APPARATUS AND METHOD FOR PRODUCING CELESTE ANIMATION IN MUSIC BY PRODUCING SIMULTANEOUS SHARP AND FLAT TONE SIGNALS FROM TONE SIGNALS OF TRUE FREQUENCY

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Fig. 1.

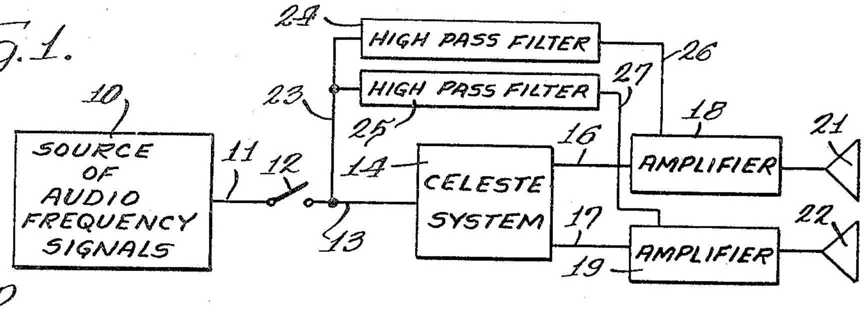


Fig. 2.

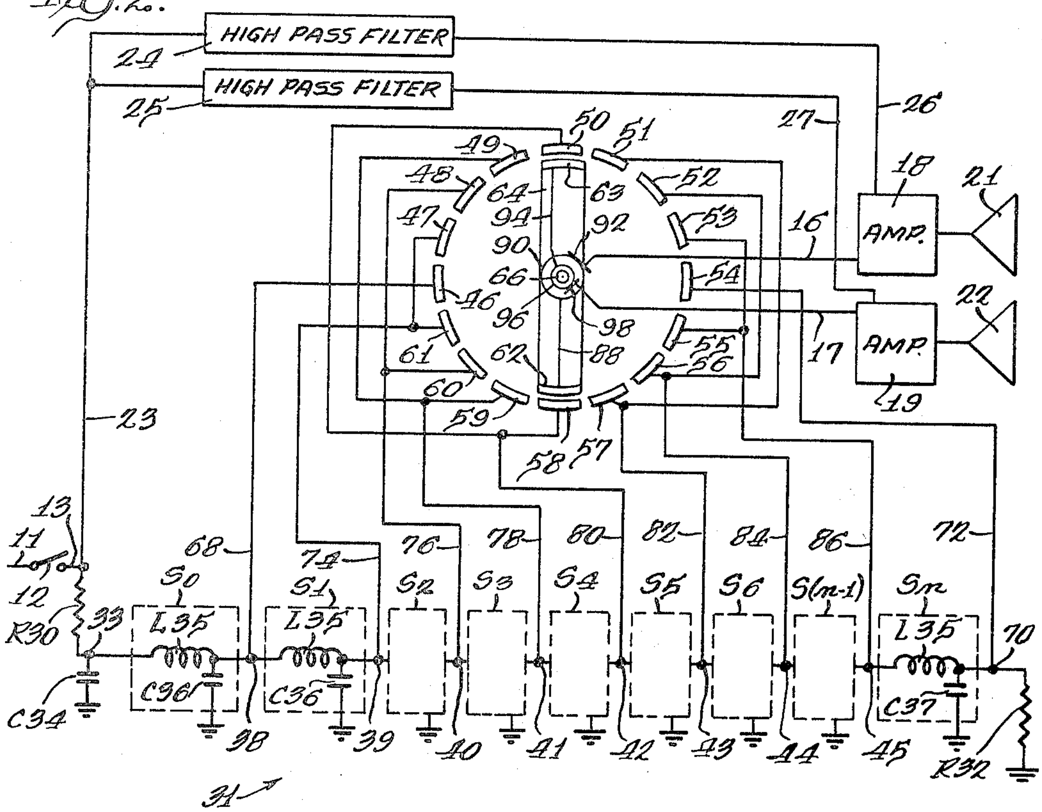
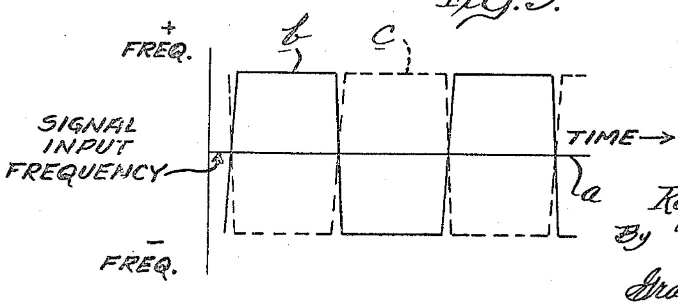


Fig. 3.



