June 29, 1943. F. D. MERRILL, JR 2,323,231

METHOD AND APPARATUS FOR THE PRODUCTION OF MUSIC

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Fig. 1

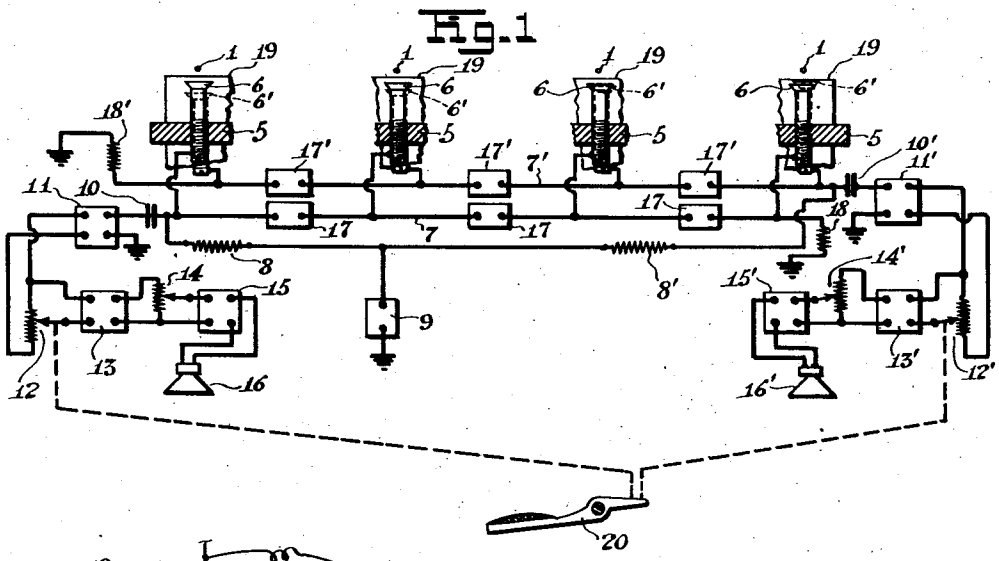


Fig. 2

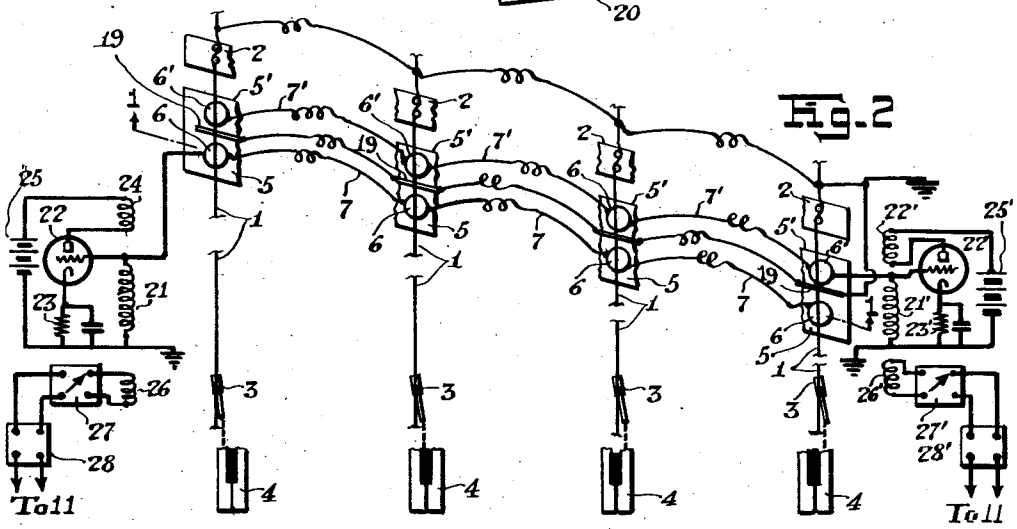
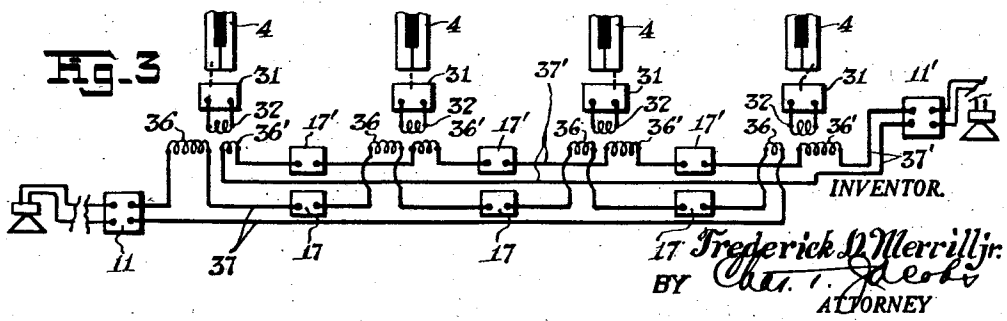


