

Sept. 13, 1966

A. J. DE VRIES ETAL
AUDIO REPRODUCTION SYSTEM

3,272,906

Filed Oct. 25, 1960

3 Sheets-Sheet 1

FIG. 1

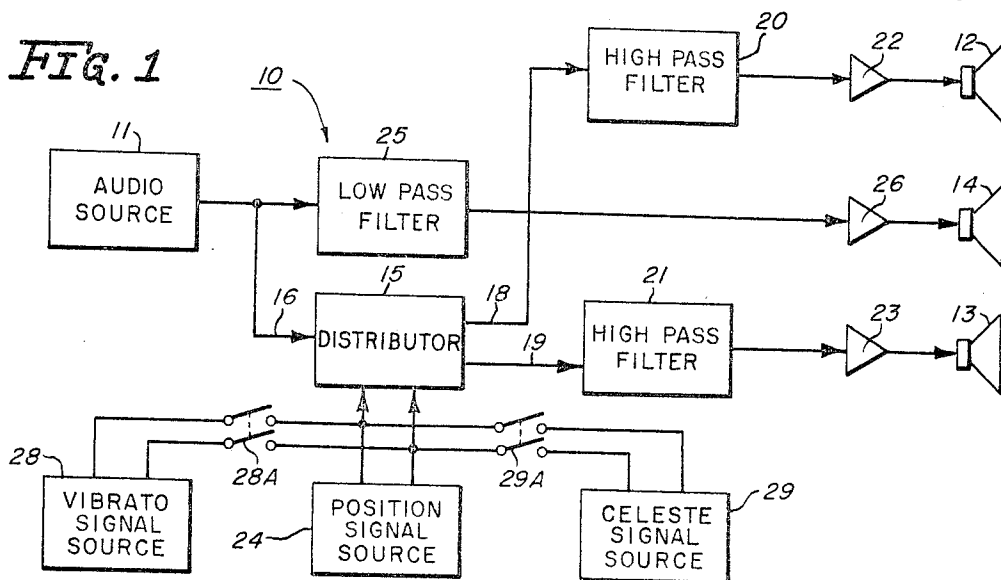
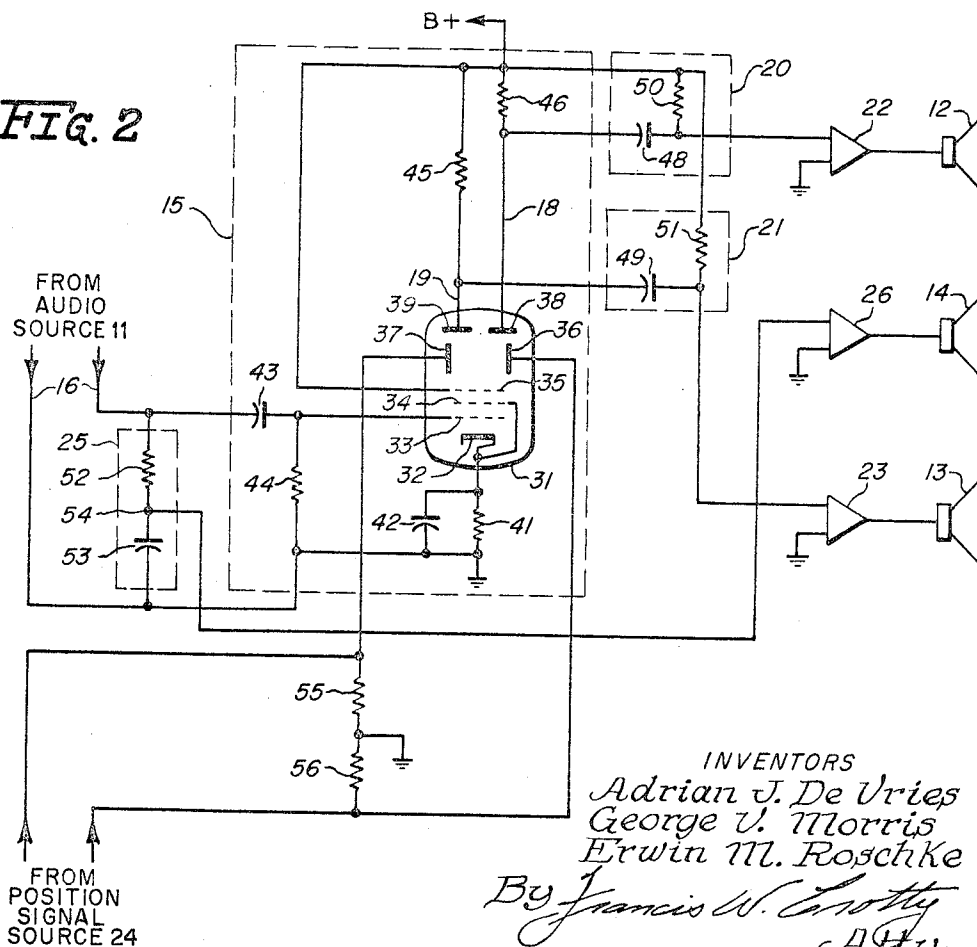


FIG. 2



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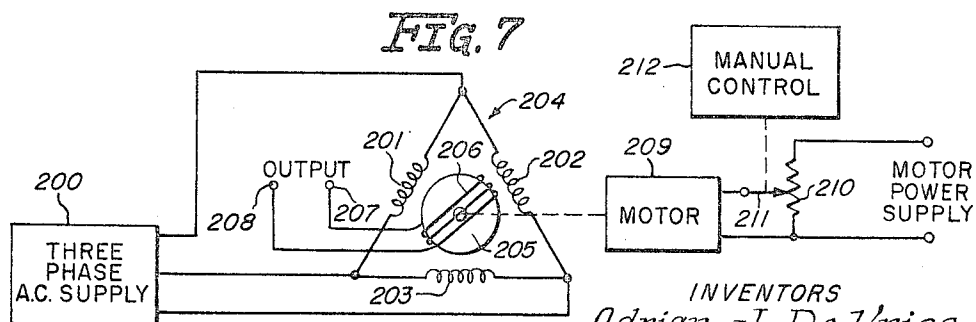
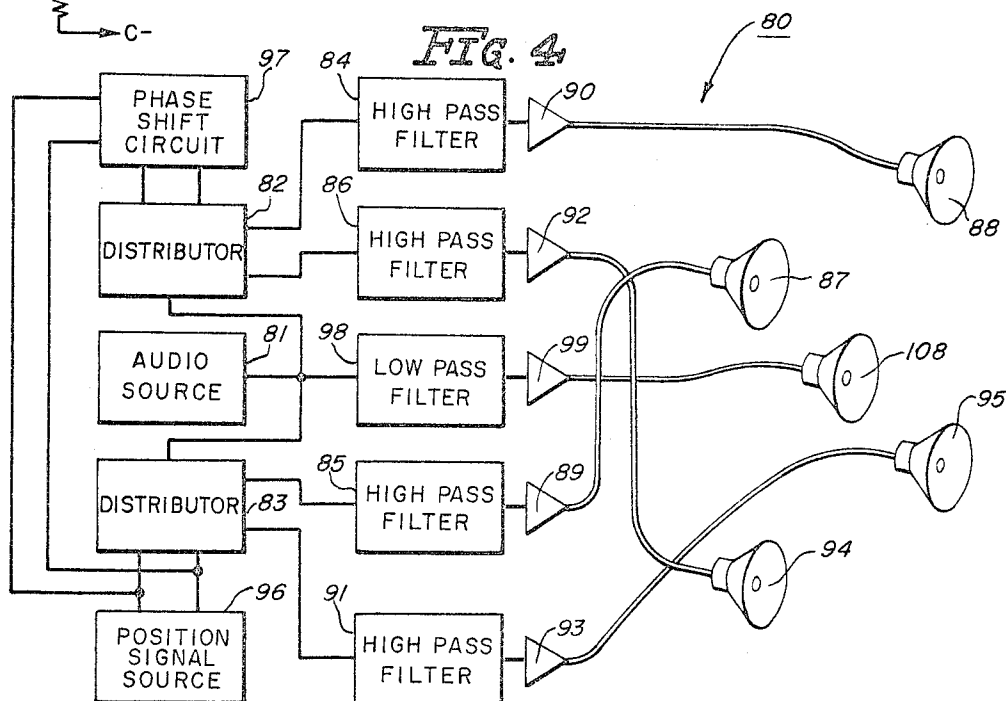
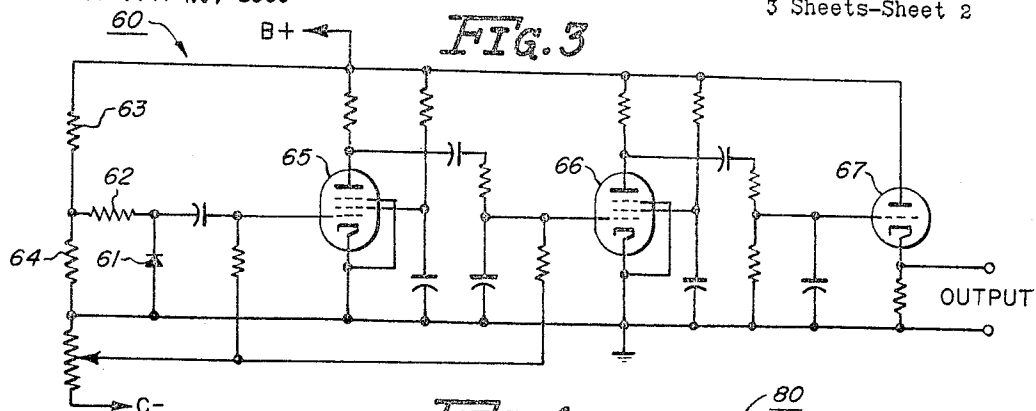
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