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1

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APPARATUS AND METHOD FOR PRODUCING CELESTE ANIMATION IN MUSIC BY PRODUCING SIMULTANEOUS SHARP AND FLAT TONE SIGNALS FROM TONE SIGNALS OF TRUE FREQUENCY

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ABSTRACT OF THE DISCLOSURE

A celeste system for an electric organ or other electrical musical instrument which progressively and uniformly phase shifts the musical signal in opposite directions simultaneously on a slow cyclical basis and which provides for abrupt reversal of the direction of phase shift of the two signals substantially instantaneously so as to provide two output signals one of which is slightly musically flat and the other slightly musically sharp for substantially identical periods at the end of which the two signals are abruptly reversed so that the first becomes sharp and the other flat. This cycle is repeated endlessly as long as a note is held.

This invention relates broadly to methods and means for improving musical tones, and is more particularly concerned with modifying electrical tone signals in electrical musical instruments, such as those of the organ type, to produce celeste animation whereby a brightening effect pleasing to the ear is achieved.

Celeste, or "voix celeste," is the effect produced by playing two or more closely tuned tones together. In pipe organ practice celeste may be produced by sounding together sets of pipes which are purposely tuned slightly flat and slightly sharp, so that the true frequency of the note represented by the key played by the organist lies between the frequencies of the pipes. Celeste therefore has slow "beating" associated with it, depending on the frequency spread between the tones involved; i.e., the extent to which they are out of tune as compared to the reference note of intermediate frequency.

In accordance with the present invention, celeste animation of sounds initially produced in the form of electrical signals is achieved by changing the frequency of the electrical tone signal simultaneously in opposite directions, by equal amounts, to produce two resultant signals having slightly higher and lower frequencies respectively than the original signal, and then translating the resulting signals into sound. More specifically, an electrical tone signal, or mixed signals, corresponding to the musical tone or tones desired to be brightened by celeste animation, is passed through an artificial electrical transmission line, preferably an audio frequency delay line, and a pair of scanning members in effect scan the delay line in a cyclic to and fro manner in such a way that as one scanning member is scanning the line in one direction, the other scanning member is scanning the line at the same speed in the opposite direction. The scanning of the artificial transmission line in one direction by a scanning member results in the production of a signal on the scanning member having a frequency F_1 higher than that of the input signal, and scanning the line in the opposite direction by a second scanning member results in the production of a signal on such scanning member having a frequency F_2 lower than that of the input signal.

The scanning members reverse their scanning direction at the ends of the artificial transmission line substantially simultaneously, so that when the signal produced on one scanning member changes from frequency F_1 to frequency F_2, the signal produced on the other scanning member changes from frequency F_2 to frequency F_1, such changes in frequency being effected suddenly and without voltage transients. The result is the production of two substantially continuous new frequencies F_1 and F_2 from one given input signal frequency. The signals of alternately higher and lower frequency which are picked up by, or produced on, the two scanning members may be conducted to a single electroacoustical translating means when the input signal is a complex signal rich in harmonics. However, such combining of the signals from the scanning members is not recommended when the input signal is in the form of single sine waves, since cancellations then occur. Preferably, therefore, the signals picked up by the two scanning members are passed through separate output systems, each including an electroacoustical translating means for converting the electrical signals into sound.

An object of the invention is to produce a celeste effect in an electrical tone signal by passing an input tone signal through an artificial electrical transmission line, such as an audio frequency delay line, providing uniformly phase-shifted signal output terminals along its length at which the amplitudes of the signal traversing the line are substantially the same, and scanning the transmission line cyclically in a to and fro manner simultaneously in opposite directions to produce two separate signals having different new frequencies compared to that of the input signal, one of such new frequencies being higher and the other lower than that of the input frequency.

A further object is to produce celeste animation in a musical instrument the output of which is in the form of electrical tone signals, by passing such a signal through an artificial electrical transmission line and scanning said line, in accordance with the preceding object, and then separately translating into sound the two signals produced by the scanning operation.

A further object of the invention is to provide celeste animation in musical instruments such as electrical or electronic organs, the outputs of which are in the form of electrical tone signals, by changing the frequency of such tone signals simultaneously in opposite directions and in an oscillatory manner, whereby two tone signals, respectively of higher and lower frequencies than the original signal, are produced, and then translating the resulting tone signals into sound.

A further object is to provide novel apparatus and method for producing a celeste effect in accordance with the foregoing objects wherein the original or input tone signals utilized may or may not have been previously supplied with other animations, such as vibrato, tremolo, reverberation, or percussion.

A further object is to provide novel apparatus in which celeste animation is produced by passing an electrical tone signal through an artificial electrical transmission line, scanning simultaneously with a pair of scanning members the transmission line cyclically in opposite directions and at the same constant speed, whereby the frequencies of the signals picked up by the scanners are respectively and alternately higher and lower than the frequency of the original tone signal, and then separately translating into sound the signals picked up by the scanning members.

A further object is to provide apparatus in accordance with the foregoing objects, wherein the scanning members scan the transmission line in a to and fro manner, and wherein the reversals in scanning direction at the ends of the line are substantially instantaneous, whereby voltage transients produced by irregular or uneven scanning are avoided.