Fig. 3



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METHOD AND APPARATUS FOR THE PRODUCTION OF MUSIC

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This invention relates to the production of music, and more particularly to that production by the translation of musical tones from electric oscillations selectively produced and/or controlled at the will of a player.

In instruments adapted for the production of music in the stated manner, it is of course the most common practice to employ a single electro-acoustic translating device, or loudspeaker, from which there emanate the sounds of all frequencies within the range of performance of the instrument. A fairly common variation of this practise is the employment of a plurality of loudspeakers either inherently most efficient in respective different frequency ranges within the range of the instrument, or made so by different frequency-discriminating networks respectively associated therewith, or both; in such a case the loudspeakers operate with some degree of selectivity as to frequency. It further is known (as disclosed in Patent No. 2,200,718 to Miessner, and as has been disclosed and claimed in the copending application of said Miessner, Serial No. 335,064, filed May 14, 1940, and assigned to the assignee of this application) physically to place a plurality of loudspeakers each operating most efficiently in a respective different frequency range—for example a pair of loudspeakers—in respective portions of an electronic instrument respectively corresponding to those portions of a purely acoustic instrument from which sounds within the respective ranges are most efficiently radiated—for example in an electronic piano, to place a loudspeaker most efficient in the base register near the lefthand, and a loudspeaker most efficient in the treble register near the righthand, extremity of the keyboard.

While valuable improvements over single-speaker performance may be achieved by simple recourse to the above mentioned practices, they fail to achieve a full simulation of a conventional-instrument performance. I have observed that that is because the selectivity of a position in a conventional instrument from which respective tones emanate is primarily based on the region within that instrument where the tones originate, rather than simply on the absolute frequency of those tones. The distinction may be without point for the lowest partials of a tone, but becomes important for the higher partials. For example, all the partial components of a bass tone produced by a conventional piano appear to radiate most strongly from its lefthand side—the position of the string which serves as their origin—and this is true for the higher partials which are usually prominent in such a tone, as well as for the lower partials. Yet by the practises above-mentioned the higher partials would be caused to radiate most strongly from the opposite (righthand) side of the electronic instrument which was designed to simulate the acoustic one.

It is an object of my invention to improve or complete the simulation, by an electronic instrument, of conventional-instrument performance in the respect just discussed.

It is an object to cause the different notes produced by an electronic instrument to appear to originate in respective different portions of the instrument.

It is an object automatically to vary the apparent source of the different notes according to the fundamental frequencies, or pitches, of those notes, without distinction within any note between its several partials.

It is an object to accomplish the foregoing for the predominate portion, in respect of amplitude, of each note as produced by the instrument, while permitting the remaining portion of the tone to have a different or diffuse apparent source.

It is an object to provide means and methods appropriate to the fulfilment of the foregoing objects; and it is a particular object to provide such means and methods adapted for use in electronic pianos.

Other and allied objects will more fully appear from the following description and the appended claims.

