Feb. 15, 1966 D. J. LESLIE 3,235,649

APPARATUS FOR MINIMIZING BEAT EFFECTS

Filed Feb. 17, 1959 2 Sheets-Sheet 1

FIG. 1.

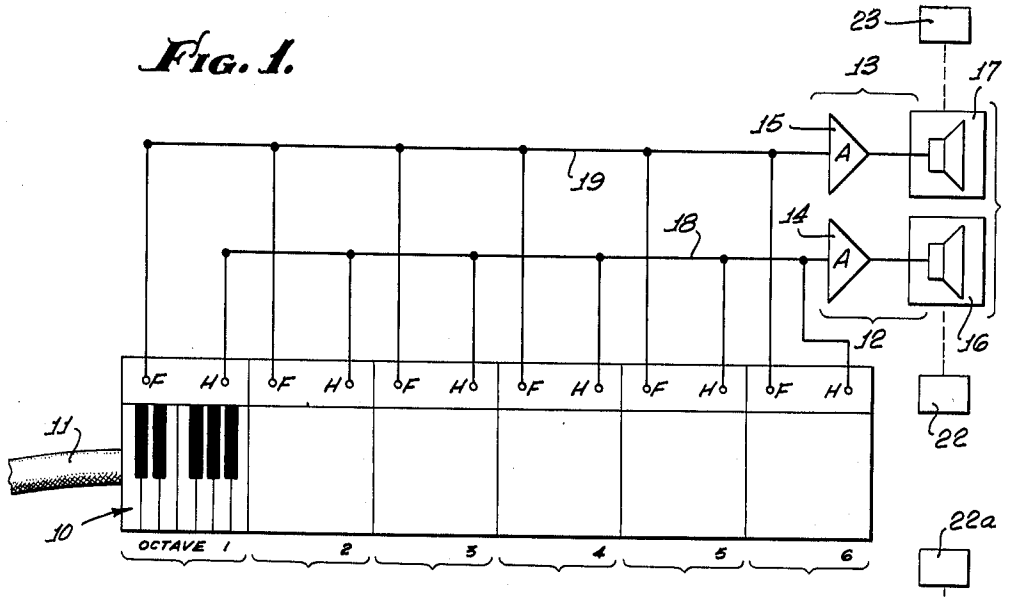

FIG. 2.