FIG. 5

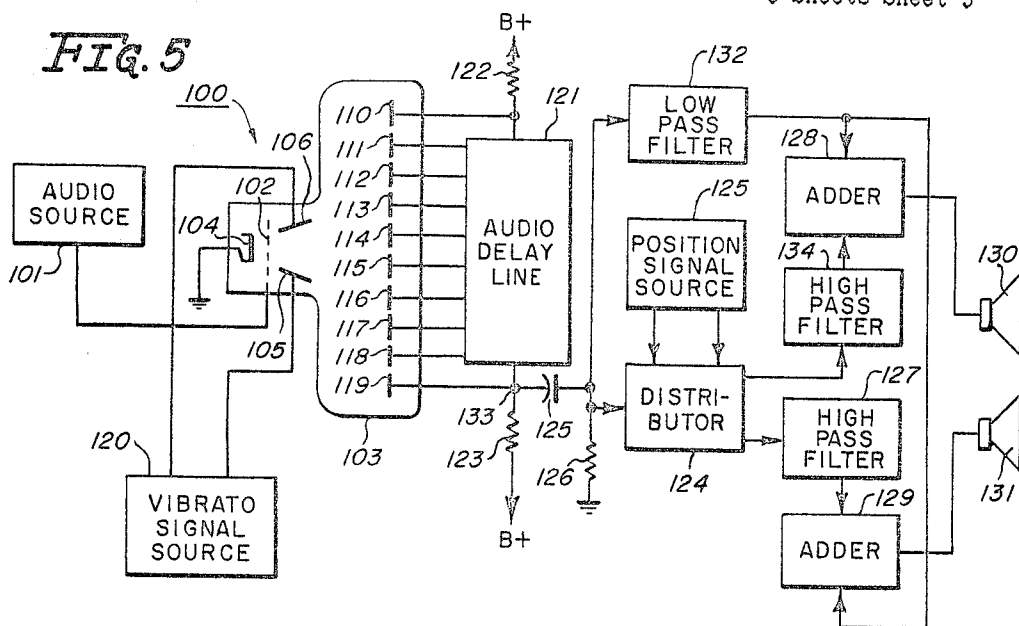
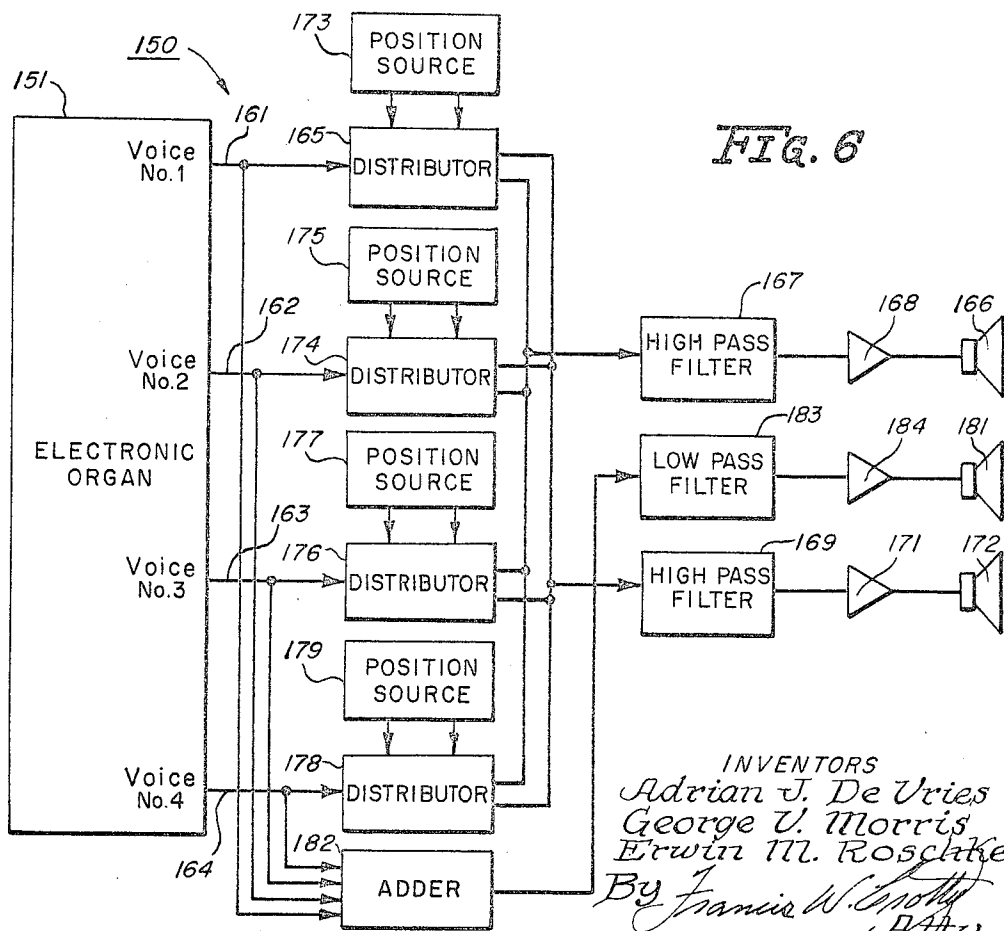


FIG. 6



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3,272,906

AUDIO REPRODUCTION SYSTEM

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Filed Oct. 25, 1960, Ser. No. 64,762
12 Claims. (Cl. 84-1.25)

This invention relates to a new and improved audio reproduction system for electrical musical instruments such as electric organs, record players, radios and the like. In particular, the invention relates to an audio reproduction system which produces pleasing stereophonic and chorus, celeste and vibrato effects in the reproduced sound.