In the description reference is had to the accompanying drawing, in which:

Figure 1 is a view, partly in vertical section and partly schematic, of portions of an electronic piano in which my invention has been incorporated and of one form of associated electrical circuit which may be associated therewith;

Figure 2 is a view, partly plan (Figure 1 being taken along the line 1—1 of Figure 2) and partly schematic, of the same portions of the piano illustrated in Figure 1, but by way of example with another form of electrical circuit which may be associated therewith; and

Figure 3 is a schematic view of an electronic musical instrument in which my invention has been incorporated in a modified embodiment.

Figure 1 and the mechanical portion of Figure 2 illustrate an embodiment of my invention in an electronic piano. (Assuming the piano to be of the "grand" arrangement, Figure 1 will be a ver-

tical cross-sectional view and Figure 2 a partial plan view, though it will be understood that this is purely by way of example.) The piano is provided with the strings 1, supported in any known way appropriate to electronic piano construction; by way of example, it has been assumed that only one string per note is employed, and for simplicity of illustration only four strings (for the lowest, highest, and two separated intermediate tones) have been illustrated, each terminating its active portion at the rear bridge 2. The strings may be adapted to be excited in the usual manner, hammers 3 having been illustrated in Figure 2 underneath forward portions of the respective strings; the hammers may be operated by the usual keyboard fractionally shown as 4 in Figure 2.

Electric oscillations, whose translation into sound will produce the output tones of the instrument, are translated from the vibrations of the strings 1 by suitable mechanico-electric translating apparatus. While no unexpressed limitation between the several known types of that apparatus is intended or necessary, I have preferred that general type which operates by vibratory variation of the spacing of the string from the translating apparatus; and among the several forms of this type, I have purely by way of example illustrated an electrostatic form. Herein, as is understood, an electrode is provided in quite close spaced relationship to a region along the active portion of the string, for example underneath the string; this electrode forms a minute electrostatic capacity with the string, and the vibration of the string causes the oscillatory variation of this capacity in correspondence with the vibration of the mentioned string region—this oscillatory capacity variation being availed of electrically in one or another known manner, such as one of those more detailedly described hereinbelow.

Spaced a convenient distance below the strings, and for example at an appreciable distance forwardly from the bridge 2, there may be provided a support 5 for electrodes. This support 5, which may be in the form of a strip of insulating material (such as the phenol-resin composition known as "Bakelite"), may in turn be supported in the instrument in any of the manners known in the art. Through the support 5, underneath each string, may be threaded an adjustable electrode 6 in the form of a screw, of which the top extremity may be a flat head, and of which the bottom extremity may be slotted to facilitate adjustment from the bottom when desired.

Electrically the electrodes 6 may be interconnected through a conductor 7; and they may be connected through a high resistance 8 to one terminal of an electrical source 9. (When a certain optional feature mentioned below is employed, the connection of the electrodes 6 to the source 9 is preferably made from the electrode associated with the lowest-frequency string, and it has been so shown.) The other terminal of the source 9 may be connected to "ground"—a reference-potential point to which the strings, as illustrated, may also be connected.

The series combination of high resistance 8 and source 9 may be connected through a capacity 10 to the input of a control system 11, which may comprise any or all known forms of qualitative electric-oscillation control means appropriate to instruments of the character under description. To the output of the control system 11 there may be connected an amplitude-regulating potentiometer 12, to the output of which may be connected the input of an electronic amplifier 13. To the output of the amplifier 13 there may be connected. in cascade, potentiometer or volume control 14, further amplifier 15, and loudspeaker 16.

The source 9 may be operated as a high-voltage direct-current source, in which event its effect will be to charge the paralleled small capacities formed as abovementioned between the strings and their respective electrodes. The charge in these capacities being precluded by the high resistance 8 from rapid variation, the effect of the vibrations of the strings is to modulate, or vary oscillatorily, the otherwise steady voltage across the capacities; and the oscillatory variations in the voltage—constituting vibration-representing oscillations—are transmitted through capacity 10 to the input of the cascade 11—12—13—14 15—16, by which they are controlled in various respects, amplified, and translated into sound.