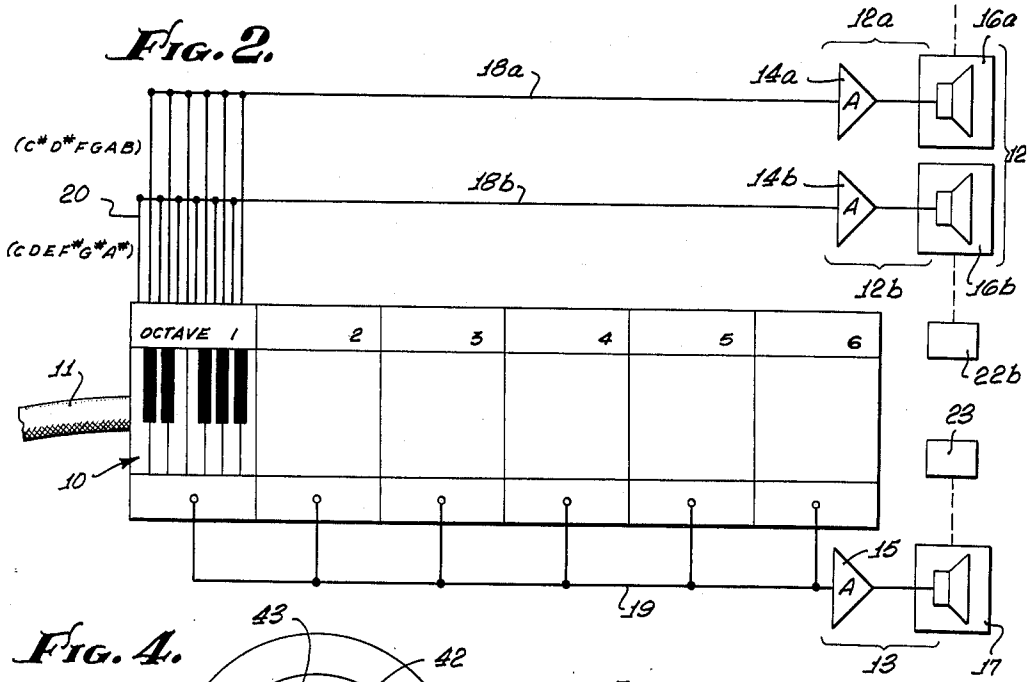

FIG. 4.

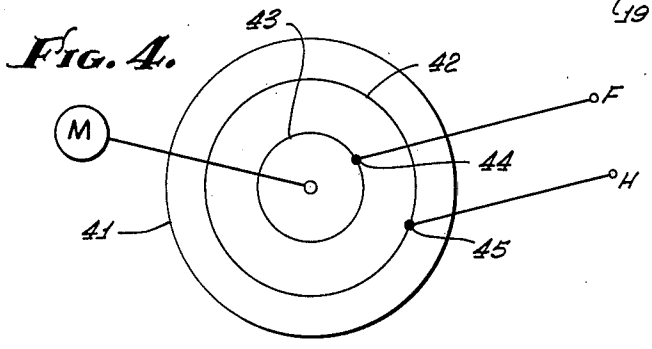

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FIG. 3.

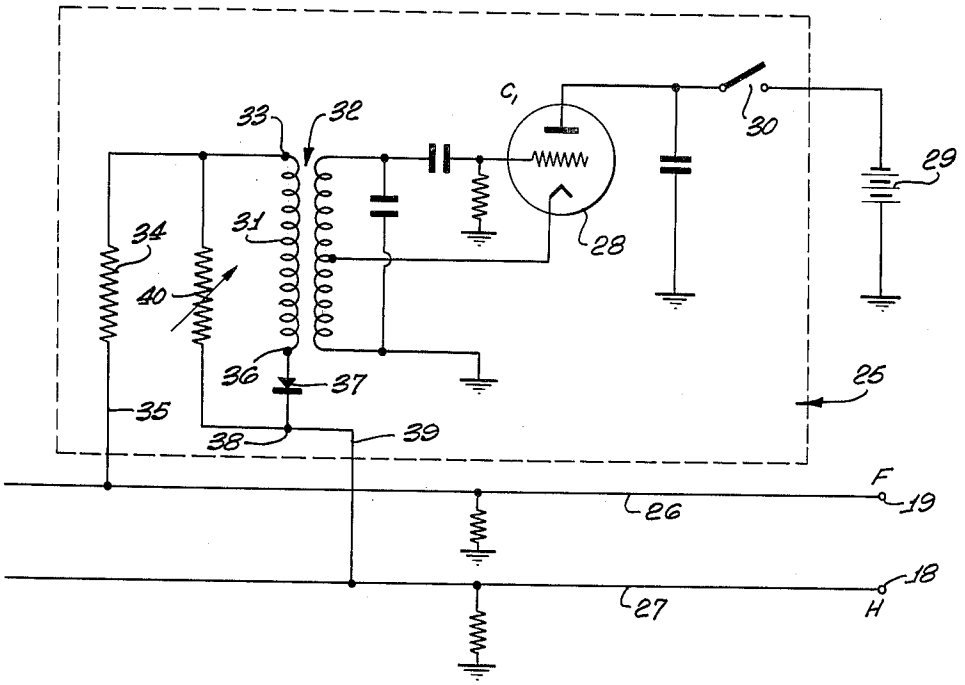
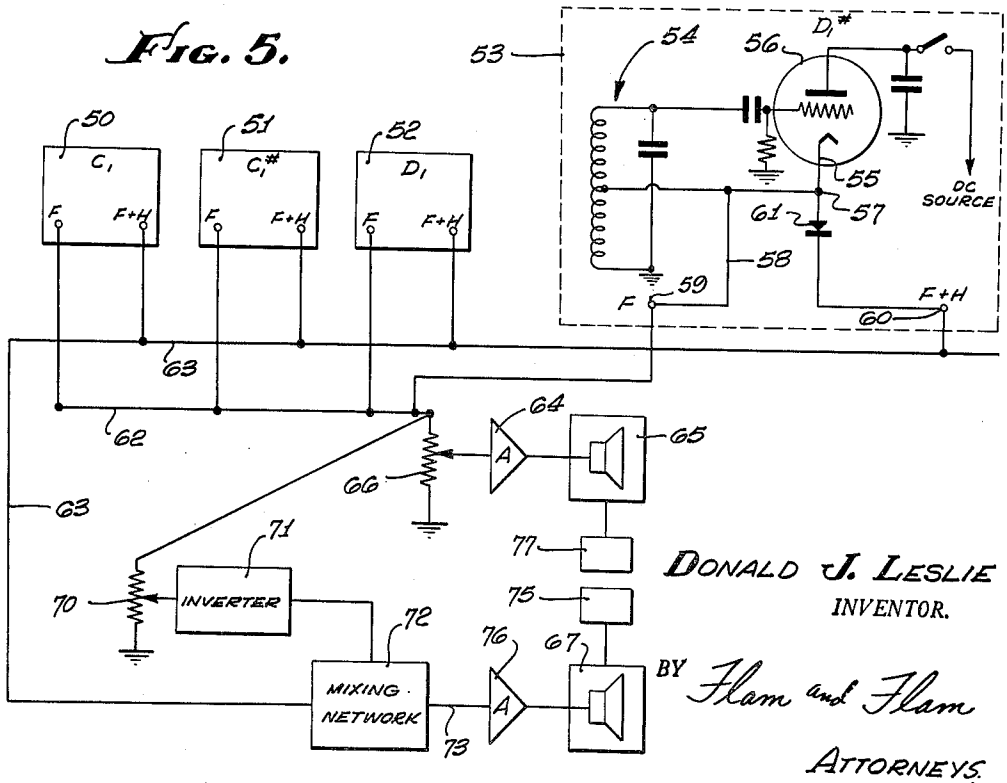


