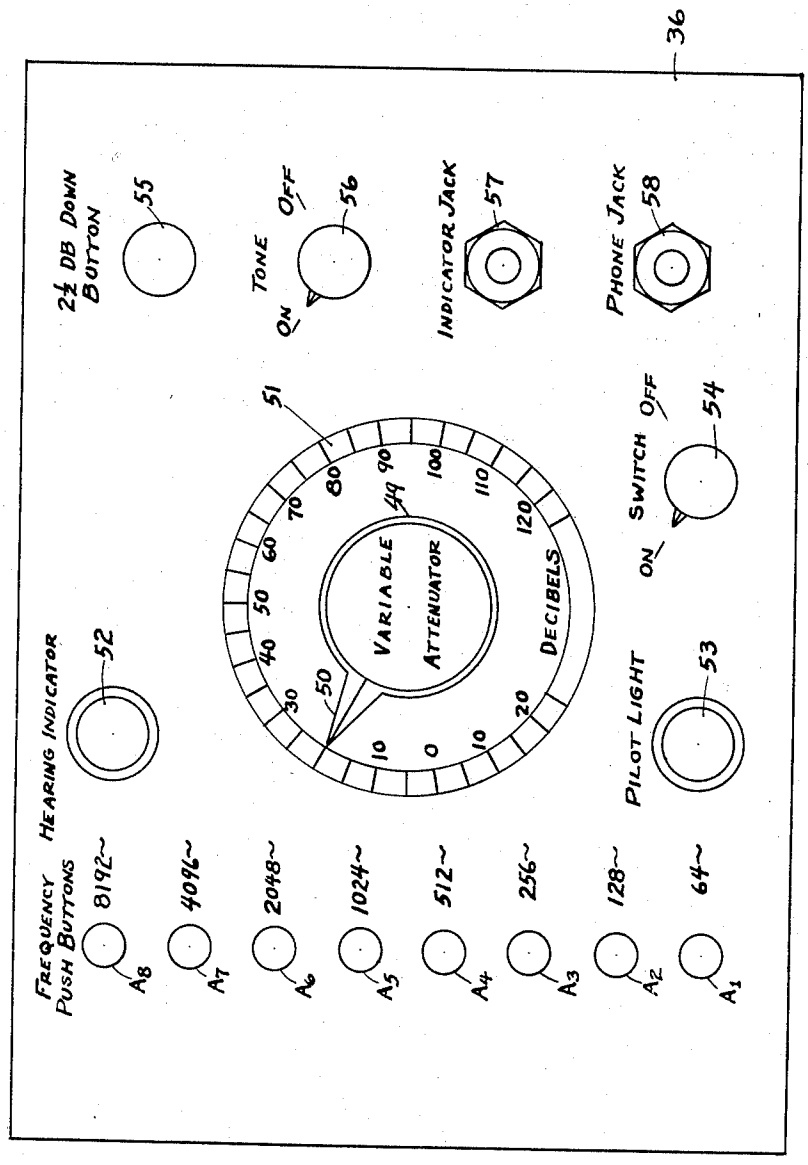



FIG. 4

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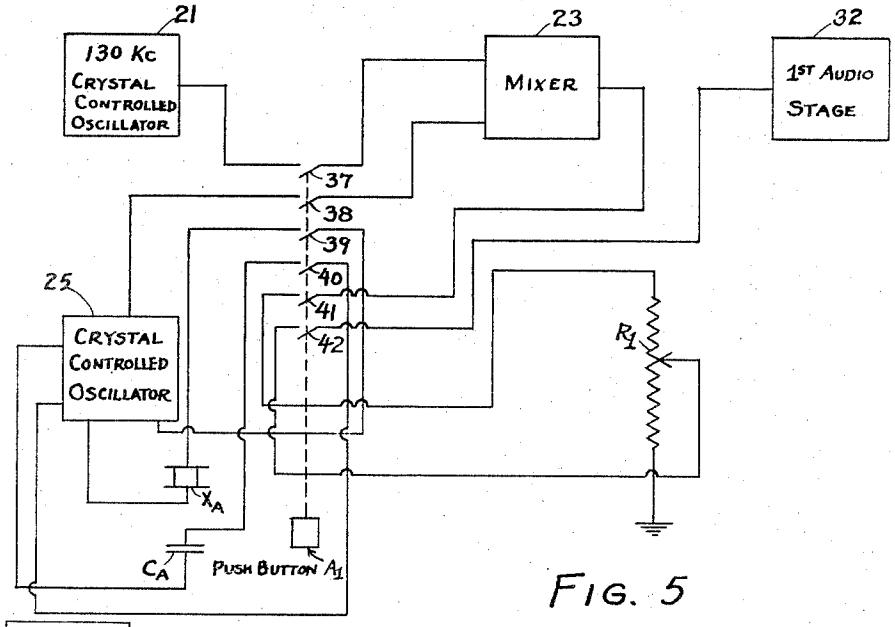