The source 9 may alternatively be operated as a superaudible-frequency alternating-current source, in which event its effect will be to pass a similar-frequency current through the paralleled small capacities between strings and electrodes. The vibrations of the strings, oscillatorily varying these capacities, will correspondingly modulate this current; and the so modulated current will be transmitted through the capacity 10 to the input of the cascade abovementioned. In this event the amplifier 13 may be operated as a demodulator as well as an amplifier; and it will be understood that the modulated current will be controlled, demodulated—to create oscillations representing the string vibration—amplified, and translated into sound by the cascade.

In carrying out my invention I may arrange the translating apparatus thus far described to act most effectively at the base extremity of the instrument scale and progressively less efficiently in progressively higher-frequency portions of the scale; and I may arrange the loudspeaker 16, as illustrated, to radiate from a portion of the instrument in the vicinity of the bass extremity of the keyboard—since it is from this region in a conventional piano that the base tones predominately radiate. While many methods are available for so arranging the translating apparatus, and while I intend no unexpressed limitation in this respect, I may first mention that which is probably the simplest for an instrument employing translating apparatus which operates by vibratory variation of the spacing of the vibrator from the translating apparatus.

Thus it will be appreciated that, however, the source 9 be operated, the effectiveness or efficiency of the translation of the vibrations of each string will be established by the closeness of the spacing of its respective electrode from it—the maximum practicable efficiency being achieved when that electrode is as close to the string as is possible without risk of the electrode actually being contacted by the string under conditions of maximum vibration of the latter. Accordingly I may employ as close as practicable a spacing for the electrode 6 associated with the most extreme lefthand string, and a spacing progressively greater for the progressively more rightward strings. This I have illustrated for the electrodes 6 in Figure 1. It will be noted that the spacing of these electrodes from the

strings in this figure appears approximately similar throughout the scale; but it is to be appreciated that this actually meets the specification just laid down, because of the fact that the maximum amplitudes of vibration of the strings progressively decrease with higher fundamental frequencies of the strings.

To provide the relative efficiencies of translation last mentioned, recourse may be had to an appropriate adjustment of the spacings of the electrodes 6' from the strings. Such an adjustment will involve a very close spacing of the electrode 6' associated with the extreme treble string (to obtain a high efficiency of translation from a string whose vibration amplitude at maximum is relatively small) and a progressively wider spacing of the electrodes 6' associated with progressively lower-frequency strings, terminating in a relatively wide spacing from the lowest-frequency string. Such adjustments of the electrodes 6' have been illustrated in Figure 1.

It will now be appreciated that all partial components of the tones translated from the most extreme bass strings are most efficiently radiated by loudspeaker 16, while all partial components of the tones translated from the most extreme treble strings are most efficiently translated by the loudspeaker 16'. This, however, is not the only effect of the incorporation of my invention. Because of the progressive arrangement of the efficiencies of translation in the two translating systems, tones derived from the middle-register strings of the instrument are about equally radiated from the two loudspeakers; and if the relative phasing of those loudspeakers be properly established (readily accomplished by test in any given case) all components of those tones will appear—to the player of the instrument and to hearers situated at some distance from the instrument—to radiate predominately from a region intermediate the two loudspeakers. In still more generic terms, the apparent source of strongest radiation of all components of the tone derived from any string will be a region in the vicinity of the key which excited that string—or a region corresponding to that from which the strongest radiation of that tone would occur in a conventional piano.

Further in carrying out my invention, I may provide other translating apparatus arranged to act most efficiently at the treble extremity of the instrument scale and progressively less efficiently in progressively lower-frequency portions of the scale; and I may supply the oscillations translated by this last-mentioned translating apparatus, after their control and amplification, to a loudspeaker arranged to radiate from a portion of the instrument in the vicinity of the treble extremity of the keyboard—since it is from this region in a conventional piano that the treble tones predominately radiate.