A further object is to provide novel apparatus in ac-

2

cordance with the foregoing objects, wherein the scanning device includes a plurality of stationary capacitor plates or stators of substantially equal length and capacitance arranged in a circle in equally spaced relation, with the number of such stators equal to 1 plus twice the number of signal output terminals in the portion of the artificial electrical transmission line being scanned, the first and last of said terminals being connected respectively to diametrically opposed stators, and the remaining ones of such terminals being progressively connected to pairs of such stators progressively from one of such diametrically opposed stators to the other in the semicircular arcs of stators forming the circular arrangement, and the scanning device also includes diametrically opposed rotatable capacitor scanning members of substantially equal length and capacitance for scanning the stators. Thus, when the rotatable scanning members are rotated at constant speed, each of them is brought into electrical pickup relation successively with each of the stators for substantially the same amount of time, whereby each of the scanning members in effect scans the transmission line between the first and last of such terminals in an oscillatory manner, and the reversal of the direction of frequency change produced by such oscillatory scanning by each of the rotatable scanning members is substantially instantaneous.

A further object is to provide apparatus of the type referred to in the foregoing objects, wherein the periodicity of scanning of the artificial electrical transmission line is maintained no higher than about three cycles per second (c.p.s.) to eliminate or reduce to acceptable tolerances audible disturbances due to minor inequalities, unbalances or defects in the transmission line and/or the scanning device.

A further object is to provide a method and apparatus for improving sound derived from a source in which the sound is in the form of electrical signals, wherein such signals are separated into two portions, one of which portions is made up of frequencies below a predetermined frequency, and the other of such portions includes frequencies above substantially said predetermined frequency, but optionally including the latter and lower frequencies, the frequencies of the signals in the said one portion are changed to produce a celeste effect in accordance with the foregoing objects, and the said other signal portion and the new-frequency signals of said one portion are translated into sound.

Other objects and advantages will appear from the following description of two preferred embodiments of the invention, reference being made to the accompanying drawings wherein similar characters of reference refer to similar elements or parts in the several figures, and in which:

FIG. 1 is a diagrammatic representation of a general arrangement of a system embodying the present invention;

FIG. 2 is a more detailed view showing diagrammatically a preferred form of frequency-changing apparatus used in the present invention; and

FIG. 3 is a diagram illustrating the principles underlying the invention, showing graphically the substantially constant two new frequencies produced from a continuous input signal, and the coincidental reversal function occurring while scanning the ends of the artificial electrical transmission line, in accordance with the invention.

In the illustrative embodiments set forth below, the invention is described as applied to an electric organ. In such illustrative applications it will be understood that the invention can be applied to any section of an organ, and the applications to the various sections may be the same, or minor changes which will suggest themselves and reflect individual preference may be made as between organ sections at the will of the designer. The arrangement illustrated in the drawing and described below may therefore be considered, in the interest of being specific, as being used with one or more keyboard sections of an electric organ.

Referring now to FIG. 1 for a description of the general character of the invention, the apparatus there shown comprises a source **10** of audio frequency signals of the type, for example, usually provided by one or more sections to the output circuit of an electric organ. The source **10**, therefore, may be the organ tone signal generator system, including whatever keying system, formant circuits, or circuits for supplying reverberation, percussion, or other effects are desired, and the signal from such source **10** is impressed on a lead **11** which is connectable through a switch **12** to the input lead **13** of a celeste system indicated generally by the block **14**. When an input signal from the lead **13** is passed through the celeste system **14**, two continuous output signals are produced, as will be described more fully hereinafter, and these output signals are preferably conducted separately, as by leads **16** and **17**, to separate conventional amplifier systems **18** and **19**, and thence to separate conventional speakers **21** and **22**, where the said output signals are translated into sound.

It is not always desired, as when economy is an important consideration, to subject to celeste animation tone signals of all frequencies supplied by the signal source, and in such cases the celeste system **14** will be designed to accommodate tone signals from the lowest frequencies up to some predetermined intermediate frequency in the audible range, e.g., about 4000 cycles per second. In such an arrangement, which is illustrated in the drawing, a lead **23** connected to the input lead **13** provides a branch conductor for the input signals, conducting them to at least one, and preferably two, high-pass filters **24** and **25** which provide a crossover at the cutoff frequench response of the celeste system, and the output sides of the filters **24** and **25** are connected by leads **26** and **27** respectively to the amplifier systems **18** and **19**. Thus, input signal frequencies below about the cutoff frequency response of the celeste system are attenuated by the filters **24** and **25**, and the remaining higher frequencies pass through the filters and are amplified and translated into sound together with the output signals from the celeste system.

It will, of course, be understood by those skilled in the art that additional switching means (not shown) may be provided for directing the signal present on lead **11** elsewhere—for example, directly to suitable amplifiers and electroacoustical translating means—and that switch **12** in FIG. 1 is merely symbolic of the fact that the celeste system can be switched into and out of the output system of the organ. Also, if desired, the signal from the leads **16** and **17** may be joined under certain conditions (e.g., in the interest of cost saving, when the input to the celeste system is in the form of complex wave signals) and conducted together to a single amplifier system, such as **18**, for instance.