FIG. 5

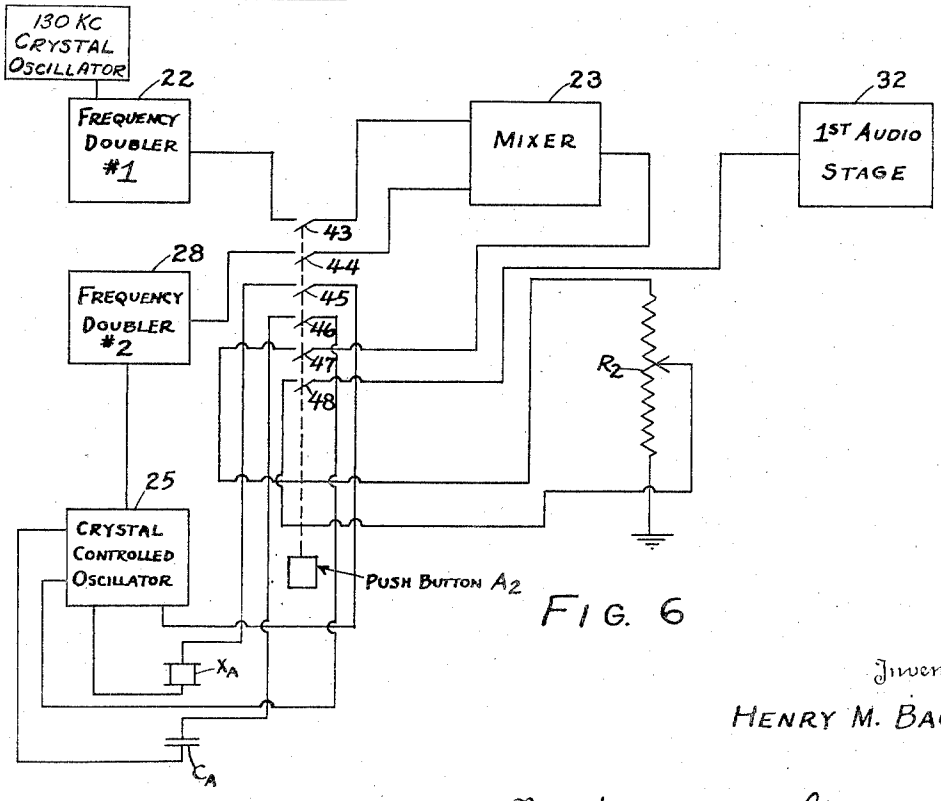



FIG. 6

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AUDIOMETER

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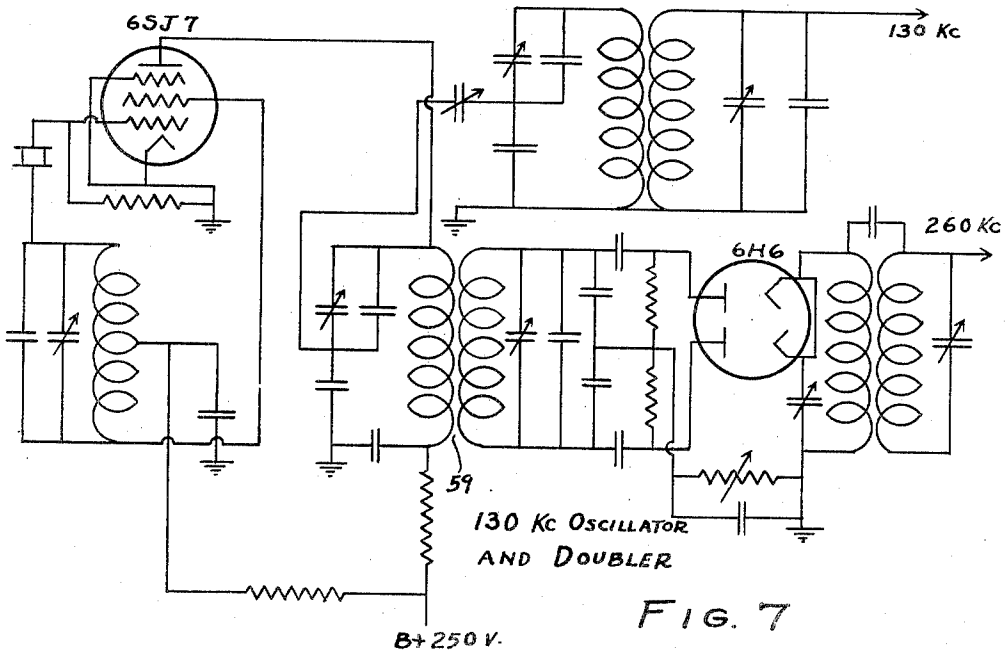