Thus in Figures 1 and 2 (reference still being had to the mechanical portions only of the latter figure) there will be seen, spaced below the strings and for example very slightly spaced behind the support 5, a support 5' generally similar to the support 5. Through the support 5', underneath the respective strings, may be threaded adjustable electrodes 6' similar to the electrodes 6. Electrically the electrodes 6' may be interconnected through a high resistance 8' to that terminal of the source 9 to which the high resistance 8 was connected. The series combination of high resistance 8' and source 9 may be connected through a capacity 10' to the input of a cascade 11'—12'—13'—14'—15'—16'—in which each element may be generally similar to the corresponding element in the cascade 11—12—13—14—15—16, excepting for the distinct position of the loudspeaker 16' already noted.

These statements are of course presented especially for the right-and-left dimension of the instrument—the apparent source of radiation in a front-and-back dimension being essentially dependent on the positions in that dimension at which the loudspeakers are actually located. Since the apparent source, insofar as the front-and-back dimension is concerned, does not shift appreciably for tones throughout the scale, an apt choice of the loudspeaker positions is all that is required for properly attending to effects in this dimension.

It was above pointed out that my invention is not limited in respect of the means or method by which the progressive efficiencies of translation in each of the two systems may be established. Purely by way of example of other methods than the spacing adjustment, I have in Figure 1 illustrated the incorporation in the conductor 7 (and in the conductor 7') of impedances 17 (and 17') between the connections of the conductor with the translating devices (i. e., electrodes) for successive vibrators (i. e., strings) or groups of vibrators. With proper choice of the characteristics and magnitudes of the impedances 17 (and 17') the efficiency of translation may be caused by the impedances to decrease progressively with increasing displacement from the point where connection is made from the conductor 7 (or 7') to the coupling capacity 8 (or 8'). Thus with the use of properly chosen impedances it is possible to relax or eliminate the requirement for progressive efficiency adjustment by the adjustment of the spacing of the translating devices from the vibrators.

In the practise according to the foregoing paragraph it is expected that the impedances will be so chosen as significantly to impede or attenuate the transfer of oscillations from the respective translating devices to the coupling capacity (in degree depending on how many of these impedances the oscillations must traverse). As still another exemplary method of securing the graduated efficiency of translation, when there are employed translating devices of the type (such as the electrostatic devices above disclosed) whose efficiency is determined by the amplitude of some parameter (such as a voltage or current) as it appears at the translating device, I may mention the progressive adjustment of that parameter for the successive translating devices.

For the illustrated electrostatic translating devices this may be accomplished by progressively attenuating the voltage or current from the source 9 (according to whether that source is being operated in the first or the second of the manners above disclosed) appearing at the successive translating devices. As an illustration of this Figure 1 may be read as still envisioning the employment of the impedances 17 and 17'—this time in a form and magnitude which need not itself occasion any appreciable attenuation of oscillations—and as additionally contemplating the use of a respective impedance connected to ground from the extremity of each of the conductors 7 and 7' opposite to that extremity of the conductor which is connected to the respective high resistance 8. Such additional impedances have been illustrated in Figure 1 as the resistances 18 and 18', respectively connected to

ground from the high-frequency extremity of the conductor 7 and from the low-frequency extremity of the conductor 7'.

With this circuit structure it will be appreciated that, in the case wherein the source 9 is operated as a high-voltage D. C. source, the steady voltage from the source as it appears at the respective translating devices will, by the several impedances 17 (or 17') and the impedance 18 (or 18') acting in combination, be progressively attenuated at translating devices progressively further from the point of reference (i. e., point of connection of the high resistance 8 or 8'). Employing the term "polarizing voltage" to denote the voltage from the source as it appears at the several translating devices, it may be said that this polarizing voltage—which determines the efficiency of the translating device—is progressively decreased for the translating devices progressively further from the reference point. And obviously in the case wherein the source 9 is operated as a superaudible A. C. source the amplitude of the current to be modulated—and hence the amplitude of the modulations as they appear, in the form of sound-frequency voltages, in the amplifier 13 or 13' following the demodulating action—is correspondingly progressively decreased for the translating devices progressively further from the reference point.