In the operation of electric musical instruments there is substantial difficulty in reproducing exactly the total audio effect produced by corresponding instruments of more conventional type. The electrical instruments usually seem to lack a richness or depth of tonal quality present in the conventional instrument which they are intended to simulate. A prime example of this is the electronic organ, in which the tonal quality, as compared with the conventional pipe organ, is usually relatively "flat." The difference, in effect, between the two instruments is probably due in part to the fact that the tones from the pipe organ emanate from a multiplicity of individual sources separated in space from each other; in the following specification, this tonal effect is referred to as the "spacial effect" or "position effect" for lack of more precise terms. Another contributing factor to the difference between the two instruments is that the tones produced by the electronic organ are usually based upon a limited number of original sources, so that the multiplicity of minor beat signals produced by sounds from the individual pipes of a pipe organ are not present in the output of the electric organ. Hereafter, this particular effect is referred to as the chorus effect. Similar deficiencies are present in other electrical and electronic instruments including record players, radios, and the like, although the difference is most pronounced in the case of the electronic organ.

In musical reproduction, it is often desirable to introduce some low-frequency amplitude or phase modulation, or both, to avoid a generally "flat" and lifeless sound. When the rate of modulation is in the range of five to ten cycles per second, the resulting effect is one of vibrato, and is so identified hereinafter. It is also desirable, in at least some electrical musical instruments, to introduce a similar modulation at a lower frequency. This produces a pleasing "singing" effect referred to, in the case of an organ, as a "celeste" effect. Hereinafter, when the modulation frequency is in the range of two to five cycles per second, the resulting effect is referred to as "celeste."

A number of different mechanical systems have been proposed, heretofore, to introduce effects equivalent to the aforementioned position, chorus, vibrato and celeste effects in the output of electrical musical instruments. For example, in some systems the audio signals to be reproduced are applied to a plurality of speakers and rotating baffles are mounted in front of the speakers to change the apparent source of the sound and thereby simulate, at least to some extent, the spacial effect produced by a pipe organ or a large orchestra. Other systems have used rotating speakers or other similar mechanical arrangements. Although some of these mechanical systems have been relatively effective in operation, they leave much to be desired with respect to compactness and compatibility with otherwise substantially fully electronic instruments. Thus, in one known system which affords relatively pleasing tone effects, a plurality of loudspeakers are mounted upon a rotatable baffle of substantial size, and this entire

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assembly is rotated to produce the desired position, vibrato, or celeste effects. This requires a large and bulky speaker assembly and introduces a number of mechanical problems in an instrument of practical size.

It is an object of the invention, therefore, to provide a new and improved audio reproduction system, suitable for use in electrical musical instruments such as electronic organs, record players, and the like, in which the illusion of sound emanating from a plurality of sources, with individually distinguishable changes between the sources, is effected by essentially completely electronic means. That is, it is an object of the invention to achieve a spacial effect and chorus effect in the output of an electrical musical instrument by means of purely electrical and electronic apparatus without requiring a mechanical arrangement for moving the actual speakers or other audio reproduction devices.

Another object of the invention is to provide an improved vibrato effect in an audio reproduction system, using entirely electronic means.

Another object of the invention is to simulate the effect of moving sound sources in order to add a celeste effect to the output of an audio reproduction system, using only electronic means, without introducing undesirable low-frequency transient signals into the output of the system.

A further object of the invention is to utilize the same basic apparatus for the introduction of a spacial effect, a vibrato effect, a chorus effect and a celeste effect into the output of an audio reproduction system.

Another object of the invention is to provide a new and improved audio reproduction system which permits an electronic organ to simulate more closely the gross tonal effects of a pipe organ without requiring mechanical movement of the speakers or of other sound-directing means, such as baffles, associated therewith.

A corollary object of the invention is to provide a new and improved audio reproduction system which permits convenient and effective control of spacial, chorus, celeste or vibrato effects by the user.

A further object of the invention is to provide a new and improved audio reproduction system which produces an unusual and pleasing stereo effect using purely electronic means.

A corollary object of the invention is to provide a new and improved audio reproduction system capable of realizing all of the above-noted objects but which is simple and economical in construction.

An audio reproduction system in accordance with the teachings of the subject invention comprises a source of audio signals and a plurality of individual audio reproduction devices such as loudspeakers. Means are provided for utilizing the audio signals to energize these speakers and this utilizing means includes at least one electric discharge device responsive to an applied control signal to control the relative intensity of sound reproduction by the speakers. Means are provided for developing a first control signal having a frequency in the low-frequency portion of the audio spectrum and for developing a second control signal also having a frequency in the low-frequency portion of the audio spectrum but higher in frequency than the first control signal. Finally, the system includes means for applying second control signal to the utilizing means for effecting a predetermined amplitude variation in the audio signals at the frequency of the first control signal to vary the effective dominant source of sound reproduced by the loudspeakers and for concurrently applying the second control signal to the utilizing means for effecting a predetermined amplitude variation in the audio signal at the frequency of the second control signal to produce a vibrato or celeste subjective listening effect.

Further aspects of the invention include a random signal generator for varying the dominant source of sound between the loudspeakers in a random fashion and means to avoid a "swimming" effect attributable to the shifting of low frequency audio components between the loudspeakers.

The features of this invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood, however, by reference to the following description taken in conjunction with the accompanying drawings, in the several figures of which like reference numerals identify like elements, and in which:

FIGURE 1 is a block diagram of an audio reproduction system constructed in accordance with one embodiment of the present invention;

FIGURE 2 is a detail schematic diagram of the distributing means, amplifiers and speakers employed in the audio reproduction system of FIGURE 1;

FIGURE 3 is a detail schematic diagram of a control signal source which may be employed in the embodiment of FIGURE 1;

FIGURE 4 is a block diagram of another embodiment of the present invention;

FIGURE 5 is a block diagram of an additional embodiment of the invention;

FIGURE 6 is a block diagrammatic representation of a further embodiment of the invention as applied to an electronic organ; and

FIGURE 7 illustrates a control signal source which may be used with any of the various embodiments of the invention.

FIGURE 1 illustrates an audio reproduction system 10 constructed in accordance with the present invention and suitable for use in conjunction with an electronic organ or other electrical musical instrument. The system 10 comprises an audio source 11; in an organ, audio source 11 may be considered to represent all of the various oscillators, filters, formant circuits, and other apparatus employed in the organ to produce audio signals suitable for reproduction by the speakers or other audio reproduction devices of the organ. Audio reproduction system 10 further includes a plurality of audio reproduction devices represented by three speakers 12, 13 and 14. Speakers 12 and 13, which are spaced apart from one another and are located on opposite sides of speaker 14, are utilized for reproduction of the high-frequency components in the audio signals produced by audio source 11, as explained in greater detail hereinafter. Speaker 14, on the other hand, is employed to reproduce the low-frequency portion of the output from audio source 11.

The audio reproduction system of FIGURE 1 includes means for utilizing the audio signals from source 11 to energize the several speakers 12-14 and this means includes at least one intensity-control device for controlling the relative intensity of sound reproduction particularly of speakers 12 and 13. A variety of arrangements for so controlling speakers 12 and 13 will occur to those skilled in the art. It is also convenient to precede the amplifiers driving such speakers by a distributor including an electric discharge device to vary the relative amplitudes of the audio signals as delivered through the distributor to the two speakers. For convenience, this latter arrangement has been represented in FIGURE 1.

More particularly the arrangement includes a distributing means 15 for applying audio signals from source 11 to speakers 12 and 13. This distributing means includes an input circuit generally designated by the reference numeral 16 and a pair of output circuits 18 and 19. Distributor 15 is provided with a switching or distributing circuit including at least one electric discharge device responsive to an applied control signal for controlling the relative amplitudes of the audio signals translated from

its input circuit 16 to its two output circuits 18 and 19. Output circuit 18, which couples the distributor to speaker 12, includes a high-pass filter 20 and a suitable amplifier 22. Similarly, output circuit 19 of distributor 16 comprises a high-pass filter 21 and an amplifier 23 and effectively couples the distributor to the remaining speaker 13. Thus, each of the output circuits 18 and 19 is provided with means for attenuating the low-frequency components of audio signals translated through distributing means 15 to speakers 12 and 13.