FIG. 7

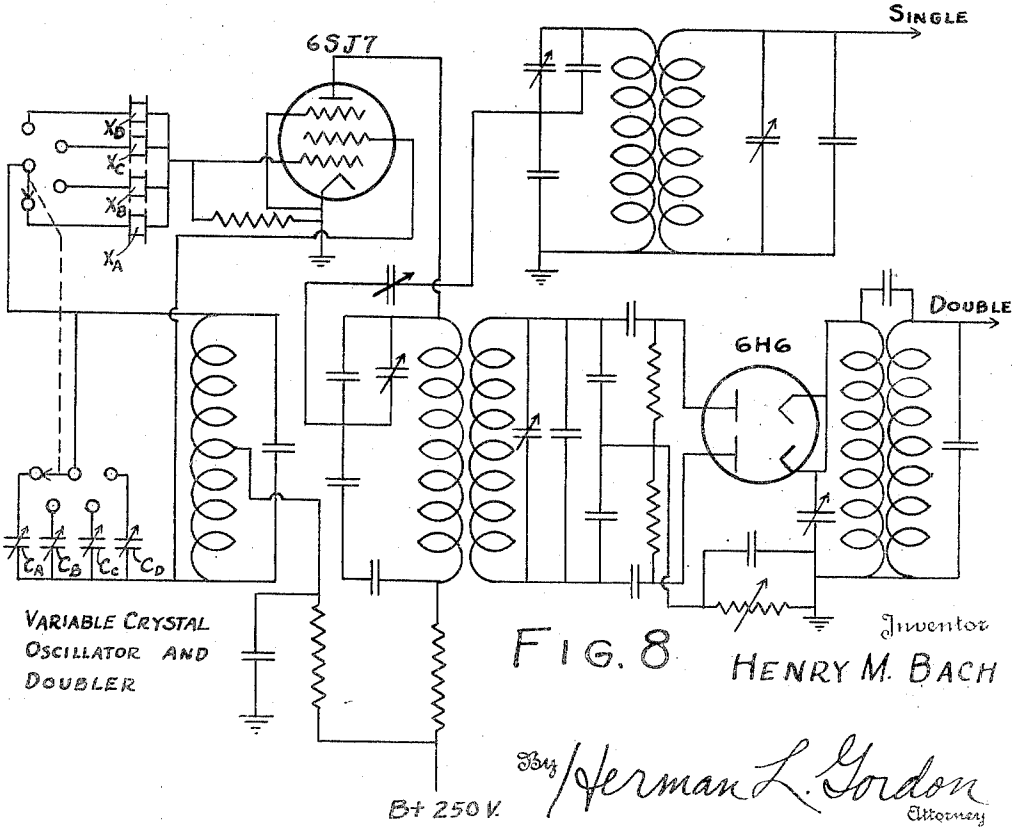



FIG. 8

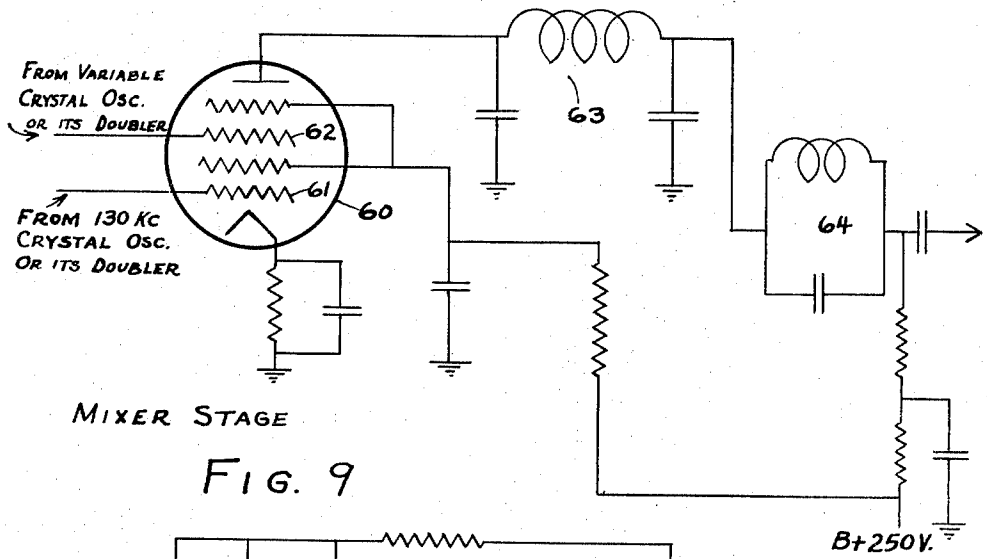
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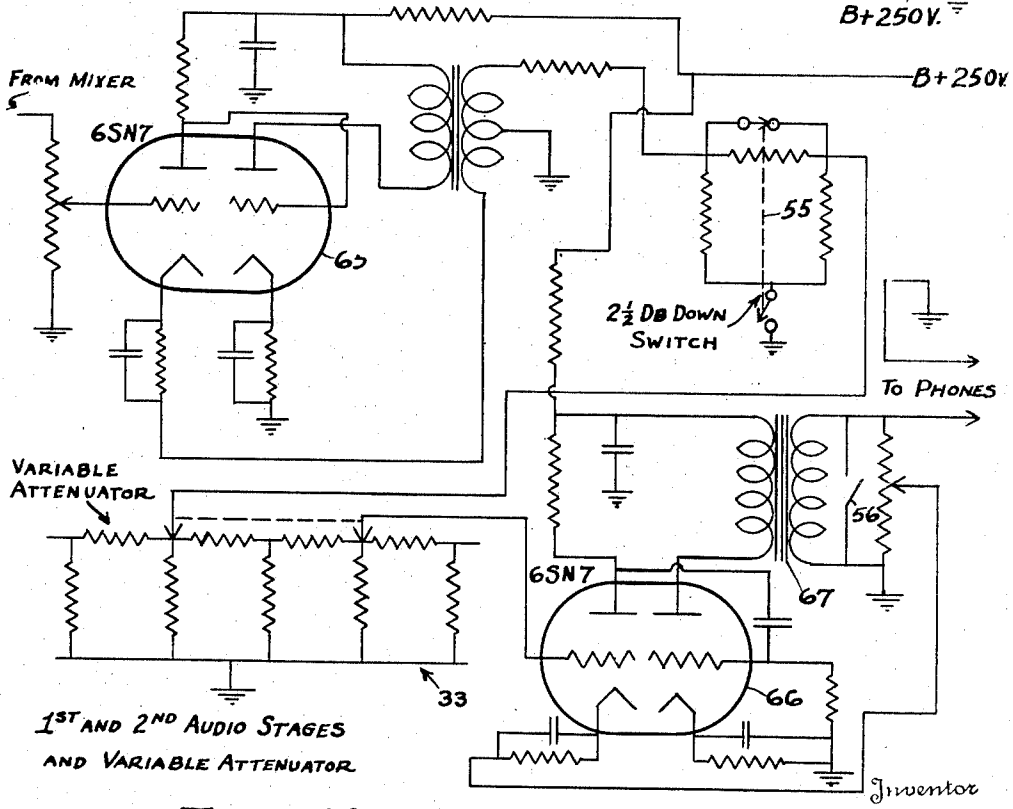
AUDIOMETER