FIG. 5.



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United States Patent Office 3,235,649 Patented Feb. 15, 1966

3,235,649

APPARATUS FOR MINIMIZING BEAT EFFECTS

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Filed Feb. 17, 1959, Ser. No. 793,846
8 Claims. (Cl. 84—1.22)

This invention relates to electronic organ systems, and particularly to the problem of certain beat effects.

The beat effect to which attention is now directed is one characterized by a tone cyclically recurring at the rate of one or two per second. The beat effects are created by electrical intermixture of two impulses that differ in frequency by only one or two cycles per second.

Impulses having frequencies differing from each other by one or two cycles per second may exist upon simultaneously playing a plurality of keys of the organ. Thus, the impulse corresponding to C_2 may contain a second harmonic that is not precisely in tune with the fundamental of C_3.

The most pronounced beats result from electrically mixing a second harmonic and a fundamental of impulses corresponding to notes one octave apart.

Two channel systems have been proposed to reduce this problem in which octaves **1**, **3**, **5**, are connected to one amplifier and speaker, and octaves **2**, **4**, **6** are connected to a second amplifier and speaker. The impulses for fundamentals and second harmonics are thus prevented from mixing electrically, and the beat effect is minimized and, for all practical purposes, overcome. It should be noted that in the foregoing system the fourth harmonic of C_1, for example, will be adjacent the fundamental of C_3 in the same electrical channel and speaker and, therefore, if the fourth harmonics are strong, there will be a beat caused in this manner, although it will usually be far less annoying than the usually stronger beat caused by the second harmonic and fundamental, but eliminated by the alternate octave system.

The object of this invention is to improve upon previous systems intended to minimize beat effects. Improvement is achieved, first, by minimizing the beat effects more effectively; second, by achieving substantial economies in equipment; third, by making possible better pipe organ simulation, as in connection with tremolo or vibrato; and, fourth, by ensuring balanced reproduction as to all notes.