The control of the electric discharge device included in distributor 15 is exercised by a signal developed in a position-signal source 24 that is coupled to distributor 15. Position signal source 24 may comprise a very-low-frequency oscillator having an output signal of essentially sinusoidal wave form. On the other hand, and as discussed in greater detail hereinafter, the position signal source may comprise a source of random signals restricted to low frequencies and derived from a random noise signal; a particular circuit of this kind is described in detail in connection with FIGURE 3. Other types of signal source may be employed, and provision may be made for controlling the frequency of the position signal developed by source 24 in response to manual actuation of a key or other mechanical control means. Position signal source 24 is coupled to distributor 15 to control operation of the distributor.

Speaker 14 is not connected to distributor 15. Instead, this speaker is directly coupled to audio source 11 through a coupling circuit comprising a low-pass filter 25 and a suitable amplifier 26. Generally speaking, filter 25 is complementary to filters 20 and 21, the latter two filters being essentially similar to each other. However, it is neither essential nor particularly desirable that the filters 20, 21 and 25 have particularly sharp cut-off characteristics or be exactly complementary in their operating characteristics. Rather, a reasonable amount of overlap between the pass characteristics of high-pass filters 20 and 21 and low-pass filter 25 is permissible and even desirable. Speakers 12 and 13 by varying the relative amplitudes of the audio signals from source 11 are reproduced directly by speaker 14, being applied thereto through low-pass filter 25 and amplifier 26. The high-frequency components of the audio signals are reproduced by speakers 12 and 13. Distributor 15 modifies the relative amplitudes of the audio signals supplied to speakers 12 and 13 in accordance with the low-frequency control signal applied to the distributor from position signal source 24. Thus, the low-frequency control signal supplied to distributor 15 varies the effective dominant source of reproduced sound between speakers 12 and 13 by varying the relative amplitudes of the audio signals supplied to the speakers. It is not necessary that the distributor cut off either of the speakers at any time. In accordance with the invention, however, it is necessary that there be a substantial variation in the relative amplitudes of the two signals supplied to speakers 12 and 13 in order to achieve the desired variation in dominant sound source.

In order to achieve the desired spacial effect, it is essential that the signal supplied to distributor 15 from source 24 be very low in frequency. In general, it is preferred that this frequency be of the order of two cycles per second or less, and a frequency of one-half cycle per second has been found quite satisfactory where signal source 24 comprises a constant-frequency oscillator. The gradual shifting of the apparent source of sound between speakers 12 and 13 produces an effect, to the listener, that is somewhat similar to the use of a moving-speaker arrangement discussed briefly hereinabove.

The difference in treatment of the high-frequency and low-frequency components of the audio signals results in considerably more pleasing effects than are derived if all frequency components are effectively shifted between different speakers or other reproduction devices. If the low-frequency components of the audio signals from

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source 11 are also passed through distributor 15, eliminating the separate channel comprising filter 25 and amplifier 26, the result is an undulating or "swimming" effect that is, in many instances, readily noticeable by the listener. This effect is not desirable and, in the preferred arrangement of FIGURE 1, the low-frequency components are handled separately.

Reproduction system 10, as thus far described, provides only for incorporation of a spacial effect into the sound reproduced by the system. To achieve an additional vibrato effect, a vibrato signal source 28 may be coupled to distributor 15 to apply a second low-frequency control signal thereto. Preferably, the frequency of the control signal supplied to distributor 15 from signal source 28 is of the order of five to ten cycles per second. The control signal from the vibrato source actuates distributor 15 in essentially the same way as the control signal from position source 24. However, the higher frequencies of the control signal from source 28 results in a different effect, insofar as the listener is concerned.

Due to the almost inevitable differences in lengths of the acoustical paths from the speakers 12 and 13 to a listener, caused by differences in the location of reflecting structures even in those instances where the listener is located at equal distances from the speakers, the effective transfer of the high-frequency signal components between the speakers introduces a phase modulation of the high-frequency portions of the audio. This phase modulation occurs, of course, at a frequency within the operating range of the signal source 28. The result is a pleasing vibrato in the reproduced audio.

To achieve a third effect, defined hereinabove as a celeste effect, a celeste signal source 29 may also be coupled to distributor 15. Celeste signal source 29 applies to the distributor a third low-frequency control signal, having an operating frequency of two to five cycles per second. The control signal from the celeste source actuates distributor 15 in essentially the same manner as control signals from sources 24 and 28. The difference in frequency of the applied control signal, however, results in an effect substantially different from that caused by the control signals from position source 24 and vibrato source 28.

Thus, the effective transfer of the high-frequency audio signal components between speakers 12 and 13 changes the audio path lengths for the listener and introduces phase modulation, just as in the case of the vibrato effect. The lower transfer frequency of celeste signal source 29, however, creates a pleasing "singing" effect of the kind usually referred to as a celeste effect.

Unlike mechanical systems which produce somewhat similar effects by the use of rotating speakers, rotating baffles, and similar arrangements, the present invention is not restricted to the production of any one effect at any given time. That is, the electronic system of the invention permits simultaneous application of position control, vibrato control, and celeste control signals to distributor 15. As a result, any of these three effects or any desired combination thereof can be employed simultaneously, thereby greatly enhancing the flexibility in sound variations from electrical musical instrument with which the system 10 is employed. To permit the user of an organ or other electrical musical instrument maximum flexibility in the audio effects produced, selection means such as the switches 28A and 29A may be incorporated in the coupling circuits between the control sources and distributor 15. With such selection means available, celeste or vibrato effects or both may be applied to the reproduced sound as desired. A similar selection switch could of course be used with the spacial effect control source 24. Usually, however, it is desirable to employ this effect on a continuous basis.

FIGURE 2 illustrates, in detail, the distribution system of audio reproduction system 10 (FIGURE 1), including particularly distributor 15 and the filters employed

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in the audio reproduction system. Distributor 15, as illustrated in FIGURE 2, comprises a beam deflection tube 31 having a cathode 32, an intensity control electrode 33, a focus electrode 34, and an accelerator 35. Tube 31 further includes a second control electrode system comprising a pair of deflectors 36 and 37, and is provided with a pair of output electrodes, the anodes 38 and 39. Thus, tube 31 is a beam deflection tube of substantially conventional construction providing both for intensity and deflection control of an electron stream which may be intercepted by either one or both of the two output electrodes.

Cathode 32 is connected to a plane of reference potential, here shown as ground, through a biasing circuit comprising a resistor 41 that is by-passed by a capacitor 42. Cathode 32 is also connected to screen electrode 34. Control electrode 33 is coupled to audio source 11 through an input circuit comprising a coupling capacitor 43 connected to the intensity control electrode and an input resistor 44 that is connected to electrode 33 and returned to ground. Electrode 35 is connected to a source of positive polarity unidirectional operating potential, here designated as B+. Anode 39 is connected to the output circuit 19, which comprises a load resistor 45 that is returned to the B+ supply. Similarly, output circuit 18 for anode 38 comprises a load resistor 46 that connects the anode to the B+ supply.

High-pass filter 20, in the circuit shown in FIGURE 2, is quite simple in construction. It comprises a coupling capacitor 48 that is connected in series from anode 38 to amplifier 22 and a resistor 50 that is returned to B+. A similar circuit is used for high-pass filter 21, and comprises simply a capacitor 49 and a resistor 51.

In the circuit arrangement of FIGURE 2, an equally simple circuit is used for low-pass filter 25. This circuit comprises a resistor 52 and a capacitor 53 connected in series with each other across the output of audio source 11. The center terminal 54 of the filter is coupled to amplifier 26 and, hence, to speaker 14.

In connection with the circuit of FIGURE 2, it is assumed that signal source 24 affords a push-pull output. One side of the output circuit from the position signal source is connected to deflector 37, being returned to ground through an input resistor 55. The other side of the push-pull circuit from position signal source 24 is connected to deflector 36, being returned to ground through an input circuit 56.