The electrical-circuit portion of Figure 1 has illustrated a translation by the electrostatic translating devices, both through modulation of a steady high voltage and through modulation of the amplitude of a superaudible-frequency current. It is also possible (as disclosed in the copending application of B. F. Miessner, Serial No. 243,127, filed November 30, 1938, and assigned to the assignee of this application, and which is now Patent No. 2,273,975) to translate the string vibrations by the electrostatic translating devices through modulation of the frequency of a superaudible-frequency current. The electrical-circuit portion of Figure 2 has been included to illustrate this alternative—it being understood that the mechanical portions of Figures 1 and 2 will be taken together as illustrating the mechanical arrangements for either of the illustrated circuit arrangements.

In the Figure-2 circuit structure the paralleled capacities between the electrodes 6 and the strings are shown connected across a coil 21, with which they act as a tuning capacity to form a parallel resonant circuit. This circuit may be connected from the grid of an oscillator tube 22 to the lower end of a by-passed bias resistance 23, that lower end also for example being grounded, and the upper end of that resistance being connected to the cathode of the tube 22. In the plate circuit of the tube there may be connected a coil 24 in feeding-back inductive relationship to the coil 21, as well as a battery or other source 25 of plate current for the tube. It will be recognized that the circuit is one adapted for the production of sustained oscillations at the frequency determined by the tuning of the grid circuit abovementioned; and it will be understood that, in view of the connection of the electrodes 6 as just described, that frequency will be modulated upon, and in accordance with the characteristics of, the vibrations of any of the strings 1. A coil 26 inductively coupled to the coil 21 may impress the frequency-modulated oscillations on a control system 27 comprising any and all desired known forms of control means appropriate to the oscillations in their frequency-modulated form; and a frequency-demodulator 28 may be associated with the control means 27 to demodulate the oscillations, and to pass the demodulated oscillations—now of frequencies corresponding to those of the string vibrations—to the cascade 11—12—13—14—15—16 as shown in Figure 1.

The oscillator and allied circuits just described are interposed between the electrodes 6 and that cascade—11—12—13—14—15—16—which is to function most efficiently for the bass register, by reason of appropriate measures taken in the electrode circuit. An essentially similar combination of elements, 21'—22'—23'—24'—25'—26'—27'—28', will be interposed between the electrodes 6' and the cascade 11'—12'—13'—14'—15'—16' which, by reason of complementary measures, is to function most efficiently for the treble register.

Insofar as the practise of my invention is concerned, the overall effect of the frequency-modulation arrangement, just described, will be appreciated to be generally similar to the effect of either of the other arrangements heretofore described. In this connection it may be noted that while, again, any of a variety of methods may be employed for securing the graduated efficiency in each of the two translating systems, the simplest is probably the spacing-adjustment method first above described; the electrode adjustment typically illustrated in Figure 1 may therefore be taken as generally appropriate for the frequency-modulation arrangement.

In connection with any of the arrangements illustrated by Figures 1 and 2 two particular further points deserve mention. One is the matter of electrostatic shielding. Over and above the electrostatic shielding (not illustrated) which is known to be desirable in instruments of this general character, there is also desirable—at least when the two electrode systems are relatively close to each other—an electrostatic shielding interposed between those systems. Such shielding I have illustrated in Figures 1 and 2 as a thin metal strip 19 vertically arranged and interposed between the supports 5 and 5' and the electrodes respectively carried thereby. The effect of such shielding is the prevention of unwanted transfer of oscillations between the electrode systems, and of the undesirable impairment of distinction of their respective outputs which would result from such transfer.