The celeste system **14** is illustrated in greater detail in FIG. 2 to which reference is now made for a more complete description thereof. The input lead **13** is connected through an impedance element **R30**, here shown as a resistor, to the input end of an artificial electrical transmission line, indicated generally as **31**, consisting of a plurality of phase-shift sections indicated by blocks designated **S0**, **S1**, **S2**, **S3**, **S4**, **S5**, **S6**, **S*n*–1**, and **S*n***, and terminating in a suitable matching impedance such as a resistor **R32** to ground which is effective to prevent reflection of the signal from the output end of the transmission line. A junction **33** in the lead connecting the resistor **R30** to the section **S0** of the transmission line is grounded through a capacitor **C34**.

Artificial electrical transmission lines of the type useful in the present celeste system are frequently referred to as audio frequency delay lines. In such lines the phase of the input signal is retarded progressively along the line from its signal input end. Similar lines can be constructed in the form of advancing-phase lines wherein the phase of the input signal is advanced progressively along the line from the signal input end, and such lines could be used, but I prefer to use a transmission line of the delay type and, accordingly, in the embodiment of the invention described herein, the transmission line **31** will be in the form of an audio frequency delay line.

As a general background, a somewhat similar audio frequency delay line to that used in the present invention, and the manner in which it may be used to change the frequency cyclically of electrical tone signals impressed upon the line, to produce a vibrato, is disclosed in U.S. Patent No. 2,382,413, to Hanert. The construction of the delay line **31** is subject to numerous variations in design in accordance with well-known principles, depending on the phase-shift per section, band-width, cutoff frequency response, and other characteristics necessary or desired for carrying out its function of changing the frequency of electrical signals impressed upon the line. Generally speaking, any audio frequency delay line may be used in this invention which provides uniformly phase-shifted signal outputs at spaced points or terminals along its length, and at which points the amplitudes of the signals are substantially the same. Thus, this invention is not specifically concerned with the particular delay line shown for purpose of illustration. One skilled in the art, once he has decided on the cutoff frequency, band-width, and phase-shift per section which he desires in an audio frequency delay line for use in a celeste system in accordance with the present invention, will be able readily to design and assemble a suitable delay line having the necessary output characteristics above mentioned.

The filters **24** and **25** are of conventional construction and are matched with the delay line **31** in that the filters attenuate signals having frequencies up to about the cutoff frequency of the delay line and allow the unattenuated higher frequency signals to pass through, and the filters may include means for controlling the amplitude of their output signals to render them compatible, when translated into sound, with the output signals of the celeste system, all in a manner well understood by those skilled in the art.

The delay line sections **S0** to **S*n*–1** are substantially identical, each being made up of an inductance element **L35** connected to ground at its output end through a capacitor **C36**. The delay line section **S*n*** also includes an inductance element **L35**, but in this section the element **L35** is connected at its output to ground through a capacitor **C37**. The inductance elements **L35** are connected in series, as shown, and are all of equal value. The capacitors **C36** are also of equal value, and each has a capacitance twice that of each of the capacitors **C34** and **C37**. In an audio freqeuncy delay line so constructed the amplitude of a signal impressed thereon can be substanially the same at both ends of the delay line and at junction points **38**, **39**, **40**, **41**, **42**, **43**, **44**, and **45** between adjacent delay line sections.

The device for scanning the delay line **31**, which constitutes part of the celeste system, comprises a plurality of stationary capacitor plates or segments **46**, **47**, **48**, **49**, **50**, **51**, **52**, **53**, **54**, **55**, **56**, **57**, **58**, **59**, **60**, and **61** arranged in a circle in equally spaced relation, and a pair of movable scanning members, in the form of capacitor plates **62** and **63**, mounted at the ends of an arm **64** of electrical insulating material extending diametrically of the circle of stationary capacitor plates. The number of such stationary segments in the scanning device is two less than twice the number of delay line sections which are to be scanned. In the embodiment specifically shown in FIG. 2 nine delay line sections are scanned, and accordingly the scanning device is shown as having sixteen stationary capacitor segments. The arm **64** is mounted at its center on a rotatable shaft **66** which is coupled in driven relation to any suitable rotating means (not shown), such as a motor-driven belt and pulley arrangement, capable of rotating the shaft **66** at a suitable slow speed up to about three revolutions per second (r.p.s.).