In operation, deflection tube 31 develops an electron stream or beam in the electron gun comprising electrodes 32-35. In the absence of any control signals applied to deflectors 36 and 37, the beam is distributed approximately equally between anodes 38 and 39, the output electrodes of the tube. The electron stream is modulated in intensity by the audio signal applied to control electrode 33 from source 11 through the coupling circuit comprising capacitor 43 and resistor 44. Accordingly, tube 31 effectively couples input circuit 16 to both of the output circuits 18 and 19; the audio signal input is reproduced in both output circuits.

The control signal supplied to deflectors 36 and 37 from source 24, through the coupling circuit including resistors 55 and 56, is effective to distribute the electron stream, in tube 31, between anodes 38 and 39. Thus, as deflector 36 goes positive relative to deflector 37, a higher proportion of the electron stream impinges upon anode 38, increasing the amplitude of the audio signal developed in output circuit 18 and reducing the audio signal amplitude in output circuit 19. Conversely, when deflector 36 swings negative relative to deflector 37, the signal amplitude in output circuit 19 increases and that in output circuit 18 decreases. One desirable attribute to this particular form of electric discharge device, as utilized in distributor 15, is that the sum of the output currents in output circuits 18 and 19 remains substantially constant. Accordingly, this particular form of distributor effectively

changes the relative amplitudes of the output signal supplied to speakers 12 and 13 without materially changing the total amplitude of the reproduced sound. Of course, other vacuum tubes or solid-state discharge devices could be substituted for deflection tube 31 and, therefore, in the appended claims the expression "electric discharge device" is used in a generic sense to embrace these devices. However, the deflection tube is preferred because it affords a relatively economical and effective distribution device as compared with most other comparable devices.

Consideration of the operation of the circuit of FIGURE 2 affords another reason why it is desirable to by-pass distributor 15 insofar as low-frequency components of the audio signals from source 11 are concerned. From the foregoing description of operation of distributor 15, it is apparent that the D.C. current of deflection tube 31 is switched between anodes 38 and 39 together with the A.C. signals carried by the electron stream. Even though this may occur at a non-audible rate, it may produce undesirable effects in operation of speakers 12 and 13. Thus, if high-pass filters 20 and 21 are omitted, the maximum D.C. signal applied to amplifiers 22 and 23 may be of sufficient amplitude to paralyze the audio amplifiers, depending upon the coupling coefficient of the circuits used to couple distributor 15 to the amplifiers. In the illustrated circuit, where only high-frequency components are effectively translated to the audio amplifiers, this cannot occur. In the illustrated circuit, the nominal cut-off frequency of the two high-pass filters is approximately 250 cycles. By the same token, the nominal upper limit for low-pass filter 25 is also approximately 250 cycles. With the illustrated arrangement, it may be preferable to utilize a speaker especially constructed for low signal frequencies as speaker 14, using middle or high range speakers for devices 12 and 13.

With respect to the circuit of FIGURE 2, the following data are set forth solely in order to afford a more specific illustration of one embodiment of the invention, and in no sense as a limitation:

Tube 31, type 6AR8		
Resistor 41	ohms	390
Resistor 44	kilohms	500
Resistors 45, 46	do	10
Resistors 50, 51	do	500
Resistor 52	do	100
Resistors 55, 56	megohms	2.2
Capacitor 42	microfarads	25
Capacitor 43	do	0.01
Capacitors 48, 49	micromicrofarads	1200
Capacitor 53	do	6000
Supply voltage B+	D.C. volts	+250

As noted hereinabove, a conventional oscillator may be used for position signal source 24 (FIGURE 1); similarly, an oscillator may be used for vibrato signal source 28 and for the celeste signal source 29. On the other hand, it may be desirable to utilize a random-frequency source for the position signal source 24 in order to minimize the possibility of detection of regularity in changes in the instantaneously dominant source of sound between speakers 12 and 13. A relatively simple and effective circuit 60 is shown in FIGURE 3, in substantial detail, which is suitable for use as a random-frequency signal source.

Circuit 60 comprises a diode 61 having a cathode connected to a suitable positive polarity supply, designated as B+, through a pair of resistors 62 and 63 connected in series with each other. The anode of diode 61 is returned to ground and a resistor 64 is connected from the common terminal of resistors 62 and 63 to ground. Thus, diode 61 is reverse-biased, an arrangement which affords a relatively effective source of low-frequency noise signals, the instantaneous value varying at random.

Diode 61 is coupled in a three-stage amplifier circuit comprising a first stage pentode 65, a second stage pentode 66, and an output triode 67. The coupling circuits are

generally conventional and effectively restrict operation of the amplifier to extremely low frequencies. In each of the pentode stages, the control electrode is returned to a negative polarity supply C— through a suitable resistor, the resulting circuit affording a negative bias arrangement for regulation of the amplifier in addition to establishing the operating level of the control electrodes.

FIGURE 4 illustrates, in block diagram form, an audio reproduction system 80 constructed in accordance with another embodiment of the invention. Reproduction system 80 includes an audio source 81 which may comprise any suitable electrical musical instrument. Audio source 81 is connected to a pair of distributors 82 and 83 which are essentially similar to each other and which may be essentially similar to distributor 15 (FIGURES 1 and 2). Distributor 82 includes two output circuits which are individually coupled to respective ones of a pair of high-pass filters 84 and 86. Filter 84 is coupled to a first audio reproduction device, a speaker 88, through a suitable amplifier 90. Filter 86, on the other hand, is coupled through a suitable amplifier 92 to a second speaker 94 disposed in spaced relation to speaker 88. Distributor 83 includes a first output circuit comprising a high-pass filter 85 coupled to a speaker 87 by means of a suitable amplifier 89. The other output circuit for distributor 83 comprises a high-pass filter 91 that is coupled through an amplifier 93 to a fourth speaker 95. Speakers 87, 88, 94 and 95 are disposed in a generally rectangular array, being located at the four corners of the rectangle. Moreover, the two speakers coupled to distributor 82, speakers 88 and 94, are located at diagonally opposed corners of the rectangular array and the speakers coupled to the other distributor, speakers 87 and 95, are also disposed in diagonally opposed relation to each other.

Reproduction system 80 further includes a position signal source 96. As in the previously described embodiments, the position signal source is coupled to distributor 83. In addition, signal source 96 is also coupled to distributor 82. In this instance, however, a phase-shift circuit 97 is incorporated in the coupling circuit between the position signal source and the distributor to afford a substantial phase shift between the control signals applied to distributor 83 and those applied to distributor 82. If signal source 96 comprises a sine-wave oscillator, circuit 97 should afford a phase shift of approximately 90° at the control signal frequency. If source 96 comprises a random-frequency device, such as that shown in FIGURE 3, it is not possible to obtain a constant phase shift; however, satisfactory results can be obtained by means of a phase shift circuit affording 90° phase shift at approximately the center frequency of the control signal frequency range.

As in the embodiment of FIGURE 1, audio reproduction system 80 (FIGURE 4) provides a separate channel for the low-frequency components of audio signals. Thus, a low-pass filter 98 and a suitable amplifier 99 are utilized to couple audio source 81 to an additional speaker 108. Preferably, speaker 108 is located at the center of the rectangular speaker array formed by the reproduction devices 87, 88, 94 and 95.

