ELECTRONIC MUSICAL INSTRUMENT FOR PRODUCING NOVEL ACOUSTIC EFFECTS FROM MULTITONE SIGNALS

Filed Dec. 20, 1966 10 Sheets-Sheet 1

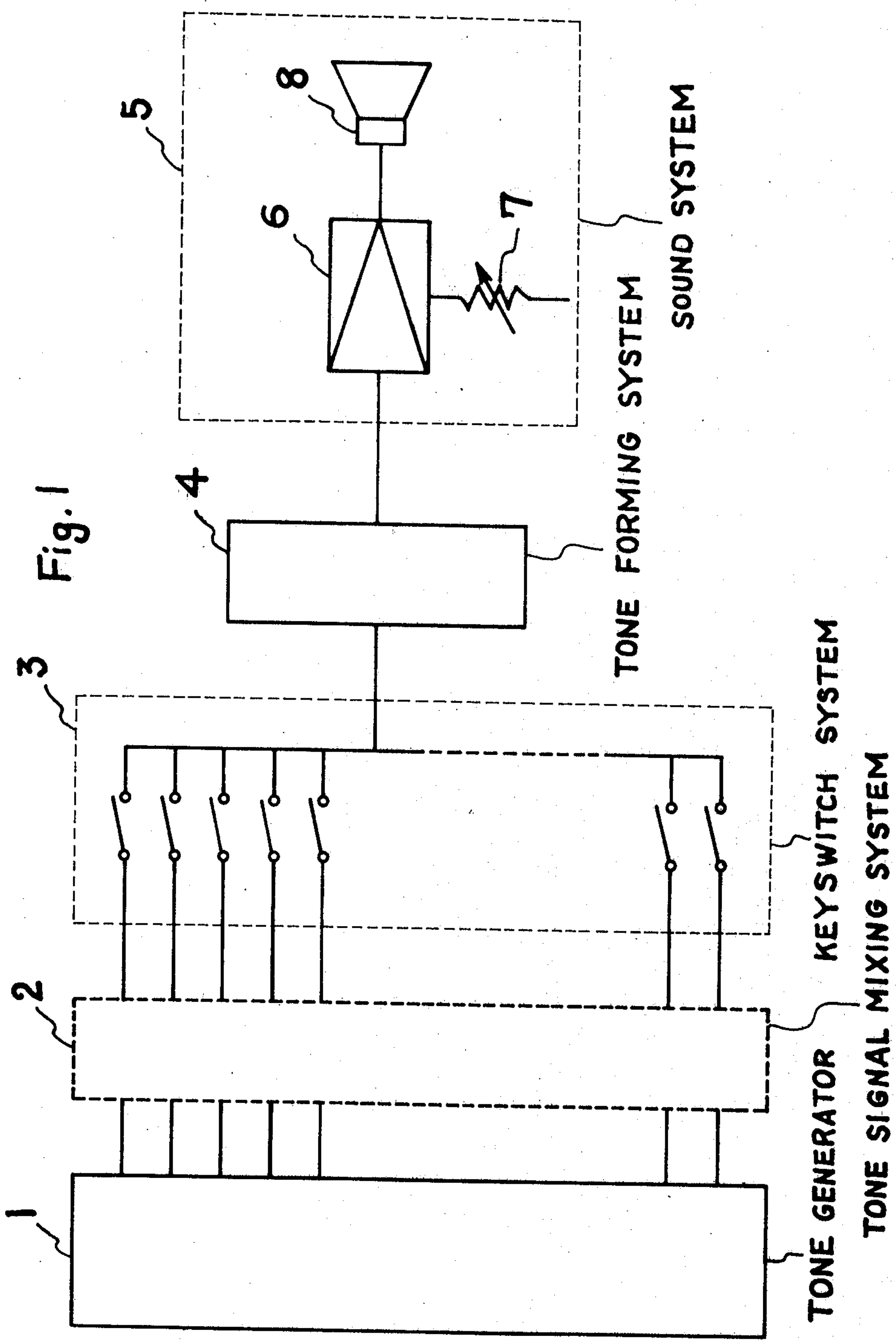

Fig. 1

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Fig. 2

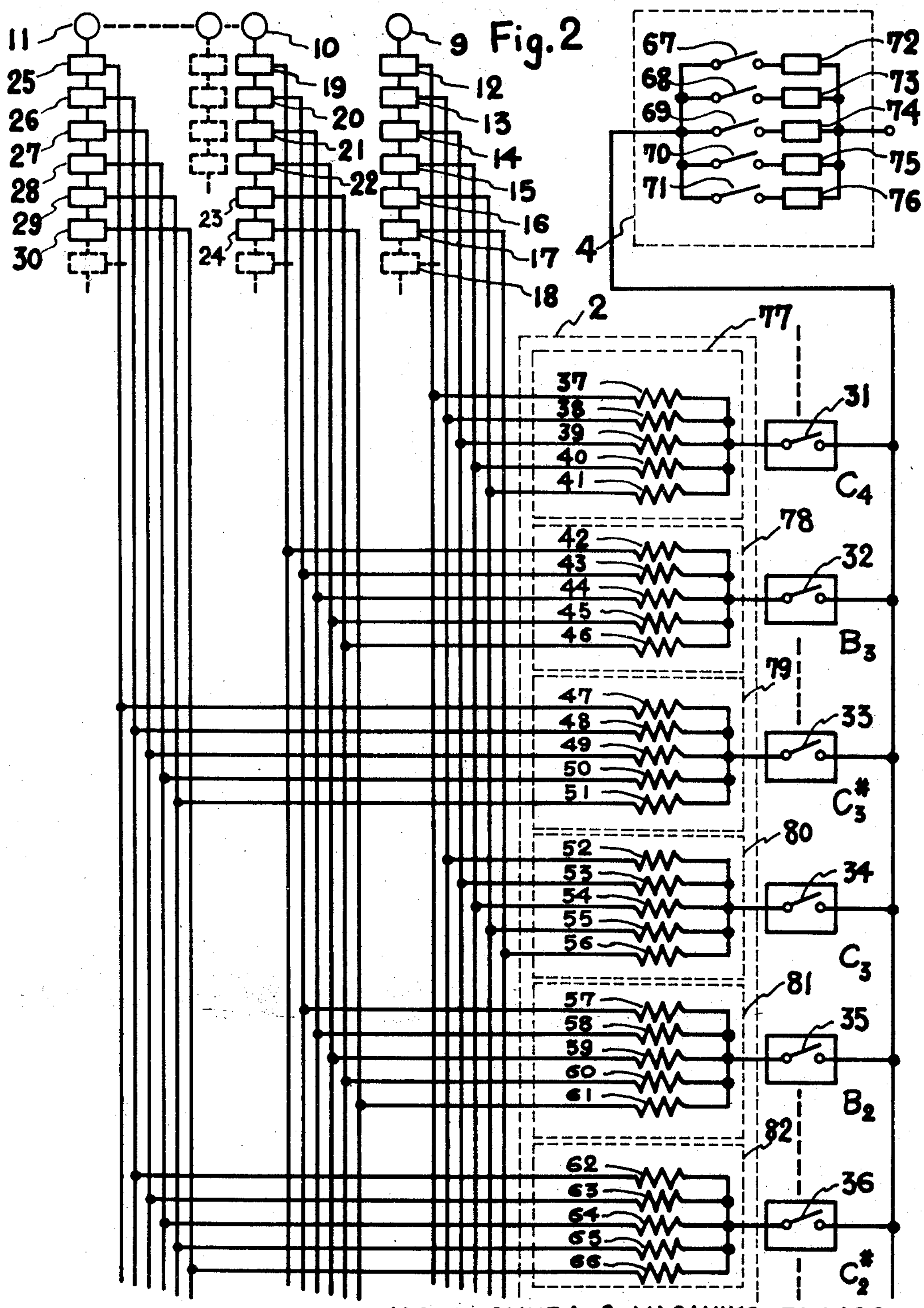

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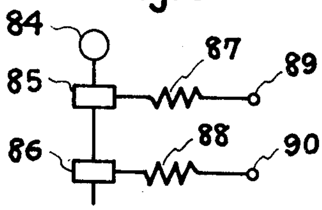
Fig. 3



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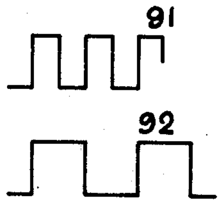

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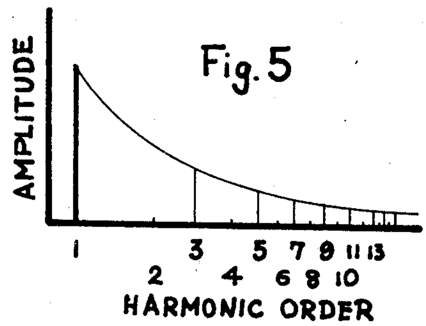

