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ELECTROACOUSTICAL SYSTEM

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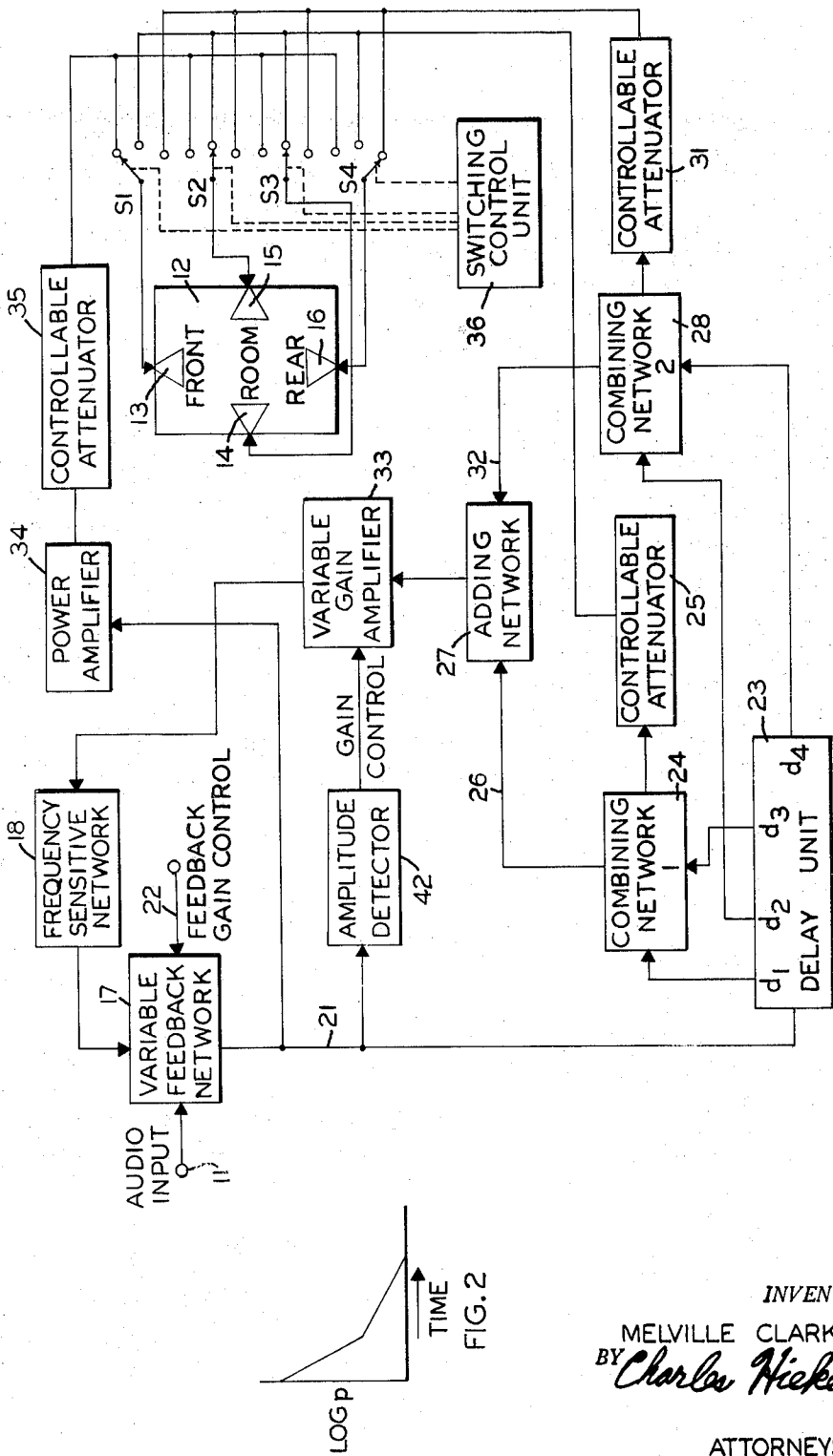


FIG. 1

FIG. 2

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ELECTROACOUSTICAL SYSTEM  
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The present invention relates in general to electroacoustical systems and more particularly concerns sound reproduction apparatus for controlling the apparent size of the acoustical environment. More specifically, the present invention is concerned with artificially creating the effect of large room acoustics in a small listening room.