Audio reproduction system 80 (FIGURE 4) is essentially similar in operation to system 10 (FIGURE 1) but "moves" the effective dominant sound source between four speakers instead of two. At the same time, the system shown in FIGURE 4 provides for shifting of the dominant sound source in a manner which is less easily distinguished by the listener. Thus, if the control signal developed by source 96 is a sine wave, at any given instant it may be assumed that the audio signal supplied from distributor 83 to speaker 87 is at a maximum; at this same instant, the signal supplied to speaker 95 is at a minimum amplitude. Thus, as between speakers 87 and 95, speaker 87 represents the instantaneously dominant sound source. At the same time, however, the signal amplitudes in the two output circuits of distribu-

tor 82 would be approximately equal, due to the 90° phase shift in the control signal introduced by circuit 97. Accordingly, under these conditions the volume of sound produced by speaker 87 would be somewhat greater than that produced by speakers 88 and 94 and considerably greater than the output from speaker 95.

One-quarter cycle later, with respect to the period of the control signal from source 96, the audio signals supplied from distributor 83 to speakers 87 and 95 are approximately equal in amplitude. At this time, however, a substantially stronger audio signal is applied to speaker 88 than to speaker 94, due to the phase shift of the control signal effected in circuit 97. Consequently, at this time speaker 88 produces a substantially greater volume of sound output than either of speakers 87 and 95, which in turn produce a higher volume of sound than speaker 94. It is thus seen that audio reproduction system 80 effectively rotates the dominant source of sound between speakers 87, 88, 94 and 95, but a substantial proportion of the sound volume always emanates from speakers other than the dominant speaker. The listener cannot detect the mechanism of the effect. Consequently, pleasing spacial effect is imparted to the reproduced sound. As in the previously described embodiment, the separate signal channel for low-frequency audio components, comprising filter 98, amplifier 99 and speaker 108, avoids introduction of switching transients into the reproduced sound and also avoids any undulating or swimming effect.

FIGURE 5 illustrates an audio reproduction system 100 which includes many of the features of previously described systems but which includes additional features and modifications, particularly with respect to introduction of a vibrato or celeste effect into the reproduced sound. Reproduction system 100 includes a suitable audio signal source 101 which is coupled to the intensity control electrode 102 of a beam deflection tube 103. Tube 103 includes a cathode 104, a pair of deflectors 105 and 106, and a plurality of output electrodes 110-119. A suitable source of celeste or vibrato control signals, or both, identified in FIGURE 5 as circuit 120, is connected across deflectors 105 and 106. This signal source may be an oscillator having an operating frequency of the order of five to ten cycles per second for a vibrato effect, while a celeste effect may be obtained using an oscillator or other sine-wave signal source having an operating frequency of two to five cycles per second. Of course, both may be used, as in the system 10 (FIGURE 1). The use of ten anodes, as illustrated in tube 103, is not critical; however, a relatively large number of output electrodes are preferred in tube 103, as compared with the two anodes in deflection tube 31 (FIGURE 2).

Audio reproduction system 100 further includes a delay line 121 having a multiplicity of individual sections. The delay of the individual sections may be approximately equal, or the sections may differ from each other in the amount of delay produced. One end of delay line 121 is connected to anode 110 of deflection tube 103 and is terminated by a suitable resistor 122 that is connected to a source of positive-polarity operating potential here designated as B+. Similarly, the other end of the delay line is connected to anode 119 of the deflection tube and is terminated by a resistor 123 that is connected to the B+ supply. The remaining deflection tube anodes are individually coupled to delay line 121 at different points therealong.

The end of delay line 121 connected to anode 119 is coupled to a distributor circuit 124 by means of a suitable coupling circuit comprising, in this instance, a coupling capacitor 125 and an input resistor 126. Distributor 124 is essentially similar to the distributing means described hereinabove, such as distributor 15 of FIGURES 1 and 2. The distributor is connected to a suitable position signal source 125 which produces a very-low-frequency control signal preferably of the order of two cycles per

second or less. Distributor 124 is provided with two individual output circuits; one of these output circuits is coupled through a high-pass filter 134 and an adder 128 to speaker 130. The other output circuit is similarly coupled to a speaker 131 by means of a high-pass filter 127 and an adder circuit 129.

A separate channel for low-frequency audio signals is provided in system 100. In this instance, the low-frequency audio channel comprises a low-pass filter 132 that is coupled to the output circuit for delay line 121. The output stage of filter 132 is, in turn, coupled to each of the two adder circuits 128 and 129.

In operation of system 100, audio signals are supplied from source 101 to control electrode 102 to modulate the intensity of an electron beam projected from cathode 104 toward anodes 110-119. The electron stream is swept back and forth across the anodes of tube 103 in response to the low-frequency deflection control signal supplied to deflectors 105 and 106 from source 120. The transition of impingement of the beam between individual anodes need not be sharply defined; rather, at any given instant the stream may impinge partially upon at least two anodes, and sometimes may be intercepted in part by three anodes. Moreover, the tube construction may be such that secondary emission from the anodes effectively prevents sharp definition in the transition of the beam between anodes. Consequently, the audio output signal from tube 103, appearing at the terminal 133, includes components which are delayed by different amounts, relative to each other, due to the effect of audio delay line 121. This produces substantial vibrato or celeste effects in the audio signal supplied to distributor 124 and to filter 132.

Audio system 100 further illustrates the fact that it is not essential to use a separate speaker to reproduce the low-frequency components of the audio signals. Thus, in FIGURE 5, speakers 130 and 131 are employed to reproduce both the high-frequency and low-frequency components of the signals from source 101. However, it is still desirable to by-pass distributor 124 with respect to low-frequency audio components, for the reasons set forth hereinabove. This is accomplished by means of the separate low-frequency channel comprising filter 132, the low-frequency components being recombined in the two adding circuits 128 and 129.

FIGURE 6 illustrates an audio reproduction system 150 specifically constructed to afford a desirable depth and richness of tone in an electronic organ previously referred to as a chorus effect. It comprises an electronic organ 151 which may be substantially conventional in construction and including the usual oscillators, filters, formant circuits, and other devices for producing a plurality of different audio signals or "voices." Organ 151, as illustrated, is provided with four different output circuits 161, 162, 163 and 164 identified as being associated with four individual voices. That is, the output signals appearing in the output circuits 161-164 are of differing harmonic content, although they may be in overlapping frequency ranges. These voices may be those usually employed in conventional organs and identified as "reed," "flute," "vox humana," "string" and the like.

In system 150, a first distributor 165 is included, the input circuit of the distributor being coupled to output circuit 161 for audio signals representing the first voice of organ 151. Distributor 165 is essentially similar to the distributor means described hereinabove and is provided with two individual output circuits. One of the output circuits of distributor 165 is coupled to a first speaker or other audio reproduction device 166 by means of a circuit including a high-pass filter 167 and an amplifier 168. The other output circuit of the distributor is coupled through a high-pass filter 169 and an audio amplifier 171 to a second speaker 172. As in the previously described embodiments, means are provided for applying a low-frequency control signal to distributor 165 to vary the effective dominant source of sound reproduced by speakers 166 and 172. This means comprises a suitable position

signal source 173 coupled to one or more electronic switching devices included in distributor 165.

The second voice of organ 151 is treated similarly, output circuit 162 being coupled to a distributor 174 that is controlled by a second independent low-frequency control signal source 175. Distributor 174 includes two output circuits that are individually coupled to high-pass filters 167 and 169, and, accordingly, to speakers 166 and 172. A third distributor 176 couples the third organ voice from output circuit 163 to the two speakers, being controlled by a separate position signal source 177. The fourth voice or audio signal from organ 151 is supplied to the speakers through a fourth distributor 178 that is controlled by a further position signal source 179.

In addition to the speakers 166 and 172, which are employed to reproduce high-frequency components of the audio signals, reproduction system 150 includes a third speaker 181. Each of the organ output circuits 161-164 is coupled to an adder circuit 182 to combine all of the output signals from the organ into a single composite audio signal. The composite audio output signal from adder circuit 182 is applied to speaker 181 through a separate low-frequency channel comprising a low-pass filter 183 and a suitable amplifier 184.