I have discovered that the beats that are most noticeable are caused by the fundamental being mixed with certain harmonics. My invention contemplates that the fundamentals be separated from the harmonics and routed to separate amplifiers and speakers, whereby electrical mixing of these troublesome frequencies is avoided and the problem is minimized.

By separating the fundamentals and harmonics and delivering these to separate speakers, it is found that even the fourth harmonic of C_1, for example, will be in a different channel and speaker than the fundamental of C_3, which is an obvious advantage over the alternate octave system. While the fourth harmonic of C_1 will be in the same channel and speaker with the second harmonic of C_2, the strength of these signals will almost always be attenuated over the fundamental signals, therefore providing a net advantage over the alternate octave system.

Another advantage possessed by the fundamental and harmonic separation is that the power and frequency range requirements of the two amplifiers and speakers are different, and since the harmonics can usually be produced with less power and speaker size than the fundamentals, a net saving in cost is effected.

In prior systems, such as the alternative octave system, adjacent notes on opposite sides of the octave division fall in different electrical-acoustic channels; hence, a substantial difference in quality or timbre may exist due to slight differences in the amplifiers and speakers of the respective channels as well as different acoustical environment of the speakers. An important advantage in the present invention lies in the fact that fundamentals for all notes fall in one channel, and the harmonics all fall in another channel. Hence, balanced treatment of all notes is now automatically ensured.

It is well known that pipe organ tremolo creates a condition whereby the fundamental and harmonics do not all have the same degree or type of tremolo. Therefore, in an electronic organ, realistic pipe organ effects can be created by separate tremolo or vibrato treatment of fundamentals and harmonics. The present invention readily makes this result possible. The method by which different tremolo is applied may vary greatly, and may take the form of electronic or electro-mechanical phase shift devices with different types or adjustments applied to fundamental and harmonic channels, or different acoustical tremulants may be provided for the speakers radiating the fundamentals and harmonics.

In my prior Patent No. 2,596, 258, issued May 13, 1952, I disclosed how the separation of alternate notes into two channels solves beat effects due to harmonics of impulses for notes in fourth or fifth musical interval relationship. Thus, the third harmonic of an impulse for one note has a frequency quite close to, but not exactly the same as, the second harmonic of an impulse for a note five musical intervals above, and all despite perfect tuning. A similar situation exists as to notes in fourth musical interval relationship.

The alternate octave system may be modified to eliminate fourth and fifth interval beating. Thus, four channels may be provided. The keyboard is first split into two groups of alternate notes, and then each of the groups is further split into sections of alternate octaves. Beats caused by electrical mixing of harmonics of fourth and fifth intervals and also beats caused by second harmonics mixing with fundamentals of mistuned octaves are thus avoided.

My invention accomplishes an even better result with less equipment. Only three instead of four channels are needed, with one channel for all fundamentals, and the other two channels for two groups of harmonics for fourth and fifth interval problems. Of importance is the fact that the harmonic amplifiers and speakers require less power and frequency range. Also, since all fundamentals are produced by the same speaker, balance of adjacent notes is achieved even though the harmonics from adjacent notes emanate from different speakers.

A further object of the present invention is to provide simplified and effective generator system and associated circuits whereby harmonics devoid of fundamental, as well as fundamentals devoid of harmonics, are isolated for use in the present system.

This invention possesses many other advantages and has other objects which may be made more clearly apparent from a consideration of several embodiments of the invention. For thus purpose, there are shown a few forms in the drawings accompanying and forming part of the present specification. These forms will now be described in detail, illustrating the general principles of the invention; but it is to be understood that this detailed description is not to be taken in a limiting sense, since the scope of the invention is best defined by the appended claims.

Referring to the drawings:

FIGURE 1 is a diagrammatic view illustrating one embodiment of the present invention;

FIG. 2 is a diagrammatic view similar to FIG. 1, illustrating a second embodiment of the present invention; and

FIGS. 3, 4 and 5 diagrammatically illustrate different generator arrangements for use in the embodiments described in FIGS. 1 or 2.

