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ACOUSTIC DECREMETER

Filed Sept. 25, 1931

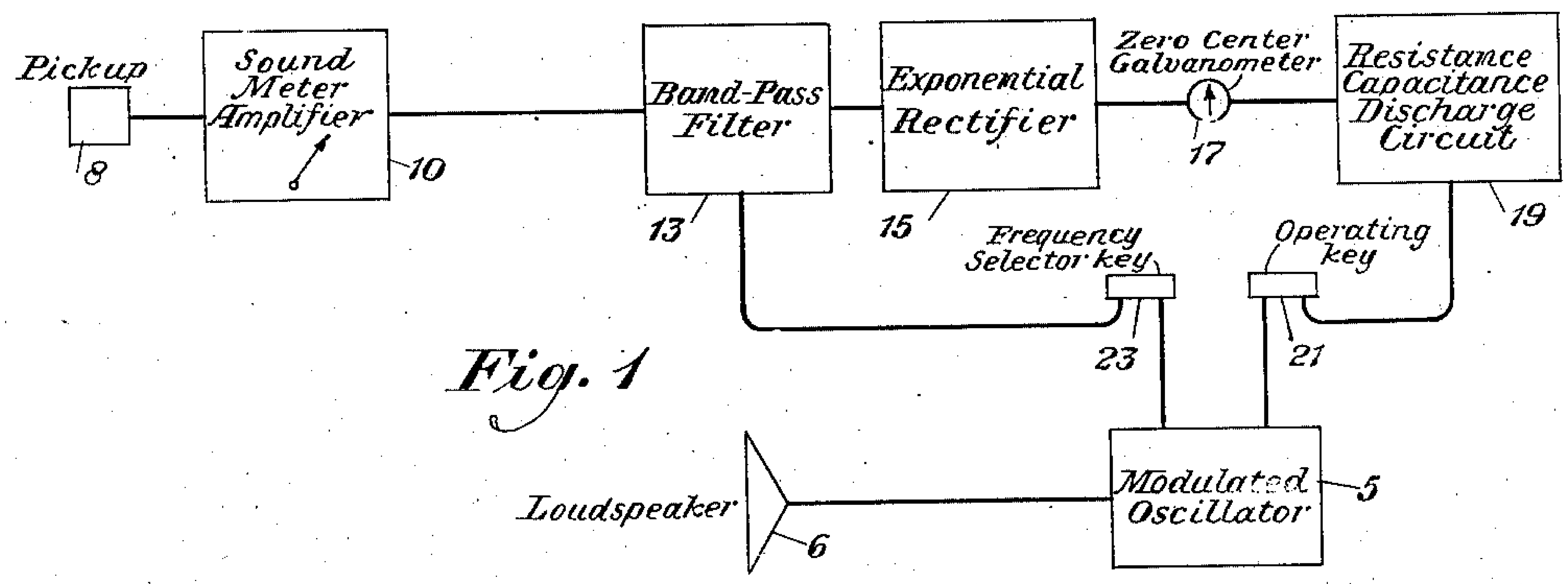

Fig. 1

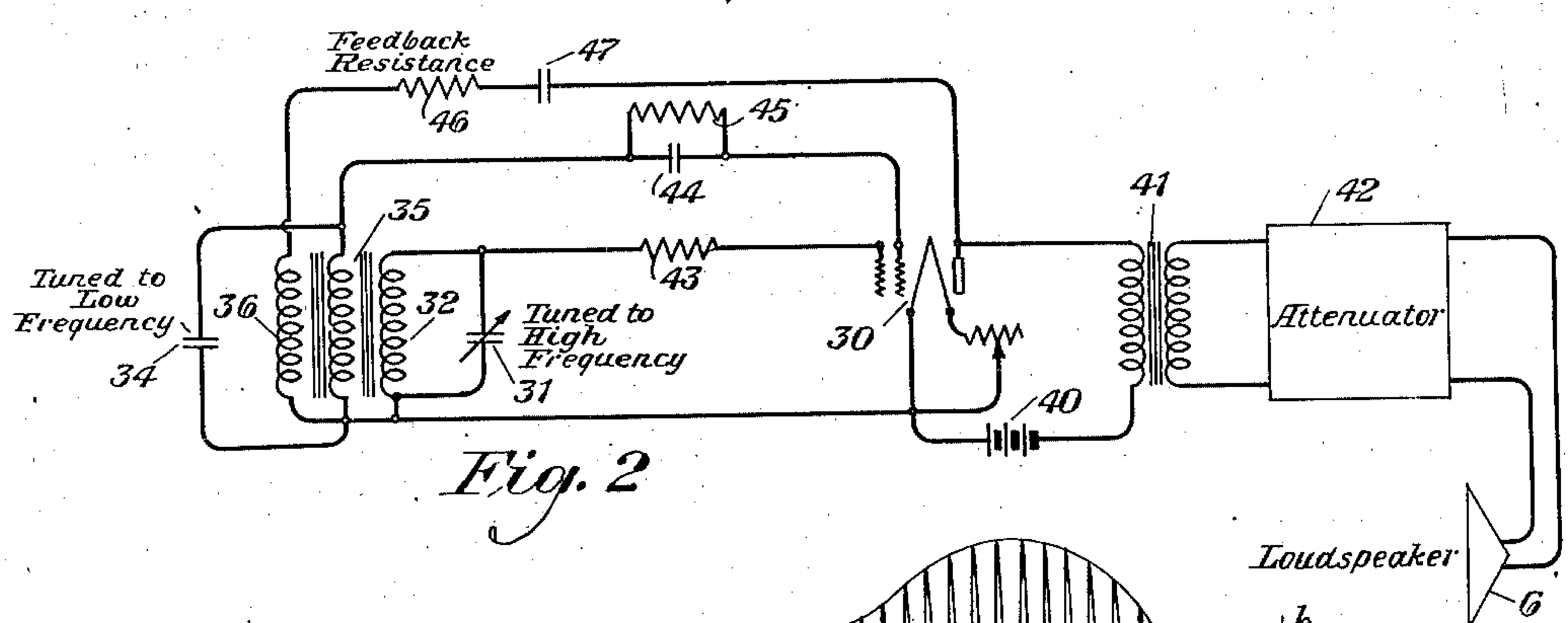

Fig. 2

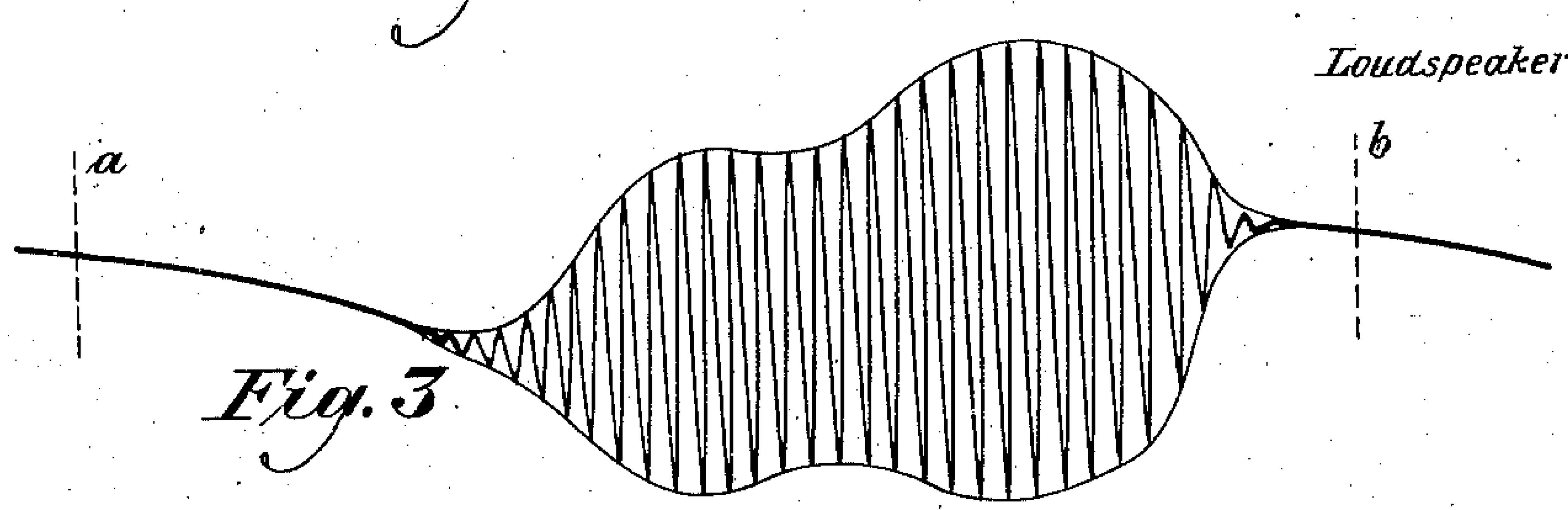

Fig. 3

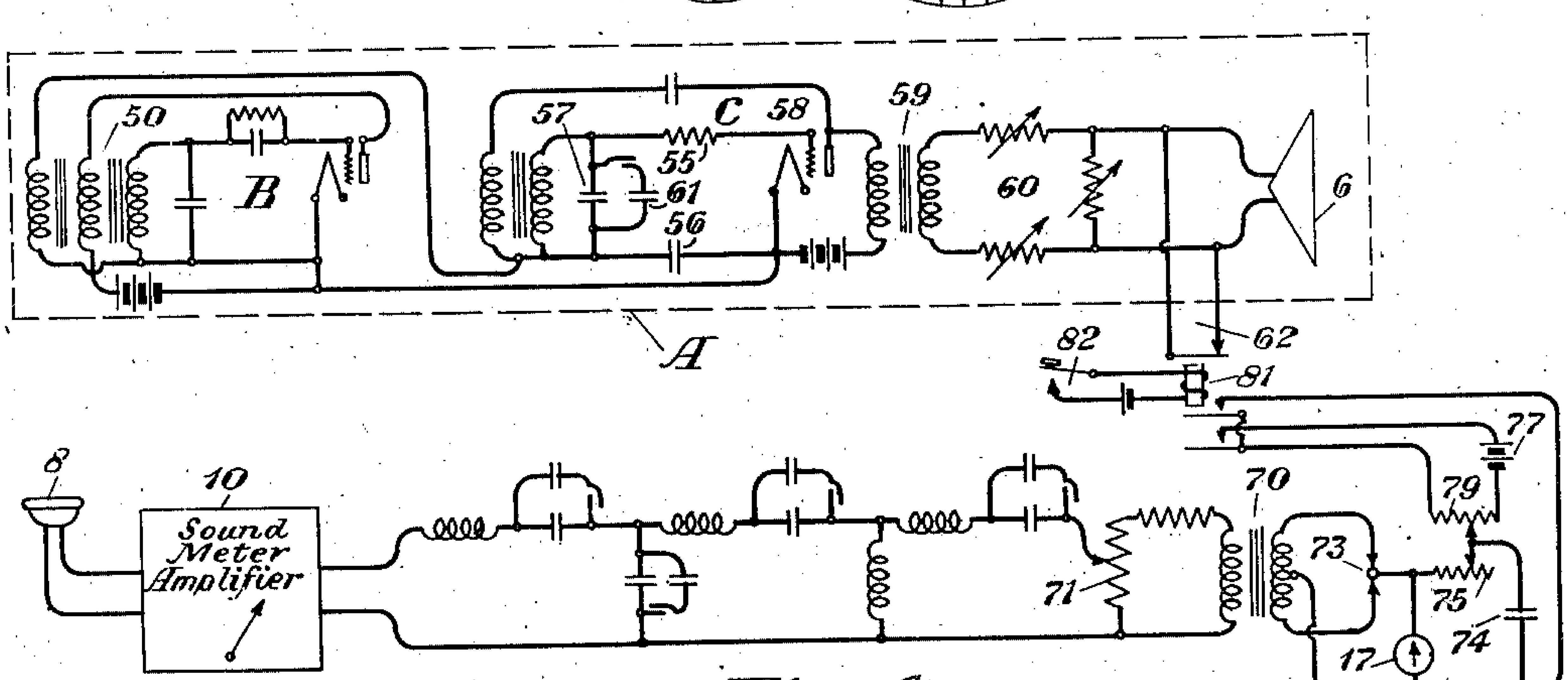

Fig. 4

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ACOUSTIC DECREMETER

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12 Claims. (Cl. 181—0.5)

This invention relates to acoustic decremeters, and more particularly to a decremeter for determining the rate of decay of sound or the reverberation period in halls and similar places.

Its object is to provide a decremeter which can be operated while the room is in normal use so far as movement of occupants is concerned, and to do this in spite of such general noise as may be present in the room.

Another object is to render possible the measurement of the decay or damping constant, or reverberation period, without the use of timing devices.