It is known that artificially reproducing sound originally recorded in a large auditorium in a small room does not have the same character as the original sound. One reason for this is due to the difference between the reverberation characteristics of a large auditorium and those of a small listening room.

Accordingly, it is an important object of the present invention to provide methods and means for simulating the acoustical environment of a large auditorium in a small listening room.

It is another object of the invention to achieve the preceding object with a relatively small amount of apparatus.

It is a further object of the invention to control the apparent location of the sound source.

Still another object of the invention is to provide means for artificially introducing amplitude-sensitive and/or frequency-sensitive reverberation.

Still a further object of the invention is to effect almost instantaneous changes in the apparent size of the listening area.

Another object of the invention is to provide means for regulating the apparent acoustical environment of the listening area to compensate for audiences of different sizes.

According to the invention, the apparent acoustic environment surrounding a listener in a small room is altered by suitably artificially reverberating the signal applied to at least one electroacoustical transducer located in the room.

More specifically, a source of an electrical audio input signal is combined with a feedback signal to provide a combined signal. The combined signal is delayed to provide a delayed combined signal which is applied to the electroacoustical transducing means and additionally utilized to derive the feedback signal.

In a specific embodiment of the invention, loudspeakers are located at the front, rear and sides of the room and suitably artificially reverberated signals are applied to the different loudspeakers.

Another feature of the invention resides in the provision of means responsive to the combined signal amplitude for effectively altering the artificially introduced reverberation decay rate so that the latter rate is extended when the sound is faint.

Other features, objects and advantages of the invention will become apparent from the following specification when read in connection with the accompanying drawing in which:

FIG. 1 illustrates the logical arrangement of a system according to the invention; and,

FIG. 2 is a graphical representation of the decay rate of a room.

With reference now to the drawing and more particularly FIG. 1 thereof, there is illustrated the logical arrangement of a system according to the invention. To avoid obscuring the principles of the invention and

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since specific circuits for performing the functions of the different system components are well-known in the art, details of such circuits are not shown in the drawing.

The specific embodiment of the invention is especially useful in connection with a novel electronic musical instrument described in a paper entitled Proposed Keyboard Musical Instrument by Melville Clark, Jr., in the Journal of the Acoustical Society of America for April 1959, at 403-419. However, the principles and structure disclosed herein are suitable for use in connection with reproducing any type of recorded sound.

An audio input signal is applied to the audio input terminal 11 and reproduced with artificially introduced reverberation in the room 12 by the loudspeakers 13-16. The source of the audio input signal may be a tone generator or a recorded signal from a tape or disc. This signal is applied to the input of a variable feedback network 17 which combines the audio input signal with a feedback signal delivered through frequency sensitive network 18 to provide a combined output signal on line 21. The relative ratio between the feedback signal and the audio input signal in the combined signal on line 21 is determined by a feedback gain control signal applied to line 22. Its function will be considered in greater detail after first discussing the physical arrangement of the system.

The combined signal on line 21 is applied to a delay unit 23 which delays the combined signal by four different increments at the taps  $d_1$ ,  $d_2$ ,  $d_3$  and  $d_4$ , respectively. First and second delayed combined signals derived from the taps  $d_1$  and  $d_3$ , respectively, are combined in a first combining network 24 to provide a side combined delayed signal coupled through controllable attenuator 25 for application to side loudspeakers 14 and 15 when switches S2 and S3 are connected as shown. Substantially the same signal is delivered on line 26 to adding network 27.