The junction **38** between the first and second sections of the audio frequency delay line **31** is connected by a lead **68** to the plate **46**, and a junction **70**, provided in the delay line between the section **S*n*** and the resistor **R32**, is connected by a lead **72** to the plate **54** diametrically opposite the plate **46**. The junction **39** is connected through a lead **74** to plates **47** and **61**, and, similarly, the junctions **40**, **41**, **42**, **43**, **44** and **45** are connected respectively through leads **76**, **78**, **80**, **82**, **84** and **86** to the pairs of stationary plates **48** and **60**, **49** and **59**, **50** and **58**, **51** and **57**, **52** and **56**, and **53** and **55**, as shown. Thus, the two ends of the scanned portion of the delay line are connected respectively to diametrically opposed stationary capacitor plates or segments of the scanning device, and the junctions between successive adjacent scanned delay line sections are progressively connected to pairs of such stationary capacitor segments progressively from one of such diametrically opposed segments to the other in the semi-circular arcs of segments forming the circular arrangement, and the voltages at the junctions **38** to **45** and **70** are impressed on the respective stationary capacitor segments thus associated with the junctions.

The movable scanning capacitor plate **62** is connected by a lead **88** to a slip ring **90** contacted by a brush **92** connected to the lead **16**. Likewise, the movable plate **63** is connected by a lead **94** to a slip ring **96** which is insulated from the shaft **66** and from the slip ring **90**, and the slip ring **96** is contacted by a brush **98** connected to the lead **17**.

A suitable mode of construction for the scanning device illustrated in FIG. 2, and its operation with an audio frequency delay line, are shown and described in the above mentioned Hanert Patent No. 2,382,413, and in U.S. Patent No. 2,905,040, also to Hanert. Referring now to the drawing for a clearer understanding of the operation of the present apparatus, and of the manner of practicing the present method, when the player of the musical instrument desires to brighten the output sound by introducing celeste animation, the switch **12** is closed, whereupon the tone signals from the source **10** are impressed on the input lead **13**. The tone signals may be those corresponding to any sound which it is desired to brighten and may correspond to a single note or a number of notes played simultaneously, and such signals may have been previously affected by other animation effects such as vibrato, reverberation, percussion, etc. Tone signals having frequencies above the range adapted to be accommodated by the selected celeste system (i.e., frequencies equal to or higher than the cutoff frequency response of the audio frequency delay line **31**) are attenuated by the impedance element **R30** and the capacitor **C34**, and by line section **S0**, so that signals reaching the junctions **38** to **45** and junction **70** of the delay line have frequencies lower than such cutoff frequency response value. The scanning arm **64** is rotated on its shaft **66** at a constant speed of not more than about 3 r.p.s. bringing the movable capacitor plates **62** and **63** successively into and out of capacitative relation with the stationary capacitor segments **46** to **61**, the plates **62** and **63** thus being individually affected by the signal voltages on the segments **46** to **61** and picking up successively the signals appearing on the latter. As described above, the connections between the plates **46** to **61** and the respective junctions **38** to **45** and **70** are such that when the capacitor plates **62** and **63** are moved successively past the capacitor segments **46** to **61**, the plates **62** and **63** respectively scan to and fro along the delay line **31**. Thus as the arm **64** rotates about the axis of the shaft **66**, the movable capacitor plates **62** and **63** scan the delay line cyclically in a to and fro manner, the scanning direction of one of said movable capacitor plates relative to the delay line being opposite to that of the other movable capacitor plate.

The signals on the respective segments **46**, **47**, **48**, **49**, 50, 51, 52, 53 and 54, and on the respective segments **46**, **61**, **60**, **59**, **58**, **57**, **56**, **55** and **54**, are characterized by progressively delayed phase starting with the segment **46**, and will, when the segments are scanned by the movable scanning members **62** and **63**, produce on such movable scanning members a new signal of higher frequency than that of the input signal when the direction of scanning is toward the input end of the delay line, and will produce on such movable scanning members a new signal of lower frequency than that of the input signal when the direction of scanning is away from the input end of the delay line. Such new signals are produced alternately on each of the scanning members **62** and **63**, and the two new frequencies differ from the input frequency by the same amount. Since the movable scanning members **62** and **63** effectively scan the delay line **31** in opposite directions, and alternately to and fro, when the signal produced on one of such movable scanning members is of the said higher frequency the signal produced on the other of such movable scanning members will be of the said lower frequency.

The signals picked up by the movable capacitor plate **62** are conducted through its slip ring **90** and brush **92** to the amplifier system **18** and speaker **21**, while the signals picked up by the movable plate **63** are conducted through its slip ring **96** and brush **98** to the amplifier system **19** and speaker **22**. Since the junctions **38** and **70** at the ends of the scanned portion of the delay line are connected respectively to but a single stationary capacitor plate (i.e., to diametrically opposed plates **46** and **54**), reversal of scanning direction by the movable plates **62** and **63** at the ends of such scanned portion of the delay line is very rapid, and consequently the change in frequency of the signal picked up by each of the scanning members **62** and **63** as a result of the reversal of scanning direction is substantially instantaneous. Scanning the delay line in this manner produces the effect of two continuous musical tones emanating from the speakers **21** and **22** for each tone signal impressed on the delay line, one such tone having the higher frequency and the other the lower frequency, as compared with the frequency of such input tone signal, for when one speaker is playing the sharped tone the other is playing the flatted tone, and vice versa, producing the effect of continuity of both output sounds for the duration of such input tone signal, when the speakers are placed close together.