Still another object is to devise a source of sound with which no appreciably fixed wave pattern is set up in the room or rooms under investigation.

The reverberation period of a hall is usually defined as the time required for the intensity of sound in a room to decay to 10^{-6} of its initial intensity or volume. In view of the fact that tht reverberation period is different for different frequencies, it has become common to establish a source of a definite frequency and find the time required for this to fall to a given volume and to repeat this for other frequencies. There are at least two definite difficulties encountered in such measurements. The first of these is that there is present a level of noise which frequently is above the level to which it is desired that the sound under study should be allowed to fall unless one starts with excessively large initial volume. The second is that for a note of a given frequency a definite wave pattern is set up in the room, and the results obtained will depend upon the positions of the source of sound and the receiving device, and this wave pattern is altered by movement of persons or of apparatus in the room. Attempts to overcome the first of these difficulties usually consists in isolating the room so as to keep out all extraneous noises, and the second is usually reduced by varying the frequency in a definite way or by having some moving article in the room which continually changes the wave pattern. These have the disadvantage, however, that the measurments must be taken under conditions of undue inconvenience to the occupants, or under conditions with which the reverberation period will not be the same as that of the room when in normal use.

To accomplish the objects of this invention our acoustic decremeter comprises essentially a warbling source of sound; that is, a composite note of a group or band of frequencies changing in amplitude irregularly with respect to each other so that the wave pattern is continually changing. Cooperating with this is a receiver of room sound followed by amplifiers and by a band-pass filter which permits only the passage of that portion of the sound spectrum which is being studied, and thus discriminates strongly against the noise normally present in the room. The output of the filter passes to a rectifier of special characteristics and then to a differential galvanometer. In addition, an electrical discharge circuit of adjustable time constant comprising a condenser and a resistance, is connected to the galvanometer. The circuits are so adjusted that when the source of sound is being activated and current is flowing through the resistance, the galvanometer deflection is zero. By deactivating the sound source and opening a battery supply to the discharge circuit, the sound continues to arrive and activate the galvanometer, but with a definite decay rate, and the condenser discharge through the resistance also falls off with a definite decay rate. When properly adjusted the two effects balance and no galvanometer deflection results. The decay constant of the discharge circuit, which can readily be calculated, is then equal to or simply related to that of the room, and consequently, the period of reverberation may be calculated without the necessity of any measurements of time.

The invention will be better understood by reference to the following specification and accompanying drawing, in which Figure 1 shows in block form the elements comprising our decremeter; Fig. 2 shows an oscillating circuit for obtaining a warbling source of sound; Fig. 3 indicates the form of output of such a source, and Fig. 4 shows in further detail the circuit of our decremeter.

Referring more specifically to Fig. 1, there is shown at 5 an oscillatory with a modulated output which supplies a loud speaker 6 constituting a source of warbling sound; that is, a band of frequencies changing irregularly in amplitude. This sound is then received by a pickup device 8 and amplified by a variable gain amplifier 10. The latter may be the amplifier of a sound meter or volume indicator. Connected to the output of this amplifier is a band-pass filter 13 adjusted to pass frequencies over a limited range only and constructed so that this region may be altered to any portion of the spectrum desired. The output of the band-pass filter is now passed through a rectifier 15, this rectifier being one of a type which has a uniform exponential characteristic throughout the working range. The rectified current is then allowed to pass through a galvanometer 17, preferably one of the zero center type, such that deflection in either direction will be shown.

In addition to the above, there is supplied an electric discharge circuit which in its simplest form may consist of a condenser and a resistance. A direct current voltage, the source of which is shown in Fig. 4 and described in connection with that figure, is also supplied to this discharge circuit 19, which in turn is connected to the galvanometer 17. The direction and magnitude of the voltage is adjusted so as to neutralize the deflection in the galvanometer while the loud speaker is being activated. An operating key 21 is provided such that, at any desired moment, the loud speaker may be deactivated. This key at the same time removes voltage from the discharge circuit through the galvanometer which then proceeds to discharge with a definite decay rate determined by the resistance and capacity of the circuit. At the same time the sound which is still present in the room continues to send current through the galvanometer, but at a definite decay rate determined by the characteristics of the room. By suitable adjustment of the constants of the discharge circuit, the two currents through the galvanometer will be of the same magnitude, and will decay at the same rate, this condition being indicated by the fact that there is no deflection, momentary or permanent, of the galvanometer. The time constant of the electrical circuit can readily be calculated and, under conditions for which adjustments have been made, it will be apparent that the "time constant" or decay rate for the room will be proportional to that of the electric discharge circuit, and by simple transformation this may be converted into the reverberation period for the room. Having made the determinations at one frequency a proper operation of a selector key 23 will then change the frequency of the oscillator 5 and also correspondingly change the transmission band of the filter 13, whereupon determination of the constant at this new frequency may be made. Further details of the operation of this circuit will be given in connection with the description of Fig. 4.