In FIG. 1 is illustrated a keyboard **10** spanning a musical range corresponding to six octaves. The keys of the keyboard **10** in a conventional manner control the circuits which determine whether or not a tone corresponding to the key exists at the output of the instrument. A cable **11** diagrammatically represents the circuits from a generator set.

There are two electrically isolated outputs for each note, one output, designated F, containing only the fundamental, and the other output, designated H, containing only the harmonics. In FIG. 1, corresponding outputs in octave groups are connected together at F and H terminals. In turn, like terminals of the several octave groups are connected together.

There are only two audio output channels **12** and **13** for the instrument, one for translating only the harmonics and the other for translating only fundamentals.

The electrical-acoustic channels **12** and **13** each include amplifiers **14** and **15**, respectively, and speaker assemblies **16** and **17**. The amplifiers **14** and **15** are provided with bus members or input connections **18** and **19** connected, respectively, to the F and H terminals. Upon depression of any key, the fundamental impulse for the note corresponding to the key is routed to the channel **13**, and the harmonics of that impulse are routed to the channel **12**. Thus, two switches (not shown) are simultaneously operated by each key for controlling the respective components.

By virtue of the routing of fundamentals of the complex impulses to the electrical-acoustic channel **13**, it is impossible for any beat effect to exist in this channel. Thus, the only impulse at or adjacent 440 cycles per second is due to the fundamental for A_4. The second harmonic of A_3 (200 c.p.s.) does not exist in this channel, nor the third harmonic D_3 (146.83 c.p.s.), nor the fourth harmonic of A_2 (110 c.p.s.), etc.

In the electrical-acoustic channel **12**, the major source of annoying beat effects do not exist. Thus, the beat effects due to the second or other harmonics beating with the fundamental of other impulses are precluded since no fundamental exists in the electrical-acoustic channel **12**. Hence, these sources of beat effects are eliminated.

However, it is possible for certain beat effects to exist in the channel **12** due to the third harmonic and second harmonic of notes respectively in fifth musical interval relationship with respect to each other, or due to the fourth harmonic and the third harmonic of notes respectively in fourth musical interval relationship with respect to each other. But such beating can be eliminated in a manner somewhat similar to that described in my prior Patent No. 2,596,258. Thus, in FIG. 2, the electrical-acoustic channel **12** is, in this instance, broken into two parts, **12***a* and **12***b*, and corresponding bus members or input leads **18***a* and **18***b*. In one of the parts **12***a*, impulses corresponding to harmonics of the notes C♯, D♯, F, G, A and B exist, whereas in the opposite channel **12***b*, impulses corresponding to harmonics of the notes C, D, E, F♯, G♯ and A♯ exist. No electrical intermixture of harmonics for notes either in fourth or fifth musical interval relationship is possible since any two notes in fourth or fifth interval relationship are in different channels. The segregation of the harmonic outputs is indicated by the connections **20** extending from adjacent notes to the respective input leads **18***a* and **18***b*.

In both FIG. 1 and FIG. 2, important advantages are achieved. Thus, for example, problems due to mistuning of impulses in octave relationship with respect to each other are minimized. The relative timbre of the notes is not altered by the system because all notes are translated by the aid of both channels. The power requirement of the components in the harmonic channels is not as great as the power requirements for the fundamental channels, and a saving in cost is effected.

Differently controlled tremolo may be applied to the fundamental and harmonic channels. This is indicated, for example, by separate controls **22** and **23** in FIG. 1 which, in this instance, indicate control of acoustic tremulant. Of course, separate tremulant or vibrato can similarly be added electrically. The intensity and rate of tremolo or vibrato in the respective electrical-acoustic channels are independent. Hence, a close simulation of pipe organ music may be effected.

In FIG. 3, there is illustrated diagramatically an oscillator **25** that may provide the separated fundamental and harmonic outputs. F and H bus bars or members **26** and **27** interconnect the separate outputs to the amplifier input leads, as at **18** and **19**. The oscillator **25** is of the vacuum tube type utilizing a triode **28**. Application of plate voltage from a source **29** is controlled by a key **30** forming a part of the keyboard **10**. Oscillations are induced in a secondary coil **31** of a transformer **32**, the transformer **32** having a primary directly in the oscillatory circuit.