For the production of celeste animation of high quality, all sections of the audio frequency delay line should be scanned at the same rate, and, accordingly, the stationary plates or segments **46** to **61** are preferably of equal length (measured in the direction of movement of the plates **62** and **63**) and of equal capacitance, and the scanning plates **62** and **63** are also preferably of equal length (similarly measured) and of equal capacitance, and are rotated about the axis of the shaft **66** at substantially constant speed. Also, the spacing between adjacent segments **46** to **61** is preferably negligible compared to the length of such segments, so that the scanning plates will be affected by the signal voltages on the successive segments **46** to **61** without interruption.

A number of other factors may also adversely affect the pure quality of celeste animation produced by scanning an audio frequency delay line through which the input signal passes. For example, unless the delay line is properly designed, the audio signal will have different amplitudes at some of the junctions between adjacent sections of the line, so that even if the line is scanned at constant speed, a disturbance similar to tremolo will appear in the sound emanating from the instrument output system. Also, differences in phase-shift per section of delay line may result from differences in characteristics of the coils and capacitors used in forming the line, and in such cases an undesirable vibrato-like effect may appear in the output sound. When the termination in the delay line is not properly designed, a disturbance in the

form of a "ringing" or "echo" effect may result in the output sound. In addition, if the stationary capacitor plates or segments of the scanning device are not equally spaced from each other throughout the entire circle defined by them, or if the movable scanning plates **62** and **63** are not maintained at the same constant distance from such stationary plates during the scanning operation, some disturbance akin to tremolo—in some cases with an accompanying vibrato-like disturbance—appears in the output sound. It is to be noted that the above mentioned disturbances may be particularly undesirable in pure celeste, that is, celeste without other accompanying animation, since celeste consists of two instantaneous frequencies slightly above and below the true frequency of the note being played and, therefore, contains no pronounced masking animation which could cover up the disturbance, as is the case with, say, vibrato or tremolo.

It is difficult, if not impossible, to construct an audio frequency delay line and scanning device with such precision as to avoid all of the defects in construction and operation which could adversely affect the quality of the celeste animation produced. However, I have found that if the scanning speed is maintained considerably below the lower end of the commonly accepted vibrato rate range of 5.5 to 7.5 cycles per second (c.p.s.)—for example, below about 3 c.p.s.—the disturbances resulting from such accidental defects may be reduced to the point where they are not perceived by the ear. Although a scanning rate generally of less than about 3 c.p.s. is usually satisfactory for producing celeste animation in accordance with the present invention, I prefer to use a scanning rate not greater than about 2.5 c.p.s. in order to provide a margin of safety in overcoming such disturbances, since the factors causing the disturbances in the output signals, and the extent to which such factors contribute to the disturbances, may differ considerably in different situations. At scanning speeds above about 3 c.p.s. the disturbances in the output sound caused by defects in construction or operation of the apparatus become increasingly apparent, and may become decidedly objectionable when the scanning is done at a vibrato rate of about 6 c.p.s.

The slow scanning rates employed in accordance with the present invention are an important factor by which this invention is distinguished over the method and apparatus of the above mentioned Patent No. 2,905,040 wherein an audio frequency delay line is scanned by two pickups simultaneously and in opposite sense or direction at a vibrato rate to produce oppositely phased vibrato, which, of course, is not a celeste. A further feature of the present invention is that the ends of the scanned portion of the delay line are connected, respectively, to but a single stationary capacitor plate of the scanning device, so that when scanning the delay line at constant speed by the two opposed movable scanning members, the change from the sharped to flatted frequencies, and vice versa, effected by reversal of the scanning direction at the ends of the scanned portion of the line, is substantially instantaneous, as shown in FIG. 3. This is in contrast to the results obtained with the apparatus of Patent No. 2,905,040, in which the ends of the scanned portion of the delay line are connected respectively to a pair of adjacent stationary capacitor plates of the scanning device, whereby, in the operation of the patented device, there occurs an interruption in th econstancy of rate of phase-shift as the movable scanning members periodically come into capacitative relation with such pairs of stationary capacitor plates, causing the instantaneous scanner output frequencies briefly to remain at the frequency of the input signal during each reversal of scanning direction at the ends of the scanned portion of the delay line. Such periodic changes in the rate of phase-shift are not desired in the production of pure celeste animation, as noted above.

The input signal impressed on the lead **13** is likewise impressed on the lead **23** connected to the high-pass filters **24** and **25**. These filters are matched with the celeste system and have the capability of passing all frequencies from the cutoff frequency response of the transmission line **31** upwardly to the highest frequencies produced by the musical instrument, and, preferably, frequencies also somewhat below such cutoff frequency response. The signals passing through the filters **24** and **25** are then conducted to their respective amplifier systems **18** and **19** and speakers **21** and **22**, where they are translated into sound along with the signals picked up by the scanning members **62** and **63**. Thus, all signals produced by the musical instrument are represented in the output sound, the signals of lower frequency being given celeste animation, and the signals of higher frequency being translated into sound without change.