The delay unit 23 also provides third and fourth delayed combined signals from taps  $d_2$  and  $d_4$ , which are applied to the second combining network 28 to provide a rear delayed combined signal which is coupled through controllable attenuator 31 to the rear loudspeaker 16 with switch S4 connected as shown. Substantially the same signal is provided on line 32 and combined with the side combined delayed signal on line 26 in adding network 27 to provide a sum signal which is applied to the variable gain amplifier 33, the output of the latter being applied to frequency sensitive network 18.

The gain of the variable gain amplifier 33 is controlled by the gain control signal provided by amplitude detector 42. This gain control signal is monotonically related to the amplitude of the combined signal on line 21. The combined signal on line 21 is also delivered to the front loudspeaker 13 through a power amplifier 34 and controllable attenuator 35 when switch S1 is connected as shown.

Having described the physical arrangement of a specific embodiment according to the invention, it is appropriate to consider the principles of operation. In a large auditorium, the sound from the stage reaches the listener directly and via reflections from the different walls of the auditorium. The time intervals between the arrival of the direct sound and the different reflections is random and complex. For example, one reflected signal reaches the listener after bouncing from the rear wall. Other signals reach the listener after reflection from the side walls. Still other signals reach the listener after reflection from the side walls, the rear wall and front wall. Thus, the actual signal which a listener hears approaching from the front of the auditorium includes the combination of a direct wave with complex reflected waves.

The system of FIG. 1 approximates such a signal in the

combined signal delivered to the front loudspeaker 13. The combined signal on line 21 includes the audio input signal on terminal 11 together with a portion of the feedback signal delivered on line 18. By decreasing the feedback gain, the effective reverberation time is reduced because the attenuation per circulation through the loop including the delay unit 23 is correspondingly increased. Thus, by controlling the feedback gain with the signal on line 22, the apparent reverberation time of the listening area may be controlled. External control of this reverberation time is desirable, especially when the system is used in association with a musical instrument, for the performer can control the apparent environmental characteristics to create a desired musical effect, such as *sostenuto*.

In a similar manner, the variable gain amplifier 33 controls the reverberation time by controlling the gain in the feedback loop. For large amplitude signals, a shorter reverberation time is normally desired and the amplitude detector 42 provides a gain control signal effective in reducing the gain under these conditions. On the other hand, when the audio signal is soft, an increase in reverberation time is desired and the gain is accordingly increased.

The amplitude detector 42 may comprise frequency selective means for causing the gain control signal to depend upon the amplitude of spectral components within a certain frequency range more than those in a different range. Means may also be provided for controlling this dependence by using adjustable attenuators or other suitable means.

The variable feedback network 17 may take numerous forms, both active and passive. For example, it may comprise a resistive adder and the feedback gain control may be a variable resistance in series with the node where the feedback signal is summed with the audio input signal. Alternatively, the variable feedback network may comprise separate electron tubes having a common cathode load impedance, the signals being applied to respective grids of the tubes. The feedback gain control could then be merely an attenuator which couples the feedback signal to the grid of its associated electron tube. Numerous other variable feedback networks may be used within the scope of the invention.

The variable gain amplifier 33 might be a remote cutoff pentode with amplitude detector 42 being a conventional diode detector providing a negative bias for the grid of the pentode, the bias magnitude being monotonically related to the amplitude of the signal applied to the amplitude detector. The gain would then be reduced for strong signals.

It will be recognized from the arrangement of the delay unit taps that the mean delay furnished for the signal used to excite the side loudspeakers 14 and 15 is greater than that furnished for the signal used to excite the front loudspeaker and less than that furnished for the signal utilized to excite the rear loudspeaker with the switches positioned as shown. Note, however, that the signal utilized to excite the side loudspeakers has a component which is delayed more than a component utilized to excite the rear loudspeaker. The latter component furnished with more delay corresponds to a signal which has bounced off the rear wall and is just reaching the listener effectively from the side, the direct reflection from the rear wall corresponding to the signal of slightly less delay radiated directly from the rear loudspeaker.