The secondary winding **31** provides a means whereby two output connections, as at opposite ends of the winding **31**, can be established. One output connection includes means for providing substantial harmonic content, whereas the other connection does not. Thus, one terminal of the transformer winding **31**, as at **33**, connects to the F bus **26** via isolating resistor **34** and lead **35**. The other side or terminal **36** of the transformer secondary **31** connects to the H bus **27** via a rectifier or other distorting device **37**, a mixing terminal **38**, and a lead **39**.

The fundamental is not eliminated by the distorting device **37**. Hence, it is bucked out. This is achieved by introducing at the terminal **38** an impulse of the identical frequency but of exactly opposite phase so that a mutual subtraction process is achieved. An impulse of identical frequency and opposite phase exists, of course, at the terminal **36**. It is supplied to terminal **38** in proper amount by the aid of a variable resistor **40**. By adjusting the value of the resistor **40**, the fundamental at terminal **38** and lead **39** to the H bus **27** is eliminated. Similar bucking circuits are provided for the other oscillators.

Harmonics and fundamentals can be isolated in other manners. Thus, in FIG. 4, there is diagrammatically illustrated a tone wheel **41**. The tone wheel **41** carries information on two concentric bands **42** and **43**. The information may be of magnetic, electrostatic or other form. Such tone wheels and pickups are well known in the art. See for example the following U.S. Letters Patent: Severy 2,178,706; Midgley 2,207,489; Hammond 2,214,-764; Miessner 2,215,708; Hammond 2,241,363; Culver, 2,248,661. The tone wheel is rotated at substantially constant speed by M. On one band, the fundamental impulse may be obtained, and on the other band, corresponding harmonics may be obtained. Pickups **44** and **45** are accordingly provided for connection to F and H terminals or busses.

In FIG. 5, still another generating system is illustrated. In this example, a simpler arrangement is provided for eliminating the fundamentals from complex waves. A plurality of generators **50**, **51**, **52**, **53**, etc. are illustrated. Typical details of one of the generators, such as **53**, are shown. As in connection with the form illustrated in FIG. 3, the generator is of the vacuum tube oscillator type. The oscillator circuit includes a simple tank section **54** that includes an inductive coil.

Output or signal is obtained from the cathode **55** of the vacuum tube **56** and at an F terminal **59**. A lead

58 from the terminal 57 provides the substantially sine wave output.

At another terminal 60, designated $F+H$, the fundamental impulse and harmonics are present. The fundamental at the $F+H$ terminal 60 is in phase with that at F terminal 57. This impulse is created by the aid of a distorter 61 interposed betwen the F terminal 57 and the $F+H$ terminal 60.

All of the generators 50, 51, 52 have corresponding terminals F and $FR+H$ respectively connected to busses 62 and 63. The bus 62 for F terminals supplies input to an amplifier 64 and a speaker 65, a potentiometer 66 being utilized as a means whereby the amplitude of the fundamental supplied the amplifiers 64 is adjusted.

At a second amplifier 76 and speaker 67, only the harmonics exist. This is achieved by mixing the signal at the $F+H$ bus with a signal —F so that only the harmonics remains. For this purpose, a mixing network 72 is provided. The $F+H$ bus 63 connects to one input of the mixing network 72. The —F signal is derived from the F bus by the aid of an inverter 71. The magnitude of the —F signal is adjusted by a potentiometer 74 so that conditions are appropriate for arithmetical substration of the F component from $F+H$. Thus, the inverter 71 is supplied from the output of the potentiometer which, in turn, is supplied from the F bus 62. The inverter output connects to the second input of the network 72.

The output from network 72, as at the lead 73, drives the amplifier 76. If all of the generators have similar characteristics so that the amplitude of the fundamental at the F terminal bears a fixed ratio to that of the fundamental at the corresponding $F+H$ terminal, perfect compensation can be achieved by adjustment of the single potentiometer 70. But even without perfect compensation, the elimination of beat effects is practically complete.