Reference has been made to the importance of having a source of sound which shall not set up a fixed wave pattern in the room. We overcome the difficulty by use of a special form of vacuum tube oscillator which has a modulated output, preferably of an irregular form. When such a source is set up, however, it will be found to consist not only of the natural frequency of the oscillator, but of numerous harmonics spread throughout the audible frequency spectrum. Such a source is shown in Fig. 2 to be described below. It is essential, however, to limit the transmission of sound to the galvanometer to a small portion of the spectrum only, and it is in part for this reason that we introduce the band filter shown at 13 in Fig. 1. A second important function of the band filter is to discriminate against the noises which are present in a room when in normal use, and the presence of such a band filter makes it feasible to carry on measurements in a room in the presence of such general noise, permitting the decay of that portion of the sound which is being studied to proceed to a much further degree without the confusion which would arise if all room noise were transmitted through the receiving system. Thus, there is a definite cooperation between the source of warbling sound, the noise of the room, and the band filter in the receiving circuit.

Referring more specifically now to Fig. 2, there is shown one form of modulated oscillator which we find particularly satisfactory. This comprises a vacuum tube 30 having two grids, the one grid is connected to filament through the tuned circuit comprising condenser 31, and winding 32 of a three-coil transformer. This circuit is tuned to the audio frequency which is to be studied such, for example, as 1000 cycles. The second grid is connected to filament through a tuned circuit comprising the condenser 34 and second winding 35 of the transformer, tuned to a low frequency which may be in the neighborhood of 10 to 20 cycles per second, and finally, a feed-back connection from the plate to the filament is provided by the third winding 36 of the transformer. The plate of the tube is also connected to filament through B-battery 40 and primary of transformer 41, the secondary of which supplies the loud speaker 6 through an attenuating device 42 by means of which the volume of sound delivered by the loud speaker may be controlled. The bias of the first grid mentioned is controlled in part by a resistance 43, and that of the second grid by means of the condenser 44 and grid leak 45, and finally, the coupling of the output to the input circuits may be controlled by the feed-back resistance 46 and condenser 47 which latter is inserted to block the flow of direct current through its portion of the circuit. Such a circuit has the property that it will commence oscillating at the high frequency but will be periodically blocked at a frequency determined by the low frequency circuit. Also, the constants of the resistances and other elements, are such as to give large distortion, so that in addition to the oscillations of frequency for which the circuit is tuned, there will be numerous harmonics, many of these being of a frequency which differ from the tuned high frequency by a multiple of the low frequency.

The form of output which we derive from such an oscillator is illustrated in Fig. 3, showing the current through the transformer 41 as ordinates plotted against time as abscissæ and extending over a length *a—b*, the time of one cycle for the low frequency circuit. It will be observed that during a portion of this cycle the oscillator is blocked, and during the rest of the time a wave of very irregular amplitude or irregular envelope is established. This is a condition which we find particularly good for satisfactory results in measuring the characteristics of a room. The filter which should cooperate with such a source is one which will exclude all frequencies except those in the neighborhood of the band to be studied. It is important that the signals passing through the receiving system shall not be restricted to a single frequency such as would be the case were a sharply tuned circuit to be used, for the system would then behave as though a single frequency were being emitted and were setting up a definite wave pattern in the room. It is for this reason that a band filter of a definite width is desired. If the frequency of the oscillator is, say 1000 cycles, then the filter could very well be one passing the band from 900 to 1100 cycles.