It is obvious that as the cutoff frequency response of the delay line is raised, and the phase-shift per section of the line is reduced, the frequency range of input signals to the delay line which may be given celeste animation is broadened, requiring a narrower range of high frequencies to be by-passed through the high-pass filters **24** and **25**, which of course would be designed to have crossovers at correspondingly higher frequencies. For the best celeste effect, therefore, the delay line should have a cutoff frequency response no lower than the upper limit of the output frequency range of the musical instrument, and a small phase-shift per delay line section. However, apparatus for achieving such desirable results in electric organs would be quite expensive, since a delay line of a great many sections would be necessary, requiring a scanning device having a correspondingly large number of stationary scanner segments, which would render such an apparatus competitively unacceptable for any commercial uses.

In an illustrative specific embodiment of my celeste apparatus in which the delay line has nine phase-shift sections, all of which are scanned as described generally above, each of the inductance elements L35 has a value of .44 henry, each of the capacitors C36 has a capacitance of .012 microfarad, each of the capacitors C34 and C37 has a capacitance of .0056 microfarad, and each of the resistors R30 and R32 has an impedance of 6000 ohms. Such a delay line has a cutoff frequency of 4400 c.p.s. and provides a phase-shift for each of the nine sections of 25° at one kilocycle. Since nine delay line sections are scanned, the scanning device has sixteen stationary capacitor segments **46** to **61**. The resistor R30 and capacitor C34, having the values just mentioned, are effective in attenuating frequencies in the input signals above the cutoff frequency response of the delay line. Correspondingly, the filters **24** and **25** in this instance are designed to attenuate signals having frequencies below about 4400 c.p.s., and will pass signals having frequencies above about 4400 c.p.s. to the respective associated amplifier systems and speakers. With this embodiment of my celeste system, satisfactory celeste animation of the frequencies of the input signals up to about the cutoff frequency response of the delay line is obtained by rotating the scanning arm **64** at 1.8 revolutions per second, which speed of rotation produces a frequency shift of .2%. Thus, referring to FIG. 3, if the instantaneous frequency of the input signal *a* is 1000 c.p.s., the instantaneous frequencies of the two output signals *b* and *c* picked up by the scanning plates **62** and **63** will be alternately 998 c.p.s. and 1002 c.p.s. Input signals are also conducted by the lead **23** to the filters **24** and **25** which pass signals having frequencies above about 4400 c.p.s. to the respective amplifier systems and speakers for translation into sound simultaneously with the two output signals from the scanning device. Thus, signals of all frequencies from the signal source **10** are represented in the output sound of the instrument, and while only the lower frequency signals are subjected to celeste animation, the final effect is pleasing to the ear and this embodiment of my celeste apparatus, which is relatively inexpensive, provides a satisfactory celeste effect for low or moderate cost electric organs or other musical instruments.

A further illustrative specific embodiment of my invention, capable of providing celeste animation to tone signals throughout an extremely wide frequency range, will now be described, reference again being made to FIG. 2. In this embodiment, the delay line **31** consists of a total of 41 phase-shift sections S0 to S*n* (*n* equals 40), of which all are scanned for producing celeste animation, and the components thereof have the following values: L35 .44 henry; C36, .0014 microfarad; C34 and C37, .0007 microfarad; and R30 and R32, 18,000 ohms. Such a delay line has a cutoff frequency of 13 kilocycles per second, and provides a phase-shift for each of the 41 delay line sections of 9° at one kilocycle. Inasmuch at 41 sections are scanned, the scanning device has 80 stationary capacitor segments similar to the segments **46–61** and similarly disposed in circular arrangement. As with the previous embodiment, the resistor R30 and capacitor C34 are effective in attenuating frequencies in the input signals above the cutoff frequency response of the delay line (13 kilocycles per second in this instance), thus preventing such high frequency signals from being conducted to the delay line.

With such a delay line, highly satisfactory celeste animation of the input signals is obtained by rotating the scanning arm **64** and its plates **62** and **63** at one revolution per second, which speed of rotation produces a frequency shift of .2%. Thus, referring again to FIG. 3, if the instantaneous frequency of the input signal *a* is 1000 c.p.s., the instantaneous frequencies of each of the two output signals *b* and *c* picked up by the scanning plates **62** and **63** will be alternately 998 c.p.s. and 1002 c.p.s. In a system using an audio frequency delay line having the characteristics of the latter embodiment just described, the branch line **23** and the high-pass filters **24** and **25** may be omitted.