The delay unit 23 may take numerous different forms, such as a lumped parameter delay line, a magnetic tape or drum unit with read out heads following the recording head and each corresponding to a tap of the delay unit. Alternatively, helical springs and acoustic pipes with appropriate taps may be used to impart the desired delay. Since these different units are well-known in the art, their specific form is not shown in detail herein. However, it is preferred that the maximum delay increment  $d_4$  corre-

spond substantially to the time required for a sound wave to travel twice the length of a typical large auditorium. FIG. 2 shows the logarithm of pressure as a function of time in which the overall room decay rate is approximated by two different decay rates.

Each combining network may comprise a preamplifier and a power amplifier to convert the output signal from the delay unit into a signal at a sufficiently high power level to drive the associated loudspeakers. Resistive adders may be used to combine the signals at the different delay unit taps. Alternatively, if the taps correspond to spaced readout heads scanning a magnetic medium, the output signals from the different readout heads may be connected in series and utilized to energize a common preamplifier stage.

An improvement in performance over a system without artificial reverberation will be effected if the variable gain amplifier 33 is a fixed gain device and only the front speaker 13 is employed, for the listener will perceive the effect of both the direct and rereflected audio signal. Of course, better results are obtained if the side loudspeakers and the rear loudspeaker with their associated system components are employed.

As indicated above, the rate of decay is determined by the amplitude and delay of the reverberation signal. Although in actual auditoriums there are many modes, each usually decaying with its individual rate, the overall decay can be satisfactorily approximated with only two rates as in the system of FIG. 1. However, as many multiple decay rates as desired can be provided by connecting a number of delay units like delay unit 23 in parallel, each with its associated auditorium echo transducers and combining networks, one unit for each mode. Also, a single delay unit having more taps and additional combining networks may be employed.

It is known that the reverberation time of a given room is frequency sensitive. This frequency sensitivity is simulated by the use of the frequency sensitive network 18 in the feedback loop. The loop gain as a function of frequency may be selected to cause different decay rates for spectral components of different frequencies. The network itself may comprise a crossover network having a number of parallel channels transmitting adjacent segments of the audio spectrum, each channel preferably having its own gain control to permit selective alteration of the relationship between frequency and decay rate.

An artificially reverberated component of the combined signal derived from combining the original signal with the fed back signal decays approximately exponentially with a time constant

$$T = \frac{T_d}{(g-1)}$$

where  $T_d$  is the delay furnished to fed back portions of that component and  $g$  is the fraction of the original signal fed back. Thus, varying the gain at any point in the feedback loop effectively varies  $g$  which in turn controls the decay rate.

The apparatus shown in FIG. 1 is adaptable for producing a number of effects. The gain may be controlled in the combining networks in addition to the other points in the feedback loop mentioned above. This is advantageous because a fast decay rate of the residual signal at late times may be introduced.

The switching control unit 36 may be used to change the arrangement of signals directed to the different loudspeakers. This feature may be used to change the apparent location of the sound source. Thus, the front and rear speakers could receive the signals shown in FIG. 1 being directed to the side speakers while the side speakers could respectively receive the signals being directed to the front and rear speakers. Random and sequential switching could be employed to create new musical effects.

The use of staggered and unequal delays between taps of the delay unit is advantageous in simulating the random intervals between direct and reflected signals which arrive at a point in an auditorium. This also minimizes the effects of destructive interference. It is preferred that the delays furnished be less than 0.05 second to prevent audible echos.

Still another feature resides in the provision of the controllable attenuators for permitting the signal levels at the different speakers to be independently adjusted. A desirable effect may be created by increasing the signal level to the side speakers while increasing the signal level to the front speaker by a lesser amount. As the sound level in the room increases, the apparent source of the sound appears to expand from a point at the center of the room to a region extending across the front wall. This effect is especially pronounced if the side loudspeakers are moved into the corners adjacent to the front wall.