Operation of audio reproduction system 150 is basically similar to that of system 10 (FIGURE 1) except that each voice of the organ is controlled individually with respect to the position effect. Thus, the low-frequency control signal supplied to distributor 165 from source 173 varies the effective dominant source of the first voice of the organ between speakers 166 and 172 by varying the relative amplitudes of the audio signals supplied to these two speakers. In a corresponding manner, an apparent dominant source of sound for each of the other organ voices is effectively moved between speakers 166 and 172 in accordance with the control signals supplied from sources 175, 177 and 179. The four control sources 173, 175, 177 and 179 are constructed to be asynchronous in operation with respect to each other, and preferably have different operating frequencies, although all should be held to a frequency of two cycles per second or less. As a consequence, the position effect for each voice is different than for the others, which results in a fullness and richness of sound that is quite pleasing to most listeners as compared with the rather "flat" sound of many electric organs, caused by synchronous relationships between the voices. As discussed hereinabove, improved diversification in the position effect can be achieved by using random-frequency signal sources, although this is not essential as long as the individual control signals are not synchronized with each other. Of course, a vibrato effect and/or a celeste effect can also be achieved by applying a control signal of somewhat higher frequency, of the order of two to ten cycles, per second to each of the distributors, as described hereinabove in connection with FIGURE 1. As in the earlier embodiments, the low-frequency channel does not include the distributors in order to avoid undesirable effects which may be produced if the low-frequency audio is effectively shifted between speakers.

In the systems and apparatus described in connection with FIGURES 1-6, it is presumed that the vibrato, celeste and position effects are produced continuously and that the amplitude changes between speakers, relative to each other, remain essentially constant. Furthermore, the individual systems as described hereinabove may produce effective shifting actions which follow a substantially fixed pattern. On the other hand, it may prove desirable to utilize variable-frequency control sources which are not necessarily random-frequency sources and which may be subject to manual control to change the frequency of the control signal employed for vibrato, celeste or position effects. A manually controllable variable-frequency source suitable for use in any of the systems described hereinabove is illustrated in FIGURE 7. This control

signal source comprises a three-phase A.C. supply 200 connected to the field windings 201, 202, and 203 of an induction frequency generator 204. The windings may be connected in a conventional delta or Y connection, being shown delta-connected. The operating frequency of the A.C. supply source 200 is not particularly important; a conventional A.C. power supply operating at a frequency of 60 cycles per second may be utilized. On the other hand, A.C. supply 200 may comprise a conventional oscillator and a suitable phase-splitting circuit to provide the necessary three phase output.

Generator 204 includes a rotor 205 which carries an output winding 206. The winding 206 is provided with suitable output terminals 207 and 208 which may be connected to the winding through a suitable set of slip rings or the like. Rotor 205 is mechanically driven by a motor 209. The motor may, for example, comprise a small permanent magnet D.C. motor of variable speed and the mechanical connection to generator rotor 205 may include suitable gearing, depending upon the normal operating speed of the motor.

Motor 209 is connected to a suitable supply source by means of an energizing circuit comprising a variable resistor 210 having a movable tap 211. The variable tap on the input resistor for motor 209 is mechanically connected to a manual control device 212. Manual control 212 may take several forms; for example, it could comprise a simple control lever for moving tap 211 from a normal or "home" position to a secondary or actuated position. On the other hand, the manual control could comprise a suitable linkage which would permit variation of resistor tap 211 between a number of different resistance values.

Alternatively, the electrical variation of the tap on resistor 210 could be accomplished by means of shunting resistors across the two points formed by the arm 211 and the common terminal of the motor and the motor supply voltage.

When the control signal source illustrated in FIGURE 7 is placed in operation, the three-phase A.C. signals supplied to windings 201-203 produce a rotating magnetic field within which winding 206 is located. Motor 209 drives rotor 205, and hence winding 206, rotating the rotor at a speed very nearly equal to the rotational speed of the magnetic field. It will be recognized that if the speed of the rotor is exactly matched to the rotation of the magnetic field, no output signal is produced at terminals 207 and 208. Even a relatively small differential between these speeds, however, produces an A.C. output signal having a frequency equal to the differential frequency between the rotating magnetic field and rotor 205. Consequently, the device of FIGURE 7 can be controlled to produce a low-frequency control signal of the kind required for the position, the vibrato, or the celeste signal sources described hereinabove.

To change the frequency of the control signal appearing at output terminals 207 and 208, the operator actuates manual control 212 to change input voltage (or current) of motor 209. The dynamic characteristics of motor 209 can be made such that a frequency change of this kind is effected in a very short time. Consequently, any of the effects of position, vibrato or celeste can be varied instantaneously and can be precisely controlled by means of a control signal source of the kind shown in FIGURE 7. A device of this sort is particularly useful in conjunction with an electronic organ as, for example, the organ system of FIGURE 6, giving the organ player considerably greater latitude in the nature of the ultimate sounds reproduced.

From the foregoing description, it is apparent that the present invention produces the illusion of sound emanating from a plurality of different sources with individually indistinguishable changes between the sources by essentially completely electronic means. No mechanical apparatus for moving speakers or other audio reproduction devices or auxiliaries is necessary. The

invention produces vibrato, spacial, celeste and chorus effects, yet avoids undesirable transient signals and other unwanted effects in the low-frequency end of the audio spectrum. In fact, spacial, vibrato, celeste and chorus effects may be introduced through the same basic apparatus. The invention provides means for conveniently and effectively controlling the vibrato, celeste, chorus or spacial effects produced thereby. The overall operation of the system affords an unusual and pleasing stereo effect using electronic means which are both simple and economical in construction.

While particular embodiments of the present invention have been shown and described, it is apparent that various changes and modifications may be made, and it is therefore contemplated in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

We claim:

1. An audio reproduction system comprising: a source of audio signals; a plurality of individual audio reproduction devices; means for utilizing said audio signals to energize said reproduction devices including at least one electric discharge device responsive to an applied control signal to control the relative intensity of sound reproduction by said audio reproduction devices; means for developing a first control signal having a frequency in the low-frequency portion of the audio spectrum and for developing a second control signal also having a frequency in the low-frequency portion of the audio spectrum but higher in frequency than said first control signal; and means for applying said first control signal to said discharge device of said utilizing means for effecting a predetermined amplitude variation in said audio signals at the frequency of said first control signal to vary the effective dominant source of sound reproduced by said audio reproduction devices and for concurrently applying said second control signal to said utilizing means for effecting a predetermined amplitude variation in said audio signals at the frequency of said second control signal to produce a "vibrato" or "celeste" subjective listening effect.

2. An audio reproduction system comprising: a source of audio signals; a plurality of individual audio reproduction devices; means for utilizing said audio signals to energize said reproduction devices including at least one electric discharge device responsive to an applied control signal to control the relative intensity of sound reproduction by said audio reproduction devices; means for developing a first control signal having a frequency in the low-frequency portion of the audio spectrum and for developing a second control signal of sinusoidal wave form also having a frequency in the low-frequency portion of the audio spectrum but higher in frequency than said first control signal; and means for applying said first control signal to said discharge device of said utilizing means for effecting a predetermined amplitude variation in said audio signals at the frequency of said first control signal to vary the effective dominant source of sound reproduced by said audio reproduction devices and for selectively and concurrently applying said second control signal to said utilizing means for effecting a predetermined amplitude variation in said audio signals at the frequency of said second control signal to produce a "vibrato" or "celeste" subjective listening effect.

3. An audio reproduction system comprising: a source of audio signals; a plurality of individual audio reproduction devices; means for utilizing said audio signals to energize said reproduction devices including at least one electric discharge device responsive to an applied control signal to control the relative intensity of sound reproduction by said audio reproduction devices; means for developing a first control signal and for developing a second control signal having a frequency higher than that of said first control signal but less than ten cycles

per second; and means for applying said first control signal to said discharge device of said utilizing means for effecting a predetermined amplitude variation in said audio signals at the frequency of said first control signal to vary the effective dominant source of sound reproduced by said audio reproduction devices and for applying said second control signal to said utilizing means for effecting a predetermined amplitude variation in said audio signals at the frequency of said second control signal to produce a "vibrato" or "celeste" subjective listening effect.