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MIXER STAGE

FIG. 9




1ST AND 2ND AUDIO STAGES AND VARIABLE ATTENUATOR

FIG. 10

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# UNITED STATES PATENT OFFICE

2,555,390

## AUDIOMETER

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Application February 18, 1946, Serial No. 648,392

7 Claims. (Cl. 250—36)

1

This invention relates to instruments for measurement of the hearing sensitivity of an individual, and more particularly to that class of instruments known as audiometers.

A main object of the invention is to provide a novel and improved audiometer structure wherein the test frequencies employed in making the measurements are accurately controlled and wherein the instrument may be easily and quickly manipulated by relatively untrained operators to make the hearing sensitivity measurements.

A further object of the invention is to provide an improved audiometer employing crystals to provide the test frequencies, said frequencies being automatically attenuated in their voltage output, whereby for any setting of the main attenuator dial within the output range for a given test frequency the calibrated setting of the main attenuator dial conforms with the minimum audibility value of a normal ear for that frequency.

A still further object of the invention is to provide an improved audiometer structure employing crystals to provide eight test frequencies, said crystals being employed in a novel circuit arrangement which is adapted to be controlled by relatively simple apparatus for the selection of a desired test frequency.

A still further object of the invention is to provide an improved audiometer of the beat frequency type, the test frequencies of the audiometer being derived by beating selectively controlled crystal-stabilized oscillator frequencies against a crystal-controlled base frequency, means being provided for multiplying the base frequency and the selectively controlled frequencies in a predetermined manner in accordance with the test frequency desired, and wherein by a single selecting operation the chosen test frequency voltage is automatically attenuated in accordance with the sensitivity of a normal ear for that particular test frequency.

Further objects and advantages of the invention will become apparent from the following description and claims, and from the accompanying drawings, wherein:

Figure 1 is a diagram showing the hearing characteristics of a normal ear expressed in terms of intensity level versus frequency.

Figure 2 is a diagram derived from Figure 1 showing the relative magnitudes of the compensating attenuations for various test frequencies over the audible range required to correct the instrument to conform with the varying sensitivity of a normal ear for said various test frequencies.

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Figure 2*a* is a block diagram illustrative of an audiometer tone selecting system employing the method and means of the present invention.

Figure 3 is a schematic block diagram of an audiometer system constructed in accordance with the present invention.

Figure 4 is a front elevational view of the control panel of an adiometer instrument embodying the system of Figure 3 but including certain additional features.

Figure 5 is a schematic diagram disclosing the wiring connections for one of the push button switch elements employed in the instrument of Figure 4 wherein fundamental frequencies of the beating oscillators are employed to obtain a test frequency.

Figure 6 is a schematic diagram disclosing the wiring connections for a second push button switch element employed in the instrument of Figure 4 wherein the frequencies of the beating oscillators are doubled to obtain a test frequency.

Figure 7 is a wiring diagram of a base frequency crystal-controlled oscillator and a doubling circuit therefor as employed in the audiometer of Figures 3 and 4.