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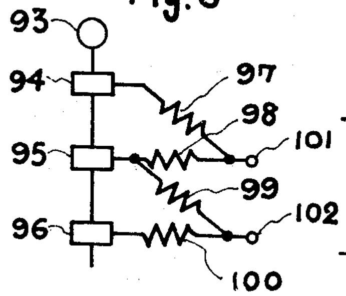

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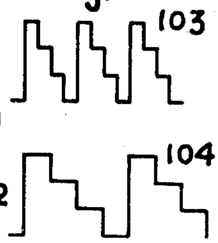

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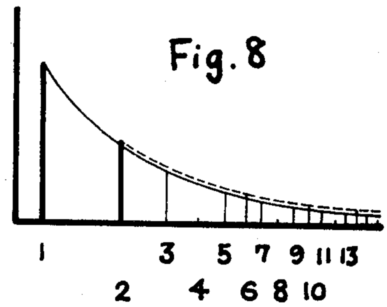

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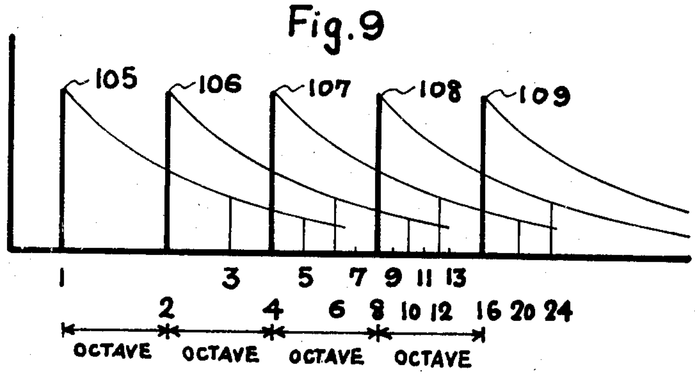

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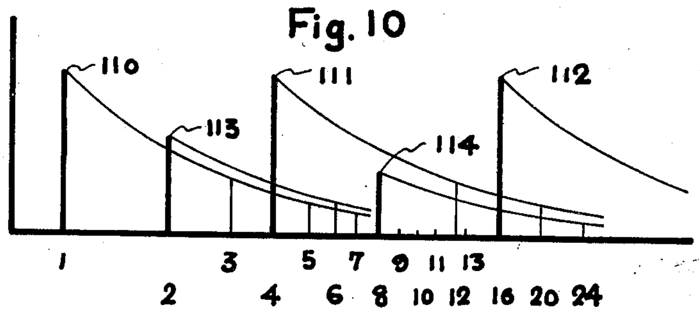

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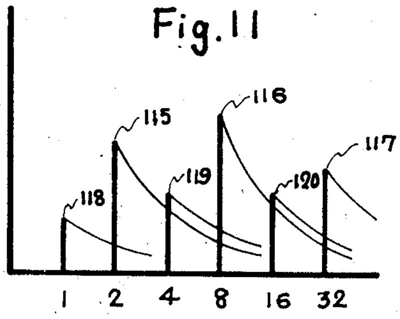

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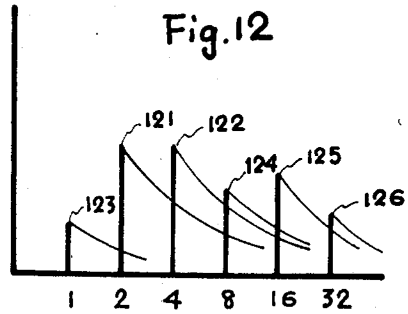

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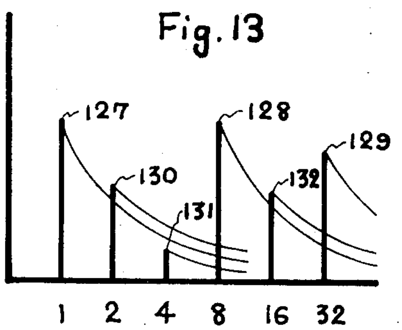

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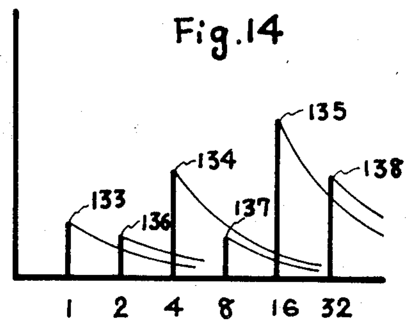

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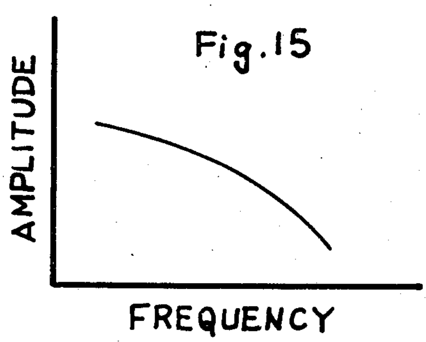

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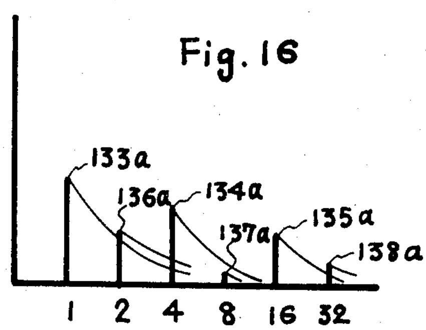

Fig.16

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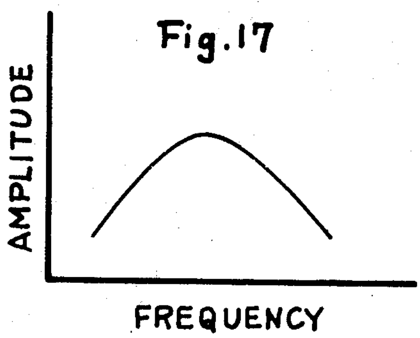

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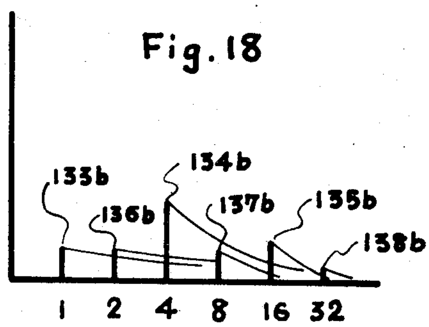

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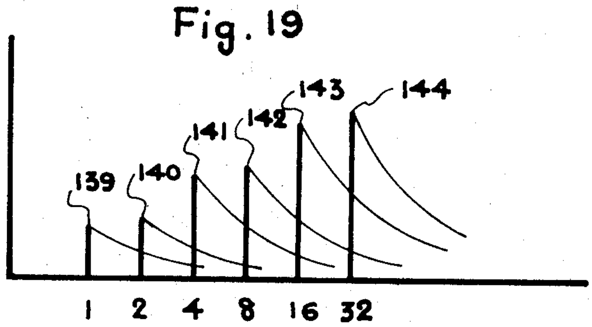

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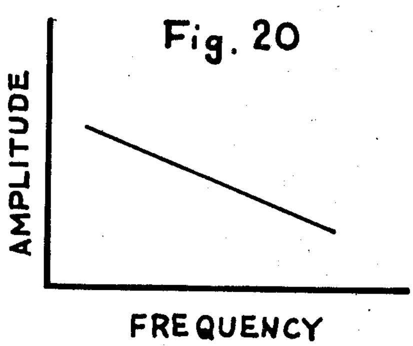

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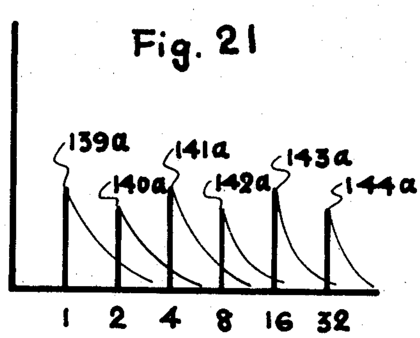