The other particular point is the frequent desirability of interlinking certain of the corresponding controls in the cascades 11—12—13—14—15—16 and 11'—12'—13'—14'—15'—16'—more particularly, of interlinking those controls which in a normal use of the instrument would be always correspondingly manipulated. By way of example such interlinking has been indicated for the volume controls 12 and 12' of the respective cascades, by the schematically shown linking of each of those controls to the common foot-pedal 20 for joint manipulation thereby—though obviously no limitation of such interlinking to the volume controls is necessary, and none is intended excepting as specifically expressed.

As above noted, the translating devices to be employed in carrying out my invention need not be electrostatic devices. And I may here point out that while the tone sources for the several notes have in Figures 1–2 been illustrated as mechanical oscillators or vibrators (specifically, strings), they may in a broader aspect of my invention be oscillators of some one of a variety of other forms—for example, electrical oscil-

lators. Purely by way of example, Figure 3 illustrates an instrument employing oscillators which may be either electrical or mechanico-electrical, together with what may be termed electromagnetic translation of their outputs. The several oscillators are schematically illustrated as 31, there being again employed the same simplified illustration, of four different-note oscillators separated throughout the instrument range, as in the case of the strings of earlier figures. The oscillators are schematically indicated to be placed under the control of respective keys of the keyboard 4 in any desired manner. Each oscillator may be considered to include a respective output coil 32. Cascades 11—12—13—14—15—16 and 11'—12'—13'—14'—15'—16' may be employed as before, with the loudspeakers similarly radiating from two respective positions as above described; by way of illustration, however, it will be assumed that the conventional instrument being most nearly simulated is an organ in which the low- and high-frequency pipes would be separated from each other by a considerably greater distance than the length of the keyboard, and accordingly the two speakers have been shown as separated by a correspondingly large distance. The translating devices effective for the cascade first mentioned may comprise coils 36 respectively coupled to the output coils 32 of the oscillators and for example connected in a series circuit 37 across the input of 11; while the translating devices effective for the second-mentioned cascade may comprise coils 36' also respectively coupled to the output coils 32 of the oscillators, but connected in a circuit 37' across the input of 11'. The graduated efficiency of devices 36 may be achieved for example, by progressive variation of the numbers of turns in the successive devices (the largest number being in the device for the lowest-frequency note), and the graduated efficiency of the devices 36' by an opposite progressive variation of the numbers of turns in those devices. Preferably these variations of numbers of turns will be carried to or substantially to the scale extremities, so that there will be achieved the unimpaired effect of shift of apparent sound origin with fundamental note frequency throughout or substantially throughout the full scale of the instrument. Further description of the instrument of Figure 3 will be unnecessary, since its operation will be readily understood in the light of the foregoing description of other embodiments.

It may be mentioned that while a principal feature of my invention involves the use of the separate cascades, and separate loudspeakers therein, I do not intend to disclaim novel subcombinational aspects of my invention which may not necessarily involve such a separated plurality of loudspeakers or of the means for supplying the oscillations thereto.

And while I have disclosed my invention in terms of particular embodiments thereof, it will be understood that this has been done in an exemplary rather than in a limiting sense, for modifications will be suggested by these embodiments to those skilled in the art. Such modifications will not necessarily constitute departures from the spirit of the invention or from its scope, which latter I undertake to define in the following claims.

I claim:

1. In an electronic piano including vibratable strings progressively tuned to the several notes of the scale: the combination of two separated electro-acoustic translating devices; and means for translating electric oscillations from said strings and supplying the same to said devices, said means being characterized by a joint selectivity with respect to said devices and with respect to said strings, whereby to cause the different notes as radiated by said devices jointly to have respective apparent sources dependent on note frequency.

2. In an electronic piano including vibratable strings progressively tuned to the several notes of the scale: the combination of two electro-acoustic translating devices radiating sounds from near the bass-string and treble-string extremities of said instrument, respectively; and means for translating electric oscillations from said strings and supplying the same to said devices, said means being characterized by a joint selectivity with respect to said devices and with respect to said strings, whereby to cause each different-frequency note as radiated by said devices jointly to have an apparent source in the side-to-side region of the string from which it was translated.