Figure 8 is a wiring diagram of a variable frequency crystal-controlled oscillator and a doubling circuit therefor as employed in the audiometer of Figures 3 and 4.

Figure 9 is a wiring diagram of a mixer stage employed to heterodyne the basic crystal-controlled frequency or double said basic frequency with a selected crystal-controlled frequency or double said selected frequency as employed in the audiometer of Figures 3 and 4.

Figure 10 is a wiring diagram showing the first and second audio frequency stages and the variable attenuator employed in an audiometer according to the present invention.

A practical audiometer instrument must provide means for accurately measuring the hearing sensitivity of an individual over the frequency spectrum of audible sound. In designing such an instrument due consideration must be given to the variation in hearing characteristics of a normal ear as a function of frequency. This variation is graphically expressed by a chart such as is illustrated in Figure 1, wherein the lower curve marked "Threshold of audibility" and the upper curve marked "Threshold of pain" give the limits of practical audibility of sounds for the average ear expressed in terms of frequency. The lower curve shows for each frequency the intensity of sound in decibels above an arbitrarily chosen level at which the signal is just perceptible to the normal ear. The

upper curve shows for each frequency the intensity of the signal in decibels at which it is so loud that it produces a sensation of pain. The points at which these two curves intersect give the lower and upper limits of audibility expressed in terms of frequency of the signal tone. These curves are employed in making measurements of hearing defects and in determining the degree of hearing loss of a person having defective hearing.

The American Medical Association has specified certain fixed frequencies at which audiometers shall be equipped to make measurements of hearing acuity. These frequencies are 128, 256, 512, 1,024, 2,048 4,096 and 8,192 cycles per second. The frequencies are required to remain within plus or minus five percent of the designated values. Obviously, the accuracy of the instrument over its period of useful life depends in a large measure on the stability of the test frequencies and the ability of the instrument to accurately reproduce a designated test frequency. For this reason the instrument of this invention employs crystal-controlled tone generators wherein the test frequencies are rendered stable and constant in pitch. However, in order to reduce the total number of crystals required to generate all the frequencies specified by the American Medical Association, it has been found convenient to employ an additional test frequency of 64 cycles per second. The reason for this will subsequently become apparent.

From Figure 1 it is apparent that in order to test hearing acuity at each of the test frequencies, due compensation must be made for the variation of hearing acuity of a normal ear over the audible range of frequencies. If the zero intensity level is selected as a reference line for making hearing measurements, it will be clear from Figure 1 that a reading at, say, 64 cycles per second must be corrected by attenuating a signal of given initial intensity by an amount equal to the normal distance from the zero intensity line to the threshold of audibility curve at 64 cycles per second, which, from Figure 1, would be line 11, or approximately 57 decibels down. Said signal intensity at 128 cycles per second must be corrected by an attenuation represented by line 12, or approximately 75 decibels down. The varying values of correction attenuation for the range of test frequencies employed are graphically shown in Figure 2 by the respective lines 11, 12, 13, 14, 15, 16, 17 and 18 measured from Figure 1. If these attenuation values are applied to a signal of given intensity for the various test frequencies, the resultant intensity at any of said test frequencies will be corrected for variation of hearing acuity of a normal ear. After such correction has been made, a single attenuation control element may be employed to measure individual hearing ability with reference to the zero intensity line, which now is the reference line of minimum audibility for a normal ear. Typical adjusted hearing curves for individuals are shown in Figure 2 at 19 and 20.

Referring to Figure 2*a*, a block diagram is disclosed illustrative of the method and means employed to obtain audio test frequencies in accordance with the present invention. In Figure 2*a*, 1 designates a fixed frequency crystal-controlled oscillator. Oscillator 1 is connected to a harmonic selector stage 2 which is adapted to be adjusted to furnish a desired harmonic of oscillator 1 at its output terminals. Harmonic selector stage 2 may be a conventional frequency doubler, tripler, or the like, or may be merely an adjustable band pass filter adapted to be set to pass any desired harmonic of the fundamental voltage wave of oscillator 1. Either the fundamental or a selected harmonic of the output wave of oscillator 1 is supplied to the input circuit of a mixer stage 3 through an adjustable switch arm 4. Mixer 3 also receives into its input circuit either the fundamental or a selected harmonic of an adjustable-frequency crystal-controlled oscillator 5 whose fundamental frequency is determined by any one of a plurality of control crystals $X_A$, $X_B$, $X_C$, etc., selectively connected to oscillator 5 through an adjustable switch arm 6. Ganged with switch arm 6 is a switch arm 7 which controls the tuning of the tank circuit of oscillator 5 in accordance with the setting of arm 6 to maintain resonance of said oscillator at the various crystal frequencies. Tank capacitors $C_A$, $C_B$, $C_C$, etc., are respectively provided for selective connection by arm 7 to oscillator 5 in accordance with the setting of arm 6.

A harmonic selector 8, similar to harmonic selector 2, is provided for oscillator 5. Mixer 3 receives into its input circut either the fundamental of oscillator 5 or a selected harmonic thereof, the mixer being alternatively connected through an adjustable switch arm 9 either directly to the output terminal of oscillator 5 or to the output terminal of harmonic selector 8.