Block diagrams 75 and 77 indicate separate tremulant devices for the respective channels.

The inventor claims:

1. In an electronic organ system or the like: a set of separate generators for producing impulses corresponding to musical notes of predetermined frequency in a range of several octaves; each generator providing a first output means at which only the fundamental exists and a second output means at which only complex harmonics exist; a pair of transducer means; means forming a separate input channel for each transducer means; first coupling means connecting the corresponding first outputs of all of the generators of said set to one of said input channels; and second coupling means connecting the corresponding second outputs of all of the generators of said set to the other of said channels.

2. The combination as set forth in claim 1 together with separate means cooperable with the respective transducers for producing tremulant.

3. In an electronic organ system or the like: a set of generators for producing impulses corresponding to musical notes of predetermined frequency in a range of several octaves; each generator providing a first output means at which only the fundamental exists and a second output means at which only complex harmonics exist; a pair of transducer means; means forming a separate input channel for each transducer means; and playing keys operatively associated with the generators; said first and second generator outputs driving said input channels respectively only upon operation of the corresponding key.

4. In combination: a set of tone generators for use in an electronic organ in which fundamental and harmonic components are provided with separate outputs, each generator including a transformer; a first bus member in circuit relationship with one end of each of the generator transformers; a second bus member; means connecting the second bus member to the other end of each of the generator transformers, and including a terminal and a distorting device for creating harmonics; and a connection between each terminal and the one end of the transformer for the corresponding generator, the connection including an adjustable element by the aid of which the fundamental component at said terminal is eliminated.

5. In combination: a set of tone generators for use in an electronic organ; each generator having a pair of outputs at the first of which a substantially sine wave fundamental signal exists, and at the second of which a complex wave signal exists, said complex wave signal including a fundamental component in phase with that at the said first output; a pair of bus means for the respective outputs; a pair of audio channels; means drivingly connecting the bus means for the first outputs to one of the said channels; a mixing circuit having two input branches, and an output drivingly connected to the other of said channels; an inverter in one input branch, means applying the signals of said first generator output to one of said mixer input branches; means applying the signals of the said second generator outputs to the other of said mixer input branches; and means for balancing the strength of the signals in the branches so that the fundamentals are substantially eliminated.

6. In an electric organ system: a set of tone generators each including a transformer; a first bus member in circuit relationship with one end of each of the generator transformers; a second bus member; means connecting the second bus member to the other end of each of the generator transformers, and including a terminal and a distorting device for creating harmonics; and a connection between each terminal and the said one end of the transformer for the corresponding generator, including an adjustable element by the aid of which the fundamental component at said terminal is eliminated; and separate output means electrically coupled to the respective bus members.

7. In an electronic organ system or the like: a pair of transducer means; means forming separate input channels for the transducer means respectvely; a set of separate electrical tone generators corresponding to notes of predetermined frequency in a common musical range; first circuit means deriving from the generators impulses corresponding to the fundamentals of the generators substantially devoid of their corresponding harmonics; second circuit means deriving from the generators complex impulses corresponding to the harmonics of the generators substantially devoid of corresponding fundamentals; means operatively associated with said first circuit means applying the impulses derived by all of the said first circuit means substantially exclusively to one of said channel means; and means operatively associated with said second means applying the impulses derived by all of said circuit means substantially exclusively to the other of said channels.

8. In an electronic organ system or the like: a set of generators for producing impulses corresponding to musical notes in a range of several octaves; each generator providing a first output means at which only the fundamental exists and a second output means at which only complex harmonics exist; three transducer means; means forming a separate input channel for each transducer means; coupling means operatively associated with the first output means of the generators, connecting said first output means to one of said channel forming means; coupling means operatively associated with the second output means of those generators corresponding only to C, D, E, F♯, G♯ and A♯, connecting said second output means to another of said channel forming means; and coupling means operatively associated with the second output means of those generators corresponding only to C♯, D♯, F, G, A and B, connecting said second output means to still another of said channel forming means.

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