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Fig. 22

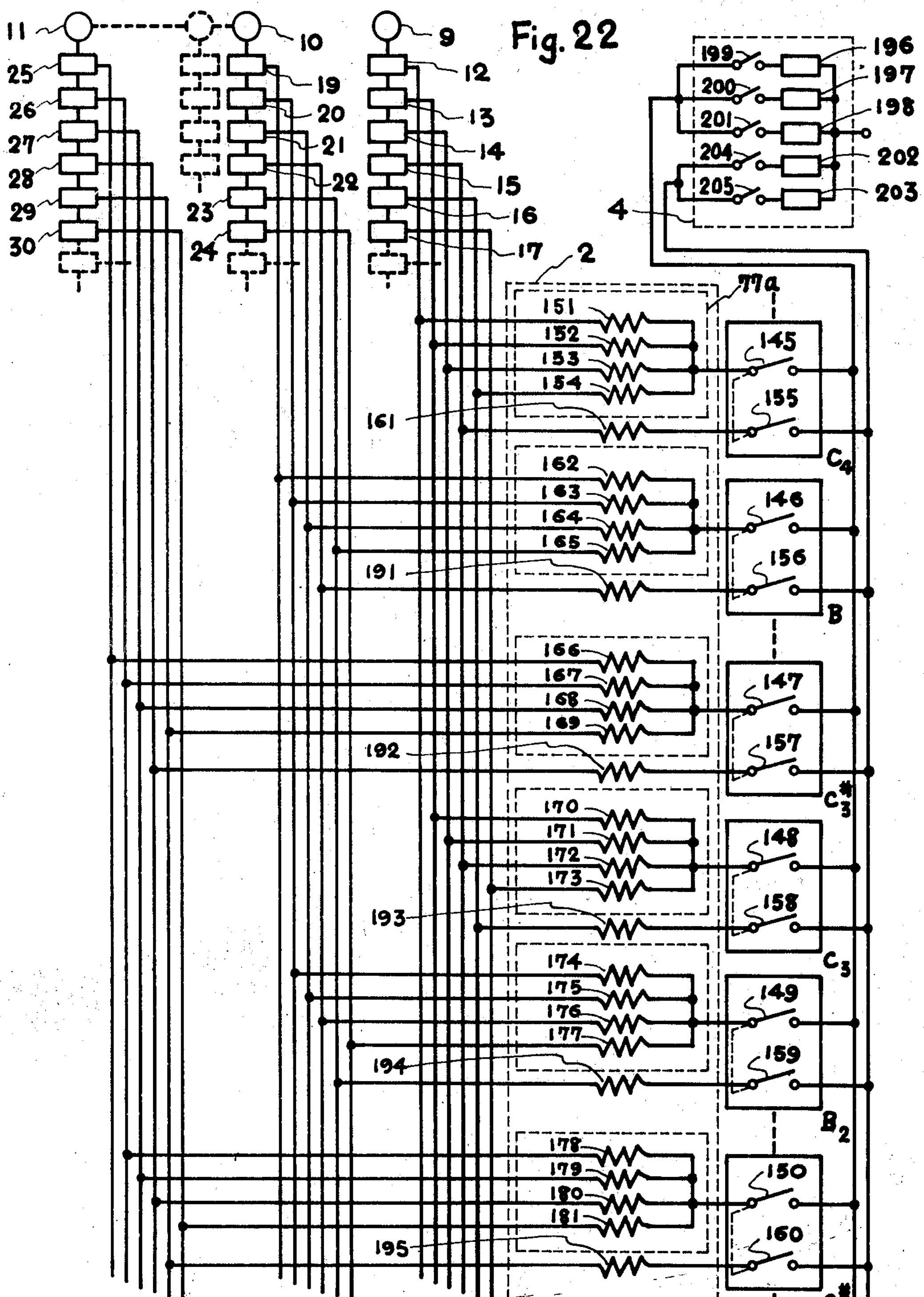

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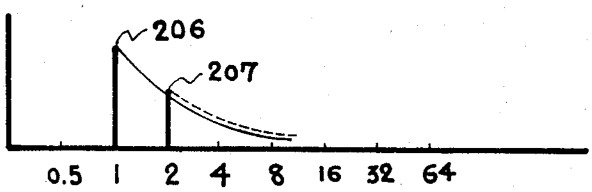
Fig.23



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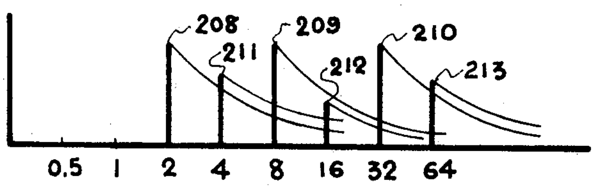

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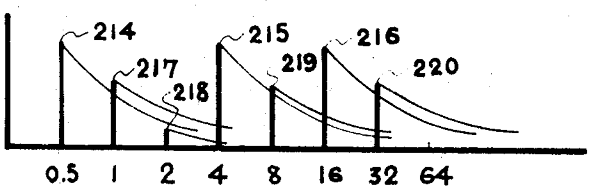

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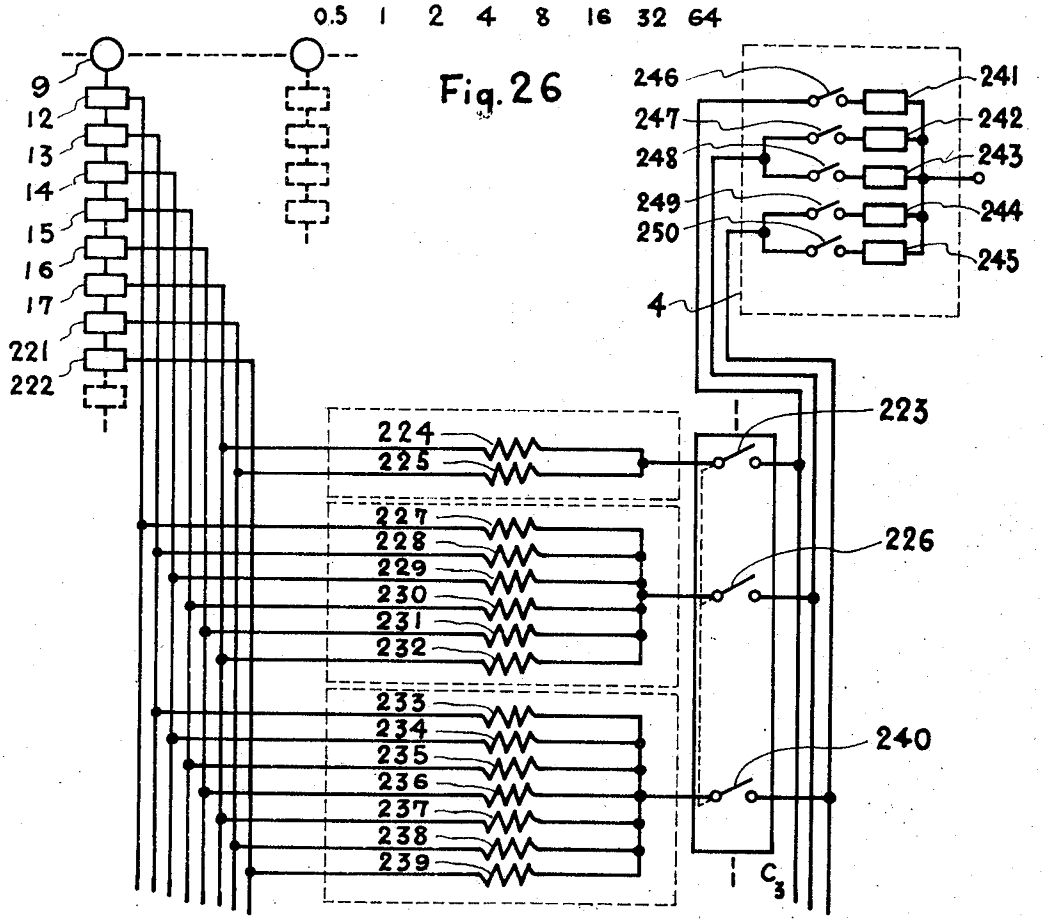

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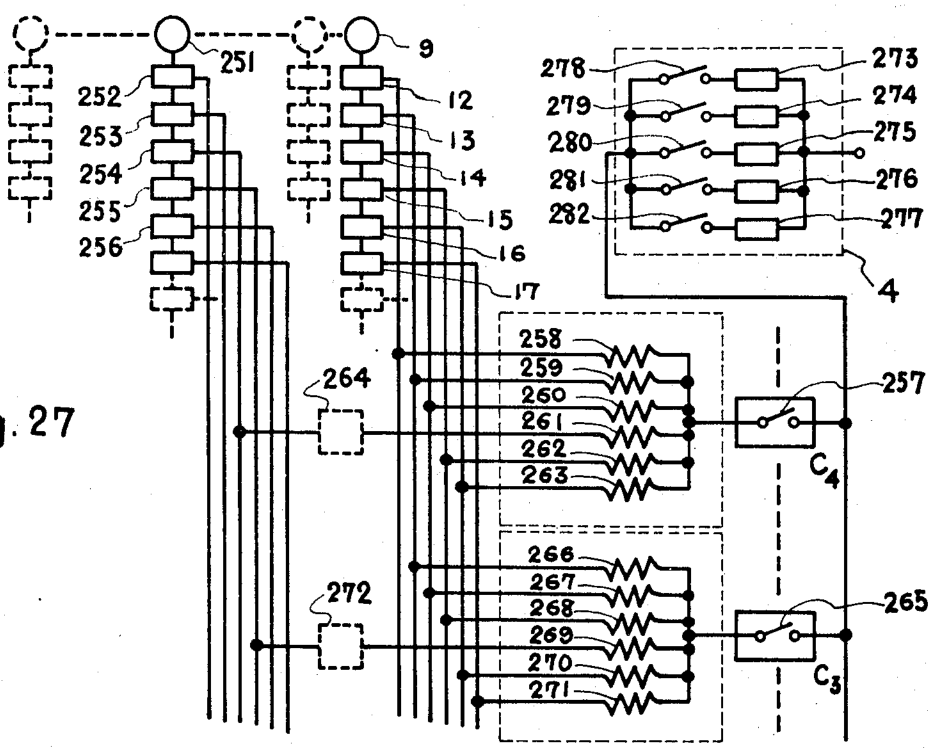