The selected input waves are heterodyned in mixer 3 and the resultant wave is delivered to suitable attenuator means, as will be subsequently described. The crystals $X_A$, $X_B$, $X_C$, etc., differ in frequency from the fundamental crystal frequency of oscillator 1 by known audio values, and differ in frequency from each other by known audio frequency increments.

It may be readily seen that a large number of accurately known audio test frequencies may be obtained from the arrangement of Figure 2*a*, while only a few crystals need be employed. A first series of accurately known audio test frequencies in octave relationship may be thus obtained by heterodyning the like harmonics of oscillator 1 and oscillator 5, employing only crystal $X_A$ in oscillator 5. An additional series of known octave-related test frequencies may be obtained through the use of an additional crystal $X_B$, and so on.

Referring to Figure 3, a schematic audiometer arrangement employing the principles discussed above is illustrated. 21 designates a base frequency oscillator which is crystal controlled and produces a 130 kc. signal. 22 is a frequency doubler which may be employed to double the base frequency to 260 kc. Either the 130 kc. signal or the 260 kc. signal may be delivered to a mixer 23 through an adjustable switch arm 24. 25 is a crystal controlled oscillator arranged to be selectively controlled as to frequency by connection to any one of four crystals $X_A$, $X_B$, $X_C$ or $X_D$, through an adjustable switch arm 26, $X_A$ being 130.064 kc., $X_B$ being 130.256 kc., $X_C$ being 130.1024 kc. and $X_D$ being 130.4096 kc. in frequency. Mechanically coupled to switch arm 26 is a switch arm 27 which selectively connects the respective tuning capacitors $C_A$, $C_B$, $C_C$, or $C_D$ to oscillator 25 in accordance with the corresponding connection thereto of a selected crystal, to thereby tune the oscillator to the crystal frequency. 28 is a second frequency doubler

which may be employed to double the output frequency of oscillator 25. Either the fundamental frequency of oscillator 25 or double said fundamental frequency may be delivered to mixer 23 through an adjustable switch arm 29 which is mechanically coupled to switch arm 24. In the position shown in Figure 3, switch arms 24 and 29 are positioned for delivering the 130 kc. crystal controlled base frequency from oscillator 21 to mixer 23 and also a 130.064 kc. crystal controlled frequency from oscillator 25. This provides a difference frequency of 64 cycles per second at the output of mixer 23. By moving switch arms 24 and 29 to their alternate positions, the input frequencies to mixer 23 are doubled and the output difference frequency therefrom will be 128 cycles per second. By thus adjusting coupled switch arms 24 and 29 and coupled switch arms 26 and 27 to their various positions, output frequencies of 64, 128, 256, 512, 1,024, 2,048, 4,096 and 8,192 cycles per second may be obtained at the output of mixer 23.

The output terminal of mixer 23 is connected to a switch arm 30 which may be selectively connected to the input terminal of any one of a series of potentiometers $R_1$, $R_2$, $R_3$, $R_4$, $R_5$, $R_6$, $R_7$, or $R_8$. Each potentiometer has an adjustable output tap which may be connected through a switch arm 31, mechanically coupled to switch arm 30, to the input of a first audio amplifier stage 32. The respective adjustable taps are set to provide preset attenuations corresponding to the correction values obtained from Figure 2 for each of the eight test frequencies. Thus $R_1$ may be preset to provide an attenuation of 57 decibels down from the zero intensity level value for the 64 cycle tone, $R_2$ may be preset to provide an attenuation of 75 decibels down from the zero intensity level value for the 128 cycle tone, etc., so that the signal admitted to audio stage 32 is automatically corrected in accordance with normal ear hearing acuity for that test frequency corresponding to the setting of switch arms 30 and 31. Switch arms 30 and 31 are of course set in accordance with the selected output frequency obtained from mixer 23. Means for providing complete setting of the various switches by a single operation for each test frequency will be subsequently described.

The amplified and corrected signal from audio stage 32 is delivered to a calibrated variable attenuator 33. The output signal of attenuator 33 is delivered to a second audio stage 34 provided with ear phones 35 which are worn by the individual whose hearing is to be tested. The hearing curve of the individual is obtained from the settings of variable attenuator 33 at which the various test frequency signals are just audible. The zero calibration value of attenuator 33 is in accordance with Figure 2, that is, is adjusted to correspond to the zero intensity level, or audibility line, for a normal ear.