Referring now to Fig. 4, to obtain a better understanding of certain features of our invention, the portion A corresponds to the circuit described in connection with Fig. 2. In this case, however, the oscillator is of a somewhat modified form comprising as it does, two tubes in tandem, the one of which B is the low frequency oscillator, and the other of which C is the high frequency oscillator. The first of these uses a series inductive feed-back to a tuned grid. This in an overloaded grid leak oscillator, and provides a distorted wave shape containing a high percentage of harmonics. The third winding of the transformer 50 is in series with the grid circuit of the oscillator C. This oscillator C is tuned to the mid-frequency of the operating band, say 1000 cycles, and is modulated by the low frequency oscillator. The type of grid cut-off modulation employed for this second oscillator provides a circuit in which the grid bias depends on the current flowing through the resistance 55 in series with the grid. The bias itself is not sufficient to block the grid but is reenforced by the voltage from the first oscillator to obtain this blocking action. The oscillator B, consequently, has control over the oscillator C, both as regards the blocking action which materially stabilizes the two, and the forcing of the tube to start more rapidly into oscillation after blocking, thus materially increasing the output from this tube. The increased stability also reduces the effect of load impedance on the performance of the oscillator. Leakage around the blocking condenser 56 is provided by the third winding of the transformer 50. Obviously, in case this leakage is not sufficient, a grid leak of appropriate value could be shunted around the condenser 56. A separate transformer 59 feeds the modulated output to the loud speaker 6 through a balanced constant impedance attenuator 60.

In general, it will be desirable to find the decrement at a number of different frequencies such, for instance, as 500 cycles, 1000 cycles and 1500 cycles. Accordingly, additional condensers 61 parallel to the condenser 57 may be provided to alter the frequency of the oscillator, and while we have shown but one such condenser 61 it is understood that there will be as many as necessary to provide for as many different frequencies as may be desired. These condensers may be introduced to the circuit by appropriate switches as shown in the drawing. Bridged across the terminals of the loud speaker 6 is a circuit 62 by means of which the loud speaker may be short-circuited.

The band-pass filter may be of any suitable form, the one which is shown herein being especially satisfactory. It will be observed that it consists of two sections of the ladder type of filter. In the first section the shunt element consists of capacity, and in the second section the shunt element consists of inductance, this filter having the property of giving equal attenuation on both sides of the band. As shown in the figure, the band which is passed by the filter can be shifted by parallel condensers, these parallel condensers being introduced by means of suitable switches, and being of such magnitude as to shift the band in accordance with the shift in the frequency of the oscillator C. And, in practice, we would find it desirable to operate all the necessary switches with one master key as shown at 23 in Fig. 1. The output of the filter is supplied to the primary of transformer 70 through a variable impedance matching network 71. The secondary of the transformer is connected to a full wave rectifier 73 of the exponential type, and in particular of a type in which the exponent shall remain constant throughout the operating range. One form which we have found particularly satisfactory is a so-called rectox, or copper oxide rectifier, which follows closely a square-law curve over a wide range. The rectifier output is supplied to the galvanometer 17. Also bridged across this galvanometer 17 is a discharge circuit comprising the condenser 74 and variable resistance 75. Voltage is supplied to the discharge circuit by battery 77 and potentiometer 79 through contacts of the relay 81.

The operation of the circuit may now be described as follows: Upon closing the key 82 of the relay 81, the short-circuit across the loud speaker 6 is removed, and the room becomes filled with an irregular warbling sound which is picked up by the receiver 8, amplified, filtered and applied to the rectifier 73. The rectified component therefrom flows through the galvanometer 17 tending to produce a deflection. The operation of the relay 81, however, closed circuit for battery 77 through the potentiometer 79, and also connected battery to one side of condenser 74. Thus, the condenser 74 is charged to a voltage given by the drop through a portion of the resistance 79. The current from the battery 77 through the galvanometer 17 flows through the potentiometer 75. The purpose of the potentiometer 75, which is varied simultaneously with the potentiometer 79, is to keep the current through the galvanometer 17 at approximately the same value independent of the setting of potentiometer 79. The direction of the current is so poled as to give a deflection in the opposite direction from that due to the sound source. By adjustment of the gain of amplifier 10 these deflections may be made equal so that the galvanometer shows zero deflection. With this adjustment the key 82 is now released, whereupon the loud speaker 6 is deactivated and battery is removed from the condenser. The sound in the room still continues to be received at 8 causing a current to flow through the galvanometer with a definite decay rate. The condenser 74 also discharges with its definite decay rate, and by adjustment of the resistance 75 these decay rates may be made equal to each other so that the galvanometer shows no deflection during the period of decay. This condition exists at least up to the time when the sound in the room is decayed to approximately that of the noise level of the room, whereupon a continued current will flow from the rectifier. But in general, the adjustments of the attenuator 60 and amplifier 10 are such that the desired adjustment is obtained before this condition has been reached, and in any event it will be so small as to be near the lower limit of sensitivity of the galvanometer.