4. An audio reproduction system comprising: a source of audio signals; a plurality of individual audio reproduction devices; means for utilizing said audio signals to energize said reproduction devices including at least one intensity-control device for controlling the relative intensity of sound reproduction by said audio reproduction devices; and means for actuating said intensity-control device at a random rate having a maximum frequency of approximately two cycles per second to vary, in a random fashion, the effective dominant source of sound reproduced by said audio reproduction devices.

5. An audio reproduction system comprising: a source of audio signals; a plurality of audio reproduction devices; distributing means for applying said audio signals to said audio reproduction devices, said distributing means including an electric discharge device having an input electrode coupled to said audio signal source, a corresponding plurality of output electrodes individually coupled to said reproduction devices, and control electrode means responsive to an applied control signal, for controlling the effective coupling between said input electrode and said output electrodes; and means for applying a random rate control signal having a maximum frequency of approximately two cycles per second to said control electrode means to vary in a random fashion, the effective dominant source of reproduced sound by varying the relative amplitudes of the audio signals supplied to said audio reproduction devices.

6. An audio reproduction system comprising: a source of audio signals; a plurality of audio reproduction devices; distributing means for applying said audio signals to said audio reproduction devices, said distributing means including a beam-deflection electron discharge device comprising means for developing an electron beam, an input electrode coupled to said audio signal source to modulate the intensity of said beam, a corresponding plurality of output electrodes individually coupled to said reproduction devices, and control electrode means comprising at least one deflection electrode for controlling the distribution of said beam between said output electrodes in response to an applied control signal; and means for applying a random rate control signal having a maximum frequency of approximately two cycles per second to said deflection electrode to vary, in a random fashion, the effective dominant source of reproduced sound by varying the relative amplitudes of the audio signals supplied to said audio reproduction devices.

7. An audio reproduction system comprising: a source of audio signals; a plurality of at least three audio reproduction devices; distributing means for applying said audio signals to two of said audio reproduction devices, said distributing means including an input circuit coupled to said audio signal source, a pair of output circuits individually coupled to said two reproduction devices, and at least one electric discharge device, responsive to an applied control signal, coupling said input circuit to said output circuits; means for applying a low-frequency control signal to said electric discharge device to vary the effective dominant source of reproduced sound by varying the relative amplitudes of the audio signals supplied to said two audio reproduction devices; a pair of high-pass filters individually incorporated in respective ones of said output circuits of said distributing means, for substantially attenuating the low-frequency components of the audio signals applied to said two reproduction devices through

said distributing means, said filters affording substantial attenuation for frequencies below approximately 250 cycles; and coupling means, coupling said audio source to a third one of said audio reproduction devices, for applying the low-frequency components of said audio signals to a third audio reproduction device independently of said distributing means, said coupling means comprising a low-pass filter affording substantial attenuation for frequencies above approximately 250 cycles, the effective dominant source of reproduced sound being shifted in a predetermined fashion between said two audio reproduction devices while avoiding an unpleasant listening effect attributable to the shifting of signals having a frequency of approximately 250 cycles and less.

8. An audio reproduction system comprising: a source of audio signals; a beam-deflection tube comprising means for developing an electron beam, an intensity-control electrode, coupled to said audio signal source, for modulating the intensity of the beam, a plurality of output electrodes positioned to intercept the beam, and a deflection electrode system for deflecting said beam between said output electrodes in response to an applied control signal; a multi-section audio delay line, having individual sections coupled to respective ones of said output electrodes; an audio reproduction device, coupled to said delay line; and means for applying a low-frequency control signal to said deflection electrode system to modify the time delay of the audio signals supplied to said audio reproduction device by shifting said beam between said output electrodes to impart a vibrato or celeste effect to the sound reproduced by said device.

9. An audio reproduction system comprising: a source of audio signals; a beam-deflection tube comprising means for developing an electron beam, an intensity-control electrode, coupled to said audio signal source, for modulating the intensity of the beam, a plurality of output electrodes positioned to intercept the beam and a deflection electrode system for deflecting said beam between said output electrodes in response to an applied control signal; a multi-section audio delay line, having individual sections coupled to respective ones of said output electrodes and having an output terminal; means for applying a low-frequency control signal to said deflection electrode system to modify the time delay of the audio signals at said output terminal by shifting said beam between said output electrodes; electronic distributing means, coupled to said output terminal, for applying the audio signals to two separate output circuits; means, coupled to said distributing means, for varying the amplitude levels of the audio signals in said output circuits at a frequency substantially less than the frequency of said control signals; and a pair of audio reproduction devices individually coupled to said output circuits.

10. An audio reproduction system comprising: a plurality of sources of audio signals of differing harmonic content but overlapping frequency range; at least two audio reproduction devices; distributing means for applying said audio signals to said audio reproduction devices, said distributing means including a plurality of input circuits individually coupled to respective ones of said audio signal source, two output circuits individually coupled to respective ones of said reproduction devices, and a plurality of discharge devices, each responsive to an applied control signal, for coupling each of said input circuits to both of said output circuits; and means for applying individual low-frequency control signals to each of said electric discharge devices to vary the effective dominant source of reproduced sound corresponding to one of the initial audio signals by varying the relative amplitudes of the audio signals supplied to said audio reproduction devices, said control signals being asynchronous with each other.

11. An audio reproduction system comprising: a plurality of sources of audio signals of differing harmonic content but overlapping frequency range; at least two audio reproduction devices; distributing means for applying said audio signals to said audio reproduction devices, said distributing means including a plurality of input circuits individually coupled to respective ones of said audio signal source, two output circuits individually coupled to respective ones of said reproduction devices, and a plurality of discharge devices, each responsive to an applied control signal, for coupling each of said input circuits to both of said output circuits; means for applying individual low-frequency control signals to each of said electric discharge devices to vary the effective dominant source of reproduced sound corresponding to one of the initial audio signals by varying the relative amplitudes of the audio signals supplied to said audio reproduction devices, said control signals being asynchronous with each other; filter means for substantially attenuating the low-frequency components of each of the audio signals applied to said reproduction devices through said distributing means; and means for reproducing the low-frequency components of said audio signals independently of said distributing means.

12. An audio reproduction system for imparting vibrato and position effects to an electronic organ comprising: an electronic organ audio signal system for producing a plurality of different audio voice signals and having at least some voices synchronously related to each other; a plurality of speakers; distributing means for applying audio signals from said organ audio signal system to said audio reproduction devices, said distributing means including an input circuit coupled to said audio signal source, a plurality of output circuits individually coupled to respective ones of said reproduction devices, and at least one electric discharge device, responsive to an applied control signal, coupling said input circuit to said output circuits; means for applying a low-frequency control signal to said electric discharge device to vary the effective dominant source of reproduced sound by varying the relative amplitudes of the audio signals supplied to said audio reproduction devices; filter means for substantially attenuating the low-frequency components of the audio signals applied to said reproduction devices through said distributing means; and coupling means, coupling said audio source to at least one of said audio reproduction devices, for applying the low-frequency components of said audio signals to said one audio reproduction device independently of said distributing means.

References Cited by the Examiner

UNITED STATES PATENTS

2,114,680	4/1938	Goldsmith	179—1.3
2,273,866	2/1942	Holst	179—1.3
2,500,820	3/1950	Hanert	84—1.25 X
3,000,252	9/1961	Wayne.	
3,056,854	10/1962	Katzenstein et al.	179—1.3 X
3,076,873	2/1963	Owen et al.	179—1.3 X
3,083,606	4/1963	Bonham	84—1.25
3,156,769	11/1964	Markowitz	84—1.24 X

OTHER REFERENCES

Dorf, *Electronic Musical Instruments* (textbook), ML-1092-D57, page 13.

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