Figure 4 illustrates the appearance of the control panel 36 of an audiometer constructed in accordance with the principles of this invention. Mounted on control panel 36 are eight push buttons $A_1$, $A_2$, $A_3$, $A_4$, $A_5$, $A_6$, $A_7$ and $A_8$, each push button controlling the switches for one of the test frequencies. Figure 5 shows as an example the circuits and the switches therefor associated with push button $A_1$, which controls the 64 cycle per second test frequency. Mechanically coupled to push button $A_1$ is a first switch arm 37 in a connection between 130 kc. crystal controlled oscillator 21 and mixer 23, a second switch arm 38 in a connection between oscillator 25 and mixer 23, a third switch arm 39 in a connection between crystal $X_A$ and oscillator 25, a fourth switch arm 40 in a connection between tuning capacitor $C_A$ and oscillator 25, a fifth switch arm 41 in a connection between mixer 23 and the intput terminal of potentiometer $R_1$, and a sixth switch arm 42 in a connection between the adjustable tap of potentiometer $R_1$ and the input terminal of the first audio stage 32. When push button $A_1$ is depressed, the six switches controlled thereby are closed and the corrected test signal at 64 cycles per second is delivered to the first audio stage 32.

Figure 6 shows by way of further illustration the circuits and switches associated with push button $A_2$ which controls the 128 cycle per second test frequency. Mechanically coupled to push button $A_2$ is a first switch arm 43 in a connection between the first frequency doubler 22 and mixer 23, a second switch arm 44 in a connection between the second frequency double 28 and mixer 23, a third switch arm 45 in a connection between crystal $X_A$ and oscillator 25, a fourth switch arm 46 in a connection between capacitor $C_A$ and oscillator 25, a fifth switch arm 47 in a connection between mixer 23 and the input terminal of potentiometer $R_2$, and a sixth switch arm 48 in a connection between the adjustable tap of potentiometer $R_2$ and the input terminal of the first audio stage 32.

The remaining push buttons have corresponding circuits and switches associated therewith, the circuits and switches of each push button being independent of the circuits and switches of the other push buttons and the push buttons being included in a conventional mechanical assembly wherein actuation of one push button releases all other push buttons. The switching for the various push buttons respectively closes circuits for the elements according to the following table:

| Push Buttons | Crystals | Capacitors | Doublers | Potentiometers | Test Frequency |
|---|---|---|---|---|---|
| | | | | | *C. P. S.* |
| $A_1$ | $X_A$ | $C_A$ | | $R_1$ | 64 |
| $A_2$ | $X_A$ | $C_A$ | 22, 28 | $R_2$ | 128 |
| $A_3$ | $X_B$ | $C_B$ | | $R_3$ | 256 |
| $A_4$ | $X_B$ | $C_B$ | 22, 28 | $R_4$ | 512 |
| $A_5$ | $X_C$ | $C_C$ | | $R_5$ | 1,024 |
| $A_6$ | $X_C$ | $C_C$ | 22, 28 | $R_6$ | 2,048 |
| $A_7$ | $X_D$ | $C_D$ | | $R_7$ | 4,096 |
| $A_8$ | $X_D$ | $C_D$ | 22, 28 | $R_8$ | 8,192 |

Also mounted on control panel 36 is a variable attenuator control knob 49 having a pointer 50 which indicates the setting of the variable attenuator with respect to a scale 51 calibrated in decibels. A pilot lamp 52 is provided on panel 36, said lamp being under the control of the individual whose hearing is to be tested, the individual closing a switch when the test signal becomes barely audible, said switch energizing pilot lamp 52. A second pilot lamp 53 is provided on panel 36 to indicate whether the instrument is on or off, a control switch 54 being provided to energize or de-energize the instrument. A subsidiary attenuator is provided under the control of a switch 55 mounted on panel 36, said subsidiary attenuator providing 2½ decibel attenuation down with respect to the setting of the main variable attenuator, which itself operates in 5 decibel steps. A switch 56 on the control panel is provided for turning the test signal tone on or off. A jack 57 is provided for connecting the subject-operated switch device for hearing indicator 52 to the instrument, and a second jack 58

is provided for the ear phones through which the test signal is delivered to the individual whose hearing is being tested.

Figure 7 is the schematic circuit diagram of the 130 kc. crystal controlled oscillator and its frequency doubler. The oscillator is of the Hartley type and is substantially conventional in design. The doubler circuit comprises a full wave rectifier which employs a dual diode tube of the 6H6 type. The 130 kc. output signal in the plate circuit of the oscillator is inductively coupled through a transformer 59 to the input circuit of the dual diode and is impressed across the plates of the dual diode. The cathodes of the dual diode are connected together and provide full wave rectification of the 130 kc. signal, the rectified voltage being impressed across an output network. The rectified wave contains a large 260 kc. component which is made available at the output terminal of the doubler output network.

The circuit for the variable crystal oscillator and its doubler, shown in Figure 8, is similar to the circuit of Figure 7 for the 130 kc. oscillator and its doubler except for the provision for switching the crystals $X_A$, $X_B$, $X_C$, $X_D$ and the tuning capacitors $C_A$, $C_B$, $C_C$, $C_D$ to obtain the different frequencies which must beat with the base frequency or its double value to obtain the test frequencies. Here again the crystal oscillator is of the Hartley type and full wave rectification of the oscillator output signal is employed to obtain the double frequency signal.