3. In an electronic musical instrument including oscillators progressively tuned to the several notes of the scale: the combination of two electro-acoustic translating devices radiating sounds from respective separated positions; and means for translating electric oscillations from said oscillators and supplying the same to said devices, said means being characterized by a joint selectivity with respect to said devices and with respect to said oscillators, whereby to cause the different notes as radiated by said devices jointly to have respective apparent sources dependent on note frequency.

4. In electronic piano-tone production from the vibrations of tuned strings, the method of creating the illusion of origin of each note sound in a region dependent on note frequency, which comprises translating two separate series of electric oscillations from the string vibrations; rendering the efficiencies of translation of said two series highest in respectively opposite first extreme regions of the scale and progressively lower toward the respective second extreme scale regions; translating each of said series of oscillations into sounds; and radiating the respective sounds from separated respective regions.

5. In electronic tone production from tuned oscillators, the method of creating the illusion of origin of each note sound in a region dependent on note frequency, which comprises translating two separate series of electric oscillations from the oscillators; rendering the efficiencies of translation of said two series highest in respectively opposite first extreme regions of the scale of the instrument and progressively lower toward the respective second extreme scale regions; translating each of said series of oscillations into sounds; and radiating the respective sounds from separated respective regions.

6. In an electronic piano including vibratable strings progressively tuned to the several notes of the scale: the combination of two mechanico-electric translating systems each associated with said strings and responsive to the vibrations thereof, said systems being characterized by highest efficiencies of translation in respectively opposite first extreme scale regions and by progressively lower efficiencies in regions progressively nearer the respective second extreme scale regions; and individual electro-acoustic translating

devices respectively radiating sounds from separated regions and respectively responsive to said translating systems.

7. In a musical instrument including a series of oscillators progressively tuned to the several notes of the instrument scale, the combination of a translating system associated with the several said oscillators and responsive thereto with an efficiency greatest for substantially the lowest-frequency oscillator and progressively decreasing for progressively higher-frequency oscillators; a second translating system also associated with the several said oscillators and responsive thereto with an efficiency greatest for substantially the highest-frequency oscillator and progressively decreasing for progressively lower-frequency oscillators; and individual electro-acoustic translating devices respectively radiating sounds from two separated regions, and respectively connected with and responsive to said translating systems.

8. In a musical instrument including a series of oscillators progressively tuned to the several notes of which the full scale of the instrument consists: the combination of a translating system associated with the several said oscillators and responsive thereto with an efficiency greatest for substantially the lowest-frequency oscillator and progressively decreasing for progressively higher-frequency oscillators substantially throughout said scale; and a second translating system also associated with the several said oscillators and responsive thereto with an efficiency greatest for substantially the highest-frequency oscillator and progressively decreasing for progressively lower-frequency oscillators substantially throughout said scale.

9. In a musical instrument including a series of mechanical oscillators progressively tuned to the several notes of which the full scale of the instrument consists: the combination of a translating system having sensitive portions in spaced relation to said oscillators and responsive thereto with an efficiency greatest for substantially the lowest-frequency oscillator and progressively decreasing for progressively higher-frequency oscillators substantially throughout said scale; and a second translating system having sensitive portions also in spaced relation to said oscillators and responsive thereto with an efficiency greatest for substantially the highest-frequency oscillator and progressively decreasing for progressively lower-frequency oscillators substantially throughout said scale.

10. In a musical instrument, including a series of vibrators progressively tuned to the several notes of the instrument scale: the combination of a translating system having sensitive portions each separated by a spacing from a respective vibrator and operative in accordance with vibratory variation of that spacing, the ratio of such spacing to the maximum amplitude of vibration of the respective vibrator progressively increasing for progressively higher-frequency vibrators; and a second translating system having sensitive portions each separated by a spacing from a respective vibrator and operative in accordance with vibratory variation of that spacing, the ratio of such spacing to the maximum amplitude of vibration of the respective vibrator progressively increasing for progressively lower-frequency vibrators.

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