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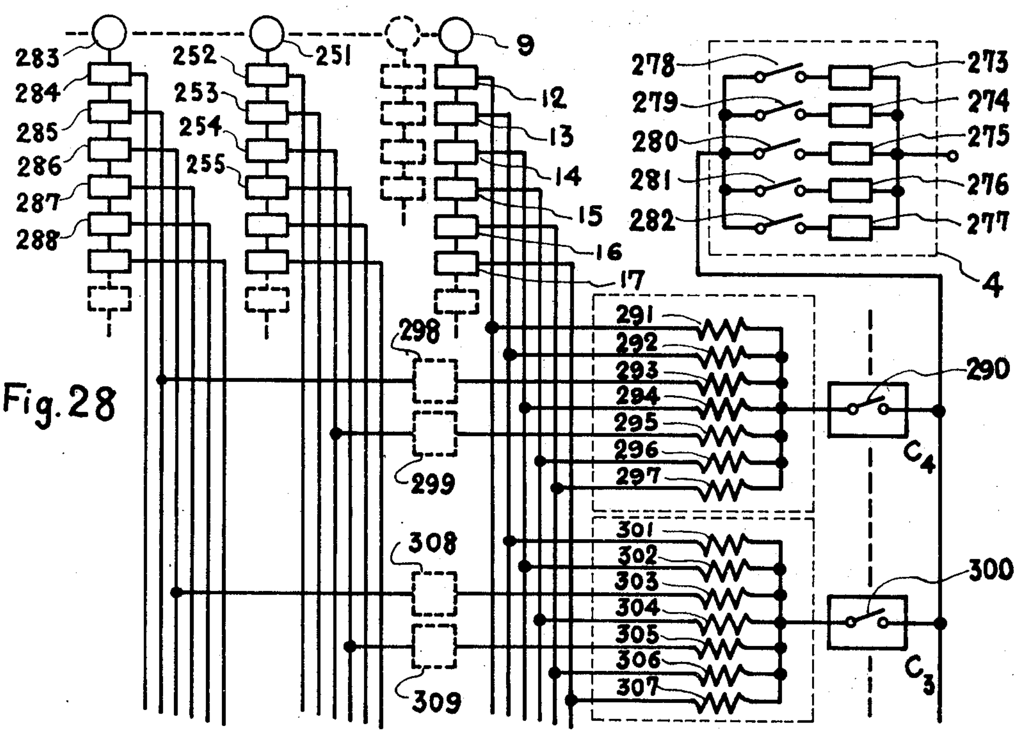

Fig. 28

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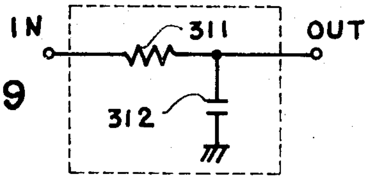
Fig. 29



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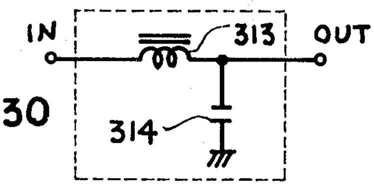

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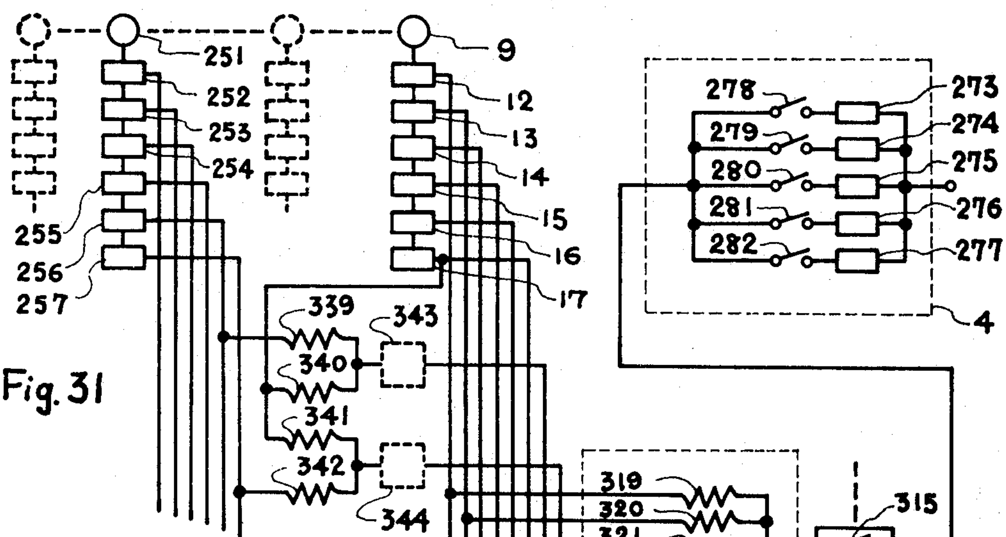
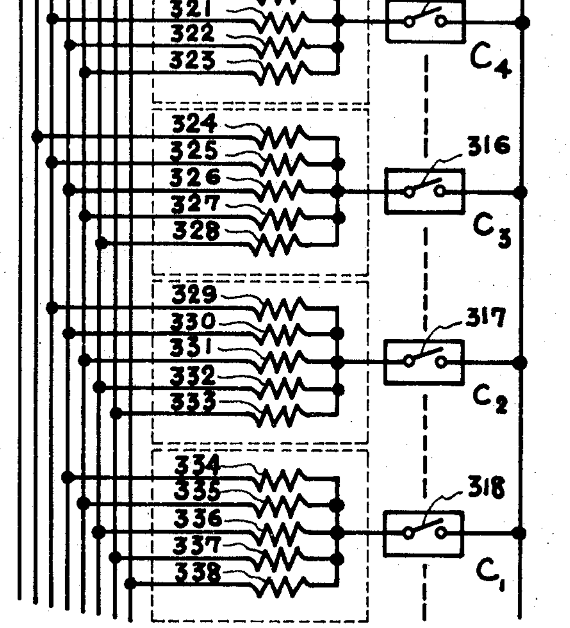

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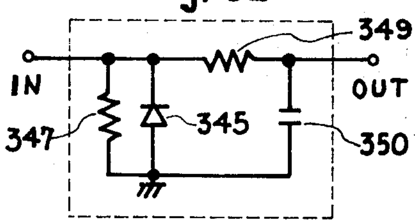