The mixer stage schematically shown in Figure 9 is substantially conventional and includes a mixer tube 60 having a first input grid 61 which receives the 130 kc. or 260 kc. signal and a second input grid 62 which receives a signal from the variable crystal oscillator or its doubler. The input signals are mixed in tube 60 and the resultant difference frequency thereof passes through a low pass filter 63 and an audio band pass filter 64 to the output terminal of the mixer stage.

Figure 10 is a schematic diagram of the first and second audio stages and the variable attenuator. The first audio stage employs a dual triode 65 of the 6SN7 type. The first grid of tube 65 receives a signal from the adjustable tap of one of the correcting potentiometers and after two stages of amplification in tube 65 the signal is passed through the variable attenuator to the first grid of a second dual triode 66 where it again goes through two stages of amplification, being finally delivered to the ear phone terminals through an output transformer 67.

While a specific embodiment of an audiometer device has been disclosed in the foregoing description, it will be understood that various modifications within the spirit of the invention may occur to those skilled in the art. It will be further understood that the fundamental crystal frequency employed for the base oscillator may have other values than 130 kc., the 130 kc. value being employed herein solely by way of illustration. Of course, if a value different from 130 kc. were employed for the fundamental crystal frequency of the base oscillator the fundamental crystal frequencies employed in the variable crystal oscillator would be altered in accordance with the new crystal frequency of the base oscillator in order to obtain the required audiometer test frequencies.

It is therefore intended that the foregoing disclosure be construed only as illustrative of a preferred embodiment of the invention and that no limitations be placed on the invention other than as defined by the scope of the appended claims.

What is claimed is:

1. In an audiometer, a first generator producing a signal of frequency F and including a frequency doubler, a second generator, tuning means connectable to said second generator and arranged to produce individual frequencies differing from F by predetermined audio values, said second generator including a frequency doubler, a mixer connected to said generators and arranged for heterodyning the output of the first generator with the output of the second generator, respective attenuators, and switch means arranged for selectively connecting the attenuators to the output of said mixer and simultaneously controlling the tuning means and the frequency doublers.

2. In an audiometer, a first generator producing a signal of frequency F and including a frequency doubler, a second generator formed and arranged to produce individual frequencies $(F+x)$, $(F+4x)$ . . . $(F+4^n x)$, where $x$ is an audio frequency and $n$ is an integer, and including a second frequency doubler, a mixer connected to said first and second generators and arranged for heterodyning the output of said first and second generators, respective attenuators, and common switch means connected in controlling relation to the frequency doublers and the attenuators, the output of the mixer being connected to the attenuators through said switch means.

3. In an audiometer, a first generator producing a signal of frequency F, a second generator, tuning means connectable to said second generator and arranged to produce individual frequencies $(F+x)$, $(F+4x)$ . . . $(F+4^n x)$, where $x$ is an audio frequency and $n$ is an integer, a mixer connected to said generators and arranged for heterodyning any of said individual frequencies with the output of the first generator, respective different attenuators, one for each of the resultant heterodyne frequencies, switch means connected between the mixer and said attenuators constructed and arranged to connect the mixer to a selected attenuator, and means coupling the tuning means and said switch means.

4. In an audiometer, a first oscillator producing a signal frequency F, a second oscillator producing a frequency differing from F by a predetermined audio value, a mixer, an attenuator, a manually movable element, a plurality of switches coupled to said element, first circuit means connecting the first oscillator to the mixer and including a first one of said switches, second circuit means connecting the second oscillator to said mixer and including a second one of said switches, and third circuit means connecting the mixer to the attenuator and including a third one of said switches.

5. In an audiometer, a first oscillator producing a signal of frequency F, a second oscillator producing a frequency differing from F by a predetermined audio value, a first doubler, a second doubler, a mixer, an attenuator, a manually movable element, a plurality of switches coupled to said element, first circuit means connecting the first oscillator to the first doubler, and second circuit means connecting the second oscillator to the second doubler, third circuit means connecting the first doubler to said mixer and including a first one of said switches, fourth circuit means connecting said second doubler to said mixer and

including a second one of said switches, and fifth circuit means connecting said mixer to said attenuator and including a third one of said switches.

6. In an audiometer, a first oscillator, a second oscillator, a tuning element, a mixer, an attenuator, a manually movable member, a plurality of switches coupled to said member, first circuit means connecting the first oscillator to said mixer, second circuit means connecting the second oscillator to said mixer, third circuit means connecting said tuning element to said second oscillator and including a first one of said switches, and fourth circuit means connecting said mixer to said attenuator and including a second one of said switches.

7. In an audiometer, a first oscillator, a first frequency doubler, a second oscillator, a second frequency doubler, a tuning element, a mixer, an attenuator, a manually movable member, a plurality of switches coupled to said member, first circuit means connecting the first oscillator to the first doubler, second circuit means connecting the second oscillator to the second doubler, third circuit means connecting the tuning element to the second oscillator and including a first one of said switches, fourth circuit means connecting the first doubler to the mixer, fifth circuit means connecting the second doubler to the mixer, and sixth circuit means connecting the mixer to the attenuator and including a second one of said switches.



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