It is seen, then, in summary, that the present invention provides, broadly, method and apparatus for producing celeste animation in electrical tone signals by scanning an audio frequency delay line, on which such signals are impressed, cyclically to and fro by two movable scanning members scanning simultaneously in opposite sense or directions. As the signal produced on one scanning member suddenly changes frequency in one direction, the signal produced on the other scanning member suddenly and simultaneously changes frequency in the opposite direction. Thus, two new signals are produced having frequencies respectively and alternately higher and lower than that of the input signal and proportional in pitch throughout the range of frequencies that the delay line is responsive to. The frequencies of the new signals produced by scanning the delay line are dependent on the speed of rotation of the movable scanning members, and on the phase-shift per delay line section. Thus, for a delay line having a given phase-shift per section, the frequency change produced by scanning may be varied by varying the scanning speed. Also, for a given scanning speed the frequency change produced by scanning may be varied by varying the phase-shift per section of the delay line. However, in accordance with the invention, a delay line having a phase-shift per section so small as to require scanning speeds as high as 3 c.p.s. or higher should not be used, for the reasons previously mentioned, and preferably the phase-shift per section is such as to permit scanning speeds of no more than about 2.5 c.p.s., or less, to produce the desired frequency change.

The amount of frequency change may of course be varied widely by proper selection of the scanning speed and phase-shift per section of delay line. However, for celeste animation I prefer to design and operate the apparatus so that the frequency change obtained is no more than about 1% of the input signal frequency; i.e., the output signals will have frequencies no more than 1% above and about 1% below the frequency of the input signal. It will be understood that others may prefer a greater degree of frequency change and may alter the design or operation of the apparatus accordingly. There is, of course, no minimum limit to the frequency change, although when it gets to small to be detected by the ear the celeste effect will not be produced.

As is well known in the art, the characteristics of an audio frequency delay line, such as cutoff frequency and band-width, are matters of choice with the designer, as are other factors such as the number of sections in the delay line, the phase-shift per section and the scanning speed for any given frequency shift desired in the output. For example, as shown in the foregoing description of the two embodiments of my celeste apparatus, the cutoff frequency response of the delay line may be increased by decreasing the value of th capacitors **C36** and/or decreasing the value of the inductances **L35** and consequently increasing the number of delay line sections. As the cutoff frequency response is raised, the network **R30**, **C34** is preferably changed in known manner to pass frequencis up to the new frquency response of the delay line, and the high-pass filters **24** and **25** are also changed to raise correspondingly the level of the lower cutoff frequency thereof until the band width of the delay line equals the system band width. However, as mentioned above, if an audio frequency delay line is provided with a cutoff frequency response higher than the highest frequency provided by the signal source **10**, the by-pass line **23** and filters **24** and **25** are rendered unnecessary.

It will also be understood that a scanning device having a given number of stationary capacitor segments may be used to scan delay lines of different lengths, or to scan portions of delay lines, so long as the phase-shifts between output terminals along the delay line connected progressively to the stationary capacitor segments, as described above, are the same, and so long as the maximum scanning speed, as determined by the frequency change desired, is not required to be 3 c.p.s. or greater. Also, although I have shown a scanning device having a single pair of movable scanning members **62** and **63** 180° apart for scanning the delay line, it will be understood that additional pairs of such movable scanning members may be used, if desired, provided that the scanning members of each pair are 180° apart.

From the accompanying drawing and the foregoing description of illustrative embodiments of my invention, those skilled in the art will be able readily, and without the exercise of invention, to design, construct and operate a device in accordance with the invention for producing a celeste effect in sounds originating in the form of electrical signals. Also, it will be apparent to those skilled in the art that numerous modifications and variations may be made in the form, construction and operation of my invention without departing from the spirit and scope thereof. I therefore desire, by the following claims, to include within the scope of my invention all such similar

modified forms of the apparatus and method disclosed by which substantially the results of the invention may be obtained by substantially the same or equivalent means.

I claim:

1. In apparatus for improving sound derived from a source in which the sound is in the form of an electrical signal, the combination of an artificial electrical transmission line having a plurality of terminals along its length adapted to provide at least nine substantially uniformly phase-shifted signal outputs and having its input end coupled to said source, scanning means including two pickups and means for operating said pickups effectively to and fro along said transmission line to scan said terminals progressively with a smooth prgressive transition from each terminal to the next at the same substantially constant speed of less than about 3 c.p.s. but in opposite directions so as to provide a constant rate of phase shift until the ends of the line are reached and including means for reversing the direction of scan of both said pickups simultaneously and substantially instantaneously with an abrupt transition at the ends of said line, and means for amplifying and translating into sound the signals impressed on both said pickups.

2. An apparatus for modifying an audio frequency electrical tone signal which comprises means for substantially uniformly and smoothly progressively phase shifting the signal in one direction for a half cycle of at least ⅙ of a second while simultaneously uniformly and smoothly progressively phase shifting the same signal in the opposite direction during the same period, said phase shifting means substantially instantaneously at the termination of said period reversing the two directions of uniform smooth progressive phase shift of said signal for a like time interval half cycle to provide two periodically abruptly terminated and reversed as to direction of phase shift cyclical progressively phase shifted new signals which two phase shifted new signals are phase shifted oppositely with respect to each other continuously excepting for periodic momentary transitions, and means for amplifying and transducing into sound both of said phase shifted new signals.

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