Fig. 33

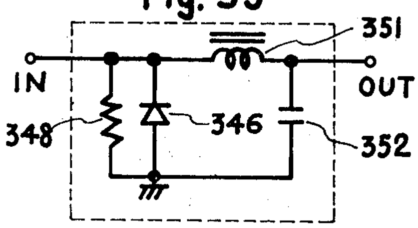

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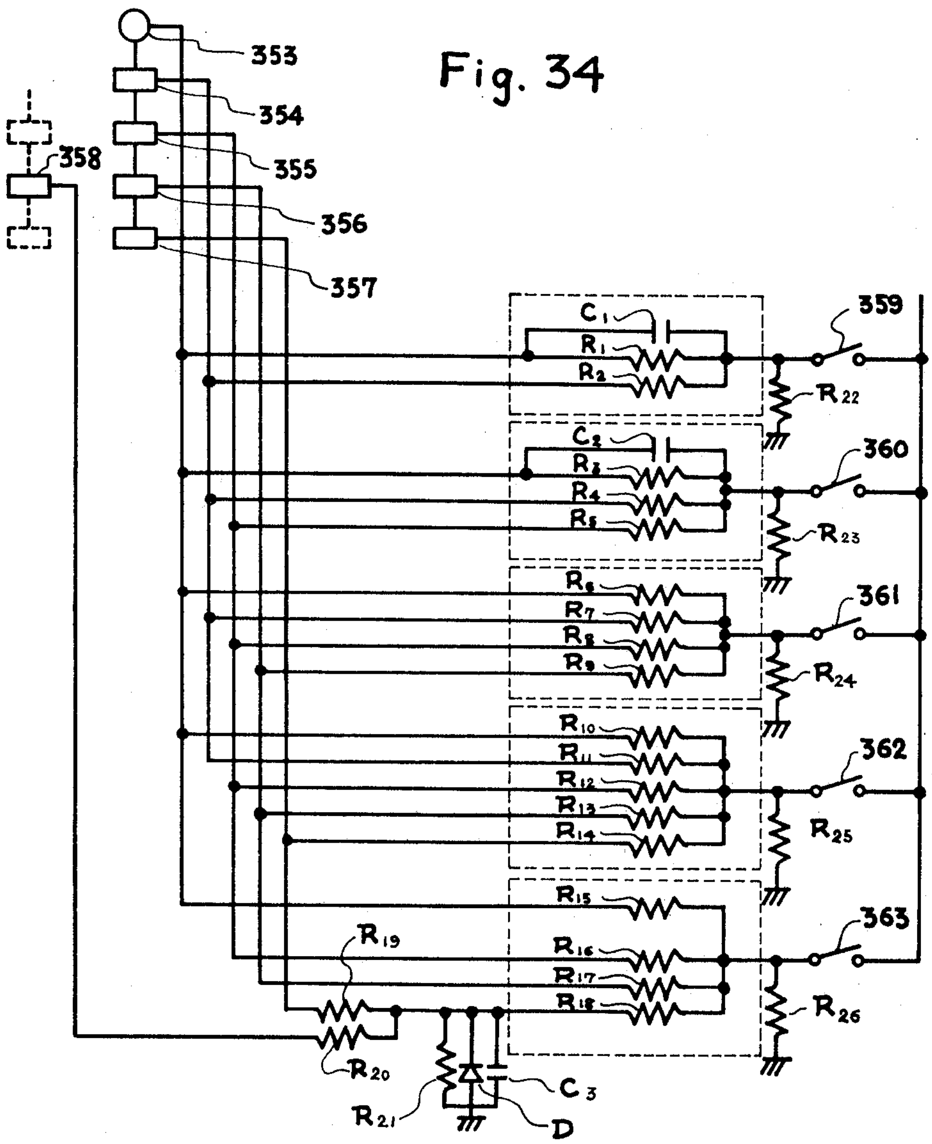
Fig. 34



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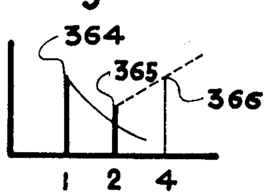
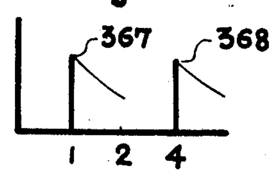


Fig. 36



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United States Patent Office

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ELECTRONIC MUSICAL INSTRUMENT FOR PRODUCING NOVEL ACOUSTIC EFFECTS FROM MULTITONE SIGNALS

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Int. Cl. G10h *1/06*
U.S. Cl. 84—1.01 22 Claims

ABSTRACT OF THE DISCLOSURE

An electronic musical instrument of the keyboard type which has a tone generator system comprised of a plurality of oscillators each having a chain of frequency dividers attached thereto for producing a series of tone signals in octave relation to each other, a keyswitch system for switching tone signals to a tone forming circuit by depressing keys on a keyboard, the tone forming circuit delivering the tone signals to a sound system which converts them to acoustic tones, and a tone signal mixing system coupled between the tone generator system and the keyswitch system. The tone signal mixing system includes a plurality of mixing networks for mixing at least some of the tone signals generated by the tone generator system in such a manner that mixed tone signals are produced which have fundamental frequencies in a 2^n order, the frequencies extending over a range of at least three octaves and having various amplitudes relative to each other.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates generally to a keyboard type electronic musical instrument and more particularly to a tone signal mixing system for an electronic musical instrument, in which a multitone-effect can be achieved by using a smaller number of tone generators and simple keyswitch contacts in a keyswitch system.

The multitone-effect referred to herein is defined as a sound produced when only one key is depressed but which includes, in addition to the tone corresponding to the depressed key, a number of acoustic tones including tones higher and tones lower in a pitch than the tone corresponding to the depressed key. The multitone-effect, therefore, enables richer and warmer tones to be produced by an electronic musical instrument.

Prior art

A conventional electronic musical instrument is usually provided with numbers of tone generators and keyswitch contacts for producing a multitone-effect, and consequently has a complicated construction which makes it very expensive. Furthermore, the complicated construction makes installation and maintenance very difficult and uneconomical.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an electronic musical instrument having multitone-signals capable of producing multitone-effects by employing a simple construction which is comparatively inexpensive.

A further object is to provide an electronic musical instrument being provided with a simple keyswitch system and a simple generator system which reduce production costs and assure reliable operation.

A further object of the invention is to provide an electronic musical instrument which can produce multitone signals, said instrument being characterized by a tone generator system which comprises a small number of tone generators, such as oscillators and frequnecy dividers and which generates difference tone signals in association with difference tone signal producing means.

A further object of the invention is to provide an electronic musical instrument which can produce multitone signals, said instrument also being capable of producing a single-tone signal so as to be able to generate various tone colors.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in connection with the accompanying drawings, in which:

FIG. 1 is a block diagram of a circuit for an electronic musical instrument according to the invention;

FIG. 2 is a basic circuit diagram of a characteristic part of one embodiment of an electronic musical instrument according to the invention;

FIG. 3 is a circuit diagram illustrating a circuit for generating tone signals in a conventional manner;

FIG. 4 is a diagram of the wave forms of the tone signals generated by the circuit of FIG. 3;

FIG. 5 is a frequency spectrum diagram for a square wave tone signal illustrated in FIG. 4;

FIG. 6 is a circuit diagram illustrating a circuit for producing mixed tone signals in a conventional manner;

FIG. 7 is a diagram of the wave forms of the mixed tone signals generated by the circuit of FIG. 6 from a mixture of two tone signals each having a square wave form;

FIG. 8 is a frequency spectrum diagram of the wave tone signal illustrated in FIG. 7;

FIG. 9 is a frequency spectrum diagram of a multitone signal produced by the instrument of the present invention;

FIG. 10 is a frequency spectrum diagram of another multitone signal produced by the instrument of the present invention;

FIGS. 11, 12, 13 and 14 are frequency spectrum diagrams of different multitone signals produced by the instrument of the present invention;

FIG. 15 is a graph illustrating the frequency characteristics of a tone forming system and a sound system according to the invention;

FIG. 16 is a frequency spectrum diagram of a multitone signal modified by the frequency characteristics as shown in FIG. 15;

FIG. 17 is a graph illustrating the frequency characteristics of another tone forming system and a sound system according to the invention;

FIG. 18 is a frequency spectrum diagram of a multitone signal modified by the frequency characteristics as shown in FIG. 17;

FIG. 19 is a frequency spectrum diagram of another multitone signal produced by the instrument of the present invention;

FIG. 20 is a graph of the frequency characteristics of still another tone forming system and sound system according to the invention;

FIG. 21 is a frequency spectrum diagram of a multitone signal modified by frequency characteristics as shown in FIG. 20;

FIG. 22 is a circuit diagram of a characteristic part of another embodiment of the musical instrument according to the invention;

FIGS. 23–25 are spectrum diagrams of still further multitone signals produced by the instrument of the present invention;

FIG. 26 is a circuit diagram of a characteristic part of another embodiment of the musical instrument according to the invention for producing the tone signals shown in FIGS. 23–25;

FIGS. 27 and 28 are circuit diagrams similar to FIG. 26 of further embodiments of the musical instrument according to the invention;

FIGS. 29 and 30 are circuit diagrams of high frequency filters for use with the musical instrument according to the invention;

FIG. 31 is a circuit diagram of a characteristic part of still another embodiment of the musical instrument according to the invention;

FIGS. 32 and 33 are circuit diagrams of filters for use with the musical instrument according to the invention;

FIG. 34 is a circuit diagram of a characteristic part of still another embodiment of the musical instrument according to the invention;

FIG. 35 is a frequency spectrum diagram of the mixed tone signal produced by the circuit of FIG. 34 and containing a plurality of frequency components; and

FIG. 36 is a frequency spectrum diagram of a multitone signal produced by using two tone signals, said two tone signals being separated by two octaves from each other.

DESCRIPTION OF PREFERRED EMBODIMENTS

Before proceeding with a detailed description of the invention, the basic principle will be explained in order to aid in an easy understanding of the scope of the invention.