The feature of having a rectifier with a uniform exponential characteristic we find to be of great importance, as is indicated by the following consideration. If we assume that the rectifier is one which follows a square-law curve, then the output current is approximately the same for an impressed sine wave or for a complex voltage having equal effective values, and is given by

$$I=\frac{1}{t_0}\int_0^{t_0} E^2dt=K_2E^2 \qquad (1)$$

where the integration is taken over the time limit t_0, and where K_2 is a proportionality factor. If the receiver 8 is either a velocity operated or a pressure operated device, then the output voltage of the receiver 8 or of the transformer 70 is

$$E_1=K_1S^{1/2} \quad (2)$$

where K_1 is a proportionality factor and S is the sound intensity at time (t).

When a sound source is cut-off in a room the sound decays according to the relation

$$\frac{S}{S_0}=e^{-ant} \text{ for live rooms} \quad (3)$$

and

$$\frac{S}{S_0}=e^{-\log(1-a)\,nt} \text{ for dead rooms} \quad (4)$$

Where S_0 is a sound intensity at time zero

a=the average absorption coefficient for the room.

$$n=\frac{cN}{4V}$$

N=total area of walls, ceiling and floor.

V=volume of room.

Both expressions are of the form

$$\frac{S}{S_0}=e^{-At} \quad (5)$$

Reverberation time T is defined as the time during which the original sound intensity is reduced by 10^6 when the source is cut off, hence

$$T=\frac{1}{A}\log_e 10^6=\frac{13.8}{A} \quad (6)$$

The voltage output of the pick-up at any instant during the decay of the tone would then from (2) be

$$E_1=E_0e-\frac{At}{2} \quad (7)$$

where E_0 is the voltage at time zero.

The amplifier has no effect on the form of the above equation. Hence, the rectifier output is from (1)

$$I=I_0e^{-At} \quad (8)$$

The current at any instant during the discharge of a condenser C through resistance R is given by

$$I'=I_0'e-\frac{t}{RC} \quad (9)$$

The adjustment of the discharge circuit is determined by the condition that the current through the meter from the condenser shall balance the current from the rectifier before and during the decay period, whence

$$\frac{I}{I_0}=\frac{I'}{I'_0} \quad (10)$$

Substituting Equations (8) and (9) in (10) we obtain the condition

$$A=RC \quad (11)$$

whence

$$T=\frac{13.8}{RC} \quad (12)$$

Thus, it is seen, that a determination of the reverberation period is obtained through the measurement of a resistance and a condenser. It should be pointed out that it is not necessary to have a rectifier obeying the square-law relationship. The only condition is that the rectifier shall be an exponential one, the exponent remaining a constant. If, for instance, the Equation (2) had been of the form

$$I=K_2E^b \quad (13)$$

where b is a constant, the treatment would have been the same and Equation (11) would have taken on the form

$$A=\frac{2RC}{b} \quad (14)$$

from which again the period of reverberation may be readily obtained.

It will be observed that a system has been devised which can be made in a very compact form and thus be readily portable. Also, that the operation has been reduced to one of great simplicity requiring the operation of but two keys, one the frequency selector key as shown at 23 in Fig. 1, and the other the operating key 21. The introduction of the filter makes it possible to take readings in a room in spite of high noise level, it being only necessary in such event to decrease the loss in the attenuator 60 to such an extent that the volume of sound given off by the loud speaker shall exceed that of room noises by a certain amount. By the introduction of a corresponding amount of attenuation in the amplifier 10, the signal volume at the rectifier may be kept to substantially the same level, and the necessary ratio of signal to noise be maintained. In general, we find it desirable to operate the loud speaker 6 at as low a volume as is feasible, and still give reliable readings, that is, no deflection of the galvanometer in a length of time corresponding to an appreciable portion of the reverberation period.

What is claimed is:

1. In an acoustic decremeter adapted to cooperate with a warbling source of sound, the method of finding the acoustic decrement of a room which consists in electrically receiving and amplifying the sound, filtering out all frequencies except those to be measured, rectifying the electrical sound wave, and comparing the rectified sound decay current with an electrical discharge decay current.