It is apparent that those skilled in the art may now make numerous other modifications of and departures from the specific embodiments and techniques described herein without departing from the inventive concepts. Consequently, the invention is to be construed as limited only by the spirit and scope of the appended claims.

What is claimed is:

1. Electroacoustical apparatus comprising, a source of an electrical audio input signal, means for combining said audio input signal with a feedback signal to provide a combined signal including a component conforming to said audio input signal, means for delaying said combined signal to provide a delayed combined signal, means defining a feedback signal path and responsive to said delayed combined signal for providing said feedback signal, said feedback signal being related to said delayed combined signal, transducing means responsive to an electrical signal for exciting corresponding pressure variations in an acoustical medium, and means introducing a delay of substantially zero for coupling only said combined signal to said transducing means.

2. Electroacoustical apparatus in accordance with claim 1 and further comprising, means responsive to the amplitude of said combined signal for controlling the magnitude of said feedback signal.

3. Electroacoustical apparatus in accordance with claim 1 and further comprising, means for controlling the relative ratio between said feedback signal and said audio input signal in said combined signal.

4. Electroacoustical apparatus in accordance with claim 1 and further comprising, second and third transducing means responsive to an electrical signal for exciting corresponding pressure variations in said acoustical medium, said delay means delaying said combined signal by first and second different increments to provide first and second delayed signals, said first-mentioned transducing means adapted for location in the front of a room, said second and third transducing means adapted for location at opposite sides of said room, means for combining said first and second delayed signals to provide a side delayed combined signal, means for coupling said side delayed combined signal to said second and third transducing means, said side delayed combined signal forming in part said delayed combined signal.

5. Electroacoustical apparatus in accordance with claim 4 and further comprising, fourth transducing means responsive to an electrical signal for exciting corresponding pressure variations, said fourth transducing means adapted for location in the rear of said room, said delay means delaying said combined signal by a third increment intermediate said first and second increments and a fourth increment greater than either of said first and second increments to provide third and fourth delayed signals, means for combining said third and fourth delayed signals to provide a rear delayed combined sig-

nal, means for coupling said rear delayed combined signal to said fourth transducing means, and means for combining said side delayed combined signal and said rear delayed combined signal to provide said delayed combined signal.

6. Electroacoustical apparatus in accordance with claim 5 and further comprising, variable gain means responsive to said delayed combined signal for providing said feedback signal, and means responsive to the amplitude of said combined signal for controlling the gain of said variable gain means.

7. Electroacoustical apparatus in accordance with claim 6 and further comprising, means for controlling the relative ratio of feedback signal to audio input signal forming said combined signal.

8. Electroacoustical apparatus in accordance with claim 1 and further comprising, a frequency sensitive network in said feedback signal providing means for establishing a relationship between the amplitude of spectral components in said feedback signal and the frequency of said components.

9. Electroacoustical apparatus in accordance with claim 4 and further comprising, means for simultaneously adjusting the signal level at said second and third transducing means while adjusting the signal level at said first transducing means so that the former signal level increases at a rate greater than that of the latter signal level.

10. Electroacoustical apparatus comprising, a source of an electrical audio input signal, means for combining said audio input signal with a feedback signal to provide a combined signal including a component conforming to said audio input signal, means for delaying said combined signal to provide a plurality of different delayed combined signals, means defining a feedback signal path and responsive to said delayed combined signals for providing said feedback signal, said feedback signal being related to said delayed combined signal, a plurality of transducing means each responsive to an electrical signal for exciting corresponding pressure variations in an acoustical medium, and switching means for selectively delivering said combined delayed signals to said plurality of transducing means and delivering said combined signal without delay to at least one of said transducing means.

11. Electroacoustical apparatus in accordance with claim 10 wherein said plurality of transducing means are spaced about a listening area, and means for operating said switching means to change the order of said delayed combined signals delivered to said plurality of transducing means to change the apparent location of the sound source in said listening area.

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