A multitone signal is a special sort of mixed tone signal capable of simultaneously producing various acoustic tones having many pitches which are different from each other. Only one multitone signal can produce many acoustic tones having different pitches in accordance with the invention. This multitone signal has a clearly different frequency spectrum from the musical tone signals well known in the prior art. The well known prior art musical ton signals are characterized by having only one pitch and are generally divided into the following two classes (1) musical tone signals having integral order harmonics which can be produced by e.g. strings and open pipes and (2) musical tone signals having odd order harmonics which can be produced by e.g. closed pipes and clarinets.

As a practical matter, these musical tone signals do not have exact integral or odd order harmonics, but rather deviate slightly from the exact order of harmonics. The deviation from the exact order harmonics increases with an increase in the frequency. It is known that some tone signals have other kinds of harmonics different from those of the above two classes. For example, tone signals produced by e.g. tuning forks of flutes have substantially no harmonics and tone signals produced by e.g. steel reeds have non-integral order harmonics. The scope of the invention, however, is not closely related to the deviation of the harmonics of tone signals and kinds of harmonics of tone signals other than those of the above two classes, but is related to the order of harmonics of the above two classes.

It is difficult to make a clear change in the pitch of musical tone signals by modifying the amplitude of the frequency components so as to modify the frequency spectrum by means of electric frequency filters. The reason for the difficulty can be explained as follows; the frequencies in a tone signal having integral order harmonics can be expressed as follows:

$$1, 2, 3, 4, 5, 6 \ldots, n \ (n\text{:integer})$$

wherein the number denotes the relative position of the harmonic in the frequency scale. The tone signal can be modified in such a way that the fundamental frequency component corresponding to 1 is almost reduced to zero in amplitude or is eliminated by an electric frequency filter so that the second frequency component corresponding to 2 is the lowest frequency. It would be expected that the modified tone signal would have a pitch higher by one octave than the unmodified tone signal. As a practical matter, the modified tone signal is not heard as a tone having a pitch one octave higher because one can subjectively hear a sound, even if it is weak, corresponding to the difference 1 between the harmonics 2 and 3, 3 and 4, 4 and 5, and so on, respectively. The tone color of the modified tone signal, of course, is observed to be clearly changed.

These facts are not exactly understood theoretically but can be observed commonly in practice. For example, the fundamental frequency of piano tones in the tone range lower than 100 cycles per second can hardly be heard but can be recognized in connection with the pitch thereof because integral order harmonics exist up to the twentieth harmonic with respect to the fundamental frequency. Said integral order harmonics, as a practical matter, deviate slightly from an exact order, and the slight deviation increases with an increase in the order of the harmonic. Taking as another example a pipe organ, sounding two tone signals having a frequency relation of 2:3 makes it possible for a person to recognize a pitch corresponding to the difference 1 between said two tone signals.

For a reason similar to that mentioned above, it is difficult to change the pitch of tone signals having odd order harmonics. Such tone signals have harmonics in the following harmonic order:

$$1, 3, 5, 7 \ldots, 2n-1 \ (n\text{:integer})$$

Reduction or elimination of amplitude of the fundamental frequency component corresponding to 1 will not change the pitch of the tone to a pitch corresponding to the lowest frequency 3 because a difference tone having a frequency of the order of 2 is produced between harmonics 3 and 5, and this difference tone produces another difference tone having the fundamental frequency 1 in association with said harmonic 3, said another difference tone of frequency 1 producing a pitch sensation at the fundamental frequency. Of course, the tone color is observed to be changed.

Thus when people hear a tone signal in which the lower order harmonics are reduced in amplitude or almost eliminated, they can still sense subjectively the pitch corresponding to the fundamental frequency as a maximum common number of harmonic order from the remaining higher harmonics. Despite the presence of many harmonics in frequency scale, the conventional tone signals mentioned above will sound as a single tone signal having only one fixed pitch.

The following description will explain the novel tone signals, each of which is independently able to produce many different pitch sensations in accordance with the basic principle of the invention. Many different pitch sensations can be obtained by arranging frequency components on frequency scale in a particular order such that the frequencies have a relationship with each other of 2^n, as:

$$1, 2, 4, 8, 16, 32 \ldots, 2^n \ (n\text{: integer})$$

wherein the number denotes the relative position of the harmonic in the frequency scale. The reason that many different pitch sensations mentioned above can be produced is that when the frequency component corresponding to the lowest harmonic order 1 is reduced in the amplitude or almost eliminated, the remaining frequency components will still be arranged in a 2^n order. Therefore, the frequency component corresponding to the harmonic 2 produces a new pitch sensation higher by one octave than that corresponding to the harmonic 1, i.e. the fundamental frequency, and the other higher frequency components are still arranged in a 2^n order with respect to the harmonic 2. Successive eliminations of the lowest frequency component of the tone signal do not change the order of the harmonics of the remaining components when a tone signal having harmonics arranged in a 2^n order is employed.

More details of this principle are as follows. Suppose that the original tone signal consists of components with frequencies in the following harmonic order

$$1, 2, 4, 8, 16, 32, 64 \ldots, 2^n$$

By eliminating the component having the first or fundamental harmonic 1, one can obtain a tone having components with frequencies in the following harmonic order:

$$2, 4, 8, 16, 32, 64 \ldots, 2^n \qquad (a)$$

By again eliminating the component having the lowest harmonic 2, one can obtain a tone having components with frequencies in the following harmonic order:

$$4, 8, 16, 32\ 64 \ldots, 2^n \qquad (b)$$

One can obtain a tone with components having frequencies in the following harmonic order by dividing the frequencies in harmonic order (a) by a factor of two:

$$1, 2, 4, 8, 16 \ldots, 2^{n-1}, 2^n \qquad (a')$$

Dividing the frequencies of the components with frequencies in the harmonic order (b) by a factor of four, then one can obtain:

$$1, 2, 4, 8, 16, 32 \ldots, 2^{n-2}, 2^{n-1}, 2^n \qquad (b')$$

and so on.

The above illustration indicates that the pitch sensation for this novel tone signal having components with f.equencies arranged in a 2^n order be changeable and uncertain, and consequently can be easily changed by using electric frequency filtering means for eliminating or reducing the amplitude of the lowest frequency component of said novel tone signal, and indicates that said tone signal can be changed to produce two or more pitch sensations by eliminating or reducing some of the other higher frequency components other than the lowest. A more detailed description of the means of producing two or more pitch sensations will be set forth hereinafter.

Therefore, such a signal is principally able to be modified to give many possible pitch sensations. This kind of novel tone signal, characterized by being able to be modified so as to give many possible pitch sensations, is considered to be a multitone signal which can produce the aforesaid multitone effect. Even though a conventional tone signal has only one pitch, as explained previously, said novel tone signal itself produces many pitch sensations which are different from each other. This kind of novel tone signal having no fixed pitch sensation offers many advantages in tonal quality over conventional tone signals for an electronic musical instrument system. It has been discovered according to the invention that many kinds of said multitone signal having components with frequencies arranged in a 2^n harmonic order can be produced by adding a tone signal mixing system to a conventional electronic musical instrument.

There will first be described the general system of the novel electronic musical instrument according to the invention. Referring to FIG. 1, a tone generator system **1** generates tone signals capable of producing acoustic musical tones, said tone signals being fed to a tone signal mixing system **2** having various tone signal mixing networks so as to obtain mixed tone signals and unmixed tone signals. Said mixed tone signals and unmixed tone signals are controlled by a keyswitch system **3** having keyswitches actuated by depressable keys on one or more keyboards. Tone signals from said keyswitch system **3** are modified by a tone forming system **4** having a number of tone forming circuits so as to obtain desired tone responses such as desired tone colors. Electric tone signals from said tone forming system **4** are converted into acoustic tone signals by a sound system **5** comprising amplifiers **6** for amplifying the electric tone signals, expression control devices **7** for controlling the intensity of said acoustic tone signals, and speakers **8** for converting electric tone signals into acoustic tone signals.

Before going into a detailed description, it is pointed out the explanation set forth hereinafter will be abbreviated as much as possible to provide an easy understanding of the embodiments and the scope of the invention. The number of frequency oscillators, the length of the tone generator chain, the number of tone signal mixing networks and keyswitches, etc., actually described has been greatly reduced. As the practical matter, of course, the number of tone generator chains should be at least twelve so as to ensure a complete musical scale comprising musical notes C, C♯, D, D♯, E, F, F♯, G, G♯, A, A♯ and B. The length of the tone generator chain the number of tone signal mixing networks and keyswitches vary with the type and the size of an electronic musical instrument. Therefore the explanations set forth hereinafter will be limited to certain characteristic parts of the electronic musical instrument. The other parts will be easily understood by referring to the parts explained.

Referring to FIG. 2, the tone generator comprises frequency oscillators **9**, **10** and **11** and frequency dividers **12**, **13**, **14**, **15**, . . . **29** and **30** connected in series to the respective frequency oscillator for dividing the frequency of an input signal by a factor of two and for feeding the divided frequency to a succeeding frequency divider. Said frequency oscillators **9**, **10** and **11** and said frequency dividers **12**, **13**, **14**, . . . **29** and **30** generate tone signals. These tone signals are combined into many groups by the mixing system **2** which comprises resistors **37**, **38**, **39**, . . . **65** and **66**, and the mixed tone signals are fed to the key switch system comprised of normally open keyswitches **31**, **32**, **33** . . . **35** and **36**, which are single-pole keyswitches and which are actuated to the closed position by depressing keys of keyboards (not shown). Tone signals from said keyswitches are fed to a tone forming system **4** and switched by tone switches **67**, **68**, **69**, **70**, **71** and fed to tone forming circuits **72**, **73**, **74**, **75**, **76** of the tone forming system **4** for the purpose of obtaining the desired tone colors.

When keyswitch **31** is actuated, a mixed tone signal derived from frequency dividers **12**, **13**, **14**, **15**, **16** in the tone generator chain connected to the tone generator **9** and corresponding to musical notes C through resistors **37**, **38**, **39**, **40**, **41** is fed to tone forming circuits **72**, **73**, **74**, **75**, **76** through tone switches **67**, **68**, **69**, **70**, **71** by which a player can choose the desired tone colors. Tone signals generated by the successive frequency dividers in the tone generator chain, such as oscillator **9** and frequency dividers **12**, **13**, **14**, . . . **17**, and **18** are in an octave relation to each other, namely the tone signal generated by the frequency divider **13** is lower in pitch by one octave pitch than the tone signal from a frequency divider **12**. A tone signal generated by the frequency divider **14** is lower in pitch by one octave than that from frequency divider **13**, and so on. Therefore, said mixed tone signal which is mixed by mixing resistors **37**, **38**, **39**, **40**, **41**, comprising the mixing network **77** and which form a part of the tone signal mixing system **2** has a frequency spectrum in which the fundamental frequencies of the tone signals mixed through resistors **37**, **38**, **39**, **40**, **41** are in the 2^n order in accordance with the invention. Tone signals generated by the frequency dividers **19**, **20**, **21**, **22**, **23** in the tone generator chain, including frequency oscillator **10** and corresponding to musical note B, are mixed by mixing resistors **42**, **43**, **44**, **45**, **46** and are fed to a keyswitch **32** corresponding to a key B_3. Tone generators, tone signal mixing networks and keyswitches corresponding to keys A_3♯, A_3, G_3♯, G_3, F_3♯, F_3, E_3, D_3♯ and D_3 are also provided but are not shown in order to keep the description simple. Tone signals generated by the frequency dividers **25**, **26**, **27**, **28**, **29** in the tone generator chain including frequency oscillator **11** and corresponding to musical note C♯ are mixed by mixing resistors **47, 48, 49, 50, 51** and are fed to a keyswitch **33** corresponding to a key C_3♯. Only tone signals generated by the frequency dividers **13, 14, 15, 16, 17** in the said tone generator chain with oscillator **9** corresponding to musical note C are mixed by mixing resistors **52, 53, 54, 55, 56** and are fed to a keyswitch corresponding to a key C_3 which produces a tone having a pitch lower by one octave than the tone produced by key C_4.

Each of the tone signals mixed in said mixed tone signal fed to said keyswitch **34** is lower by one octave than the respective tone signals mixed in the tone signal fed to said keyswitch **31**. Thus the one octave relation between said mixed tone signal corresponding to said key C_3 and said mixed tone signal corresponding to said key C_4 is obtained.

Only tone signals generated by the frequency dividers **20, 21, 22, 23, 24** in the said tone generator chain with the oscillator **10** corresponding to said musical note B are mixed by mixing resistors **57, 58, 59, 60, 61** and are fed to a keyswitch **35** corresponding to a key B_2 which produces a tone which is lower by one octave in a pitch than that produced by said key B_3. The keyswitches corresponding to keys A_2♯, A_2, G_2♯, G_2, F_2♯, F_2, E_2, D_2♯ and D_2 and the corresponding circuits including tone generators and tone signal mixing networks are provided but are not shown. Only tone signals generated by the frequency dividers **26, 27, 28, 29, 30** in the said tone generator chain having oscillator **11** corresponding to said musical note C♯ are mixed by mixing resistors **62, 63, 64, 66** and are fed to a keyswitch **36** corresponding to a key C_2♯.

In the manner explained above, the tone generator chain having oscillator **9** corresponding to musical note C forms many multitone sigals which have components having the frequencies in a 2^n order of the fundamental frequency and which correspond to musical notes C of various pitches. The tone generator chain having oscillator **10** corresponding to musical note B forms many multitone signals corresponding to musical notes B of various pitches, and so on. Each of these multitone signals can be switched by a single pole keyswitch.

In the novel electronic musical instrument system according to the invention, multitone signals can be formed successfully by a simple, inexpensive and reliable construction. Further advantages of the novel electronic musical instrument can be achieved by a special mixing method for many types of multitone signals, as explained hereinafter.

There are, of course, tone signals having various wave forms according to the types of tone generators and frequency divider circuits used. A square wave form electric tone signal which can be used frequently in an electronic musical instrument is employed as a tone signal in order to explain the novel electronic musical instrument system according to the invention. The invention, however, should not be construed as being limited to such wave forms.

Referring to FIG. 3, a tone signal from a frequency oscillator **84** has the frequency successively divided by a factor of two by the successive frequency dividers **85** and **86**. Output tone signals from frequency dividers **85** and **86** are supplied through resistors **87** and **88** to output terminals **89** and **90**, respectively. Wave forms **91** and **92** shown in FIG. 4 are the wave forms of output tone signals from frequency dividers **85** and **86**, respectively. The frequency spectrum of a square wave form tone, such as is shown in FIG. 5, is obtained by a frequency divider such as a flip-flop circuit. Each of the numbers plotted along the horizontal axis of FIG. 5 designates an order of harmonics, the vertical axis denotes the ampltiude of the harmonic components. The thick solid vertical lines and thin solid vertical lines denote the fundamental and harmonic frequency components of the tone signal, respectively. The square wave form tone signal shown in FIG. 4 contains no components having even order harmonic frequencies such as 2, 4, 6, 8 . . . , as shown in FIG. 5. This peculiar characteristic of the frequency spectrum of a square wave form tone signal produces a particular tone color such as that produced by woodwind musical instruments. This particular kind of tone color cannot be eliminated easily even though the frequency spectrum of this tone signal is modified by frequency filtering means.

This peculiar characteristic mentioned above is not favorable for every type of electronic musical instrument because a player cannot easily change a tone color by means of tone forming circuits. In order to avoid this particular tone color as well as obtain even order harmonics, the square wave form tone signal can be mixed with another square wave form tone signal which is one octave higher in the fundamental frequency than said first mentioned square wave form tone signal. This can be accomplished by mixing two square wave form tone signals, one of which is lower by one octave in a pitch and is larger by about two times in amplitude than the other one.

Referring to FIG. 6, a tone signal from a frequency oscillator **93** has the frequency successively divided by a factor of two by the successive frequency dividers **94, 95** and **96**, which frequency dividers will give square wave form tone signals. The square wave form tone signals generated by the frequency dividers **94, 95** and **96** are mixed into two groups through mixing resistors **97, 98, 99, 100** which are adjusted so as to have a mixing ratio of about 2:1 with respect to signal amplitude, i.e. the amplitude of the tone signal fed to terminal **101** from frequency divider **94** is made about half that fed from frequency divider **95** by means of resistors **97** and **98**, and the amplitude of the tone signal fed to terminal **102** from frequency divider **95** is made about half that fed from frequency divider **96** by means of resistors **99** and **100**. These combined tone signals have staircase wave forms at output terminals **101** and **102**. Said staircase wave form tone signals are shown as the wave forms **103** and **104** in FIG. 7. These combined tone signals have even order harmonics as well as odd order harmonics as shown in the spectrum of FIG. 8. This harmonic spectrum has a better harmonic distribution than that shown in FIG. 5 and consequently a better tonal quality which does not show said particular unfavorable tone color. Moreover, this combined tone signal can be changed easily into various tone colors by using tone forming circuits. This kind of method for mixing tone signals has been used in a conventional electronic musical instrument for avoiding said particular tone color explained above when a square wave form tone signal is employed as a tone signal source.

However, even when two tone signals having square wave forms are combined in a mixing ratio of about 2:1 with respect to their amplitude, people cannot hear two pitches corresponding to the fundamental frequency of each tone signal separately, but they can hear only one pitch as an auditory stimuluar in which the tone signal higher in frequency is heard as a harmonic of the lower frequency tone signal. Therefore, a multitone signal according to the invention cannot be obtained by simply mixing two or more tone signals together.

The acheivement of the multitone signal of the invention requires a different mixing method.

Referring to FIG. 9, tone signals **105, 106, 107, 108, 109** which have frequencies in octave relation to each other are mixed together at a unitary, i.e. 1:1, amplitude ratio. This mixing method in which the fundamental frequencies of said tone signals are arranged in a 2^n order produces a tone with a better tonal quality than that of the tone the spectrum of which is shown in FIG. 8 because of the aforesaid multitone effect. The reason for this is that in the frequency spectrum shown in FIG. 9, frequency components having the highest amplitudes correspond to frequencies in a harmonic order 1, 2, 4, 8,

. . . which are in a 2^n order and the frequency components having comparatively lower amplitudes corresponding to frequencies in a harmonic order 3, 6, 12, 24, . . . , are also in a 2^n order when these harmonic frequencies are divided by a factor of three, and frequency components having still lower amplitudes and corresponding to frequencies in a harmonic order 5, 10, 20, . . . are also in a 2^n order when these harmonic frequencies are divided by a factor of five, and so on.

Therefore, the mixed tone signal having the frequency spectrum of FIG. 9 has an uncertain pitch sensation and can produce said multitone effect when said mixed tone signal is modified by tone signal forming circuits. This mixed tone signal is the basic multitone signal according to the invention. Said basic multitone signal can be prepared by mixing tone signals having frequencies in a 2^n order in a range of at least three octaves. It is preferred, in order to obtain a more effective multitone signal, to mix said tone signals having frequencies in a 2^n order in a range of four or more octaves.

In order to obtain a clearer multitone effect, i.e. to obtain many pitch sensations, tone signals having frequencies in a 2^n order are mixed through resistors in such a way that tone signals having large amplitudes are separated from each other by two or more octaves. Referring to FIG. 10, tone signals from tone generators are mixed through mixing resistors of a mixing network, arranged as follows: tone signals **110**, **111** and **112** are relatively large in amplitude, and are separated from each other by two octaves. Tone signals **113** and **114** are relatively small in amplitude and are provided between tone signals **110** and **111** and between tone signals **111** and **112**, respectively. When tone signals **110** and **111** having second order harmonics, such as tone signals having a frequency spectrum as shown in FIG. 8, are employed, tone signals **113** and **114** can be eliminated because the frequencies of these tone signals **113** and **114** correspond to the frequencies of the second order harmonics of said tone signals **110** and **111**, respectively. In such an arrangement, tone signals **110**, **111** and **112** which are separated from each other by two octaves can produce three pitch sensations corresponding to the pitches of the tone signals **110**, **111** and **112**, respectively, when people hear this sound.

Thus, the modified multitone signal according to the invention can be obtained successfully by this mixing method. An arrangement of tone signals such as described above can be achieved easily in the above described tone signal mixing network by using impedance elements such as resistors having different values from each other. In order to obtain a larger amplitude of tone signal, an electric impedance element having a smaller value is chosen and vice versa. Such an arrangement of tone signals can also be achieved by using frequency filtering means. This method will be explained hereinafter.

Referring to FIG. 11, tone signals **115**, **116** and **117** have large amplitudes and are separated from each other by two octaves. Tone signals **118**, **119** and **120** have small amplitudes. A tone signal **118** is provided as a sub-octave tone signal producing its own pitch sensation and is lower by one octave than the fundamental frequency of said tone signal **115**, and tone signals **119** and **120** are provided between tone signals **115** and **116** and between tone signals **116** and **117**, respectively. Therefore, this multitone signal according to the invention can produce four pitch sensations corresponding to tone signals **118**, **115**, **116** and **117**.

Referring to FIG. 12, tone signals **121** and **122** having amplitudes larger than those of the other tone signals **123**, **124**, **125**, **126** are separated by only one octave from each other, and a tone signal **123** having an amplitude smaller than that of tone signal **121** is provided as a sub-octave tone signal having a fundamental frequency lower by one octave than tone signal **121**. Tone signals **124** and **126** having amplitudes smaller than those of tone signals **122** and **125**, respectively, are provided and have fundamental frequencies higher by one octave than the frequencies of tone signals **122** and **125**, respectively. Therefore, this multitone signal according to the invention can produce four pitch sensations corresponding to tone signals **123**, **121**, **122** and **125**. In this case, a person cannot recognize said four pitch sensations but can recognize three pitch sensations corresponding to tone signals **123**, **121** and **125** because of limitations on his auditory sensibility.

Referring to FIG. 13, tone signals **127**, **128** and **129** having amplitudes larger than those of tone signals **130**, **131** and **132** are separated by three and two octaves from each other, respectively. Tone signals **130** and **131** are provided at frequencies corresponding to the second and fourth harmonics of said tone signal **127**, respectively, and are smaller in amplitude than said tone signal **127**. Tone signal **132** is provided at a frequency corresponding to the second harmonic of said tone signal **128** and is smaller in amplitude than said tone signal **128**. Therefore, this multitone signal according to the invention produces three pitch sensations corresponding to tone signals **127**, **128** and **129**.

All of the mixed tone signals depicted in FIGS. 10–13 are novel multitone signals but have different tone qualities because of their different frequency spectra. Each of the multitone signals depicted has at least two tone signals. One of said at least two tone signals, such as a tone signal **110**, **116**, **122** or **127** respectively, has an amplitude larger than that of the adjacent tone signal, such as a tone signal **113**, **120**, **124** or **130**, said adjacent tone signal being mixed in said each of the multitone signals and having a higher fundamental frequency than that of said one of said at least two tone signals. The other of said at least two tone signals, such as tone signal **111**, **115**, **121** or **128**, has an amplitude larger than that of the adjacent tone signal, such as a tone signal **113**, **118**, **123** or **131**, said adjacent tone signal being mixed in said each of the multitone signals and having a lower fundamental frequency than that of said another of at least two tone signals.

The following description shows the effects of a tone forming circuit where the tone color of the novel multitone signal is changed without losing the multitone effect.

Referring to FIG. 14, tone signals **133**, **134** and **135** have amplitudes larger than those of tone signals **136**, **137** and **138**, respectively. Said tone signals **136**, **137** and **138** have fundamental frequencies corresponding to second order harmonics of said tone signals **133**, **134** and **135**, respectively. The tone signal **134** has an amplitude larger than that of tone signal **133**, and tone signal **135** has an amplitude larger than that of tone signal **134**. When the mixed tone signal, the spectrum of which is depicted in FIG. 14, is passed through a tone forming circuit having frequency characteristics shown in FIG. 15, there is obtained a mixed tone signal having a frequency spectrum shown in FIG. 16, in which the tone signal **134**_a_ has an amplitude smaller than that of tone signal **133**_a_, and tone signal **135**_α_ has an amplitude smaller than that of tone signal **134**_a_. Therefore, it is possible to obtain a mixed tone of different tone color from that of the mixed tone having the former frequency spectrum shown in FIG. 14.

When the mixed tone signal having the frequency spectrum depicted in FIG. 14 is passed through another tone forming circuit having the frequency characteristics depicted in FIG. 17, a mixed tone signal having still another frequency spectrum, as shown in FIG. 18, is obtained. The frequency spectrum shown in FIG. 18 produces a mixed tone having another different tone color with a multitone effect. In this case, tone signals **134** and **137** in FIG. 14 are attenuated less than tone signals **133**, **136**, **135** and **138** in FIG. 14 due to the frequency characteristics shown in FIG. 17. The frequency spectrum shown in FIG. 14 is modified to the frequency spectrum shown in FIG. 18 in which the tone signal **134***b* has an amplitude larger than those of tone signals **133***b* and **135***b*. Therefore, it is possible to obtain another mixed tone signal having a different tone color from that of the tone having the frequency spectrum shown in FIG. 14.

Referring to FIG. 19, tone signals **139** and **140** are approximately equal to each other in amplitude, tone signals **141** and **142** are approximately equal to each other in amplitude, and tone signals **143** and **144** are approximately equal to each other in amplitude. The amplitudes of these three pairs of tone signals increase gradually as the frequencies of tone signals increase, and said tone signals **139–144** are each separated by one octave from the other. When this mixed tone signal is passed through a high frequency filtering means having the frequency characteristics shown in FIG. 20, in which the attenuation increases with an increase in the frequency, the frequency spectrum shown in FIG. 19 is modified to the frequency spectrum shown in FIG. 21 because tone signals **140, 142** and **144** in FIG. 19 are attenuated more than tone signals **139, 141** and **143**, respectively. In addition, the higher frequency tone components are attenuated more than the lower frequency components. These facts make it possible to modify the frequency spectrum shown in FIG. 19 to produce the frequency spectrum shown in FIG. 21. In the modified frequency spectrum shown in FIG. 21, reference characters **139***a*, **140***a*, **141***a*, . . . **144***a* designate the modified tone signals. It will be obvious that the modified tone signals **139***a