2. In an acoustic decremeter, the method of measuring the reverberation period which consists in generating a warbling source of sound in the presence of noise, electrically receiving and amplifying the sound and noise, filtering out all frequencies except those to be measured, rectifying the electrical sound wave, balancing the rectified current against a constant direct current, deactivating the source of sound, and balancing the decaying sound current against an electrical discharge decaying current.

3. In an acoustic decremeter adapted to cooperate with a source of sound, the combination of a reciever and a rectifier of uniform exponential characteristics connected to said receiver, an electrical discharge circuit of known damping constant, and means connected to the said rectifier and also to said discharge circuit for comparing the rectifier current with the discharge circuit current.

4. In an acoustic decremeter adapted to cooperate with a source of sound, the combination of a receiver and a rectifier of uniform exponential characteristics, an electrical discharge circuit of known damping constant, a differential galvanometer associated with the rectifier and with the discharge circuit, and adapted to compare the two currents.

5. In an acoustic decremeter adapted to co-

operate with a source of sound, the combination of a receiver and a rectifier of uniform exponential characteristics, an electrical discharge circuit of known damping constant, a differential galvanometer associated with the rectifier and with the discharge circuit, and means for adjusting the damping constant of the discharge circuit to a value such that the two circuits feeding into the galvanometer yield a zero deflection.

6. In an acoustic decremeter adapted to cooperate with a source of sound of variable frequency, the combination of a receiver, a wave filter and rectifier feeding into a differential galvanometer, an electrical discharge circuit of known damping constant also feeding into the galvanometer, and means for adjusting the damping constant of the discharge circuit to a value such that the two circuits feeding into the galvanometer yield a zero deflection.

7. In an acoustic decremeter adapted to cooperate with a warbling source of sound, the combination of a receiver, a rectifier, a wave filter connected between said receiver and said rectifier, an electrical discharge circuit of known damping constant, and means connected to said rectifier and said discharge circuit for adjusting the damping constant of the discharge circuit to the damping constant of the rectifier output.

8. In an acoustic decremeter adapted to cooperate with a warbling source of sound, the combination of a receiver, a wave filter and rectifier of uniform exponential characteristic, an electrical discharge circuit of known damping constant, a galvanometer associated with the rectifier and discharge circuit, means for supplying voltage through the discharge circuit to the galvanometer of such magnitude as to neutralize in the galvanometer the current from the rectifier while a source of sound is activated, and means for adjusting the time constant of the discharge circuit to a value such that the decaying current of the discharge circuit is of the same value as the decaying current from the rectifier.

9. In an acoustic decremeter adapted to cooperate with a warbling source of sound, the combination of a receiver, a rectifier and means connected between said receiver and said rectifier for discriminating against room noise, an electrical discharge circuit of known damping, and means connected to said rectifier and said discharge circuit for adjusting the damping constant of the discharge circuit to the damping constant of the rectifier output.

10. In a system for determining acoustic decrement, a warbling source of sound, means for altering the frequency level of the source of sound, a receiver for said sound, a filter for passing a predetermined portion of the incident sound and means for altering this filter in accordance with the alteration of the frequency level of the sound source, a rectifier associated with the receiver, an electrical discharge circuit of known damping constant, and means for comparing the damping constant of the discharge circuit with the damping constant of the rectifier output.

11. In a system for determining acoustic decrement, a source of warbling sound comprising a vacuum tube oscillator of relatively high frequency, a vacuum tube oscillator of relatively low frequency so associated that the first named oscillator acts to cause blocking of itself at a frequency equal to that of the second oscillator, a receiver of said warbling sound having associated therewith a rectifier of uniform exponential characteristics, an electrical discharge circuit of known damping constant, and means for comparing the rectifier current with the discharge circuit current.

12. In a system for determining acoustic decrement, a source of warbling sound comprising a vacuum tube with two grids, a high frequency tuned circuit across one grid input, a low frequency tuned circuit across the second grid input, a coupling connection from the plate circuit to each of the tuned circuits, the coupling so adjusted that the tube oscillates at high frequency but blocks periodically at low frequency, a receiver adapted to receive said warbling sound and having associated therewith a wave filter and rectifier for selecting and rectifying a predetermined portion of said warbling sound, an electrical discharge circuit of known damping constant, and means for comparing the rectifier current with the discharge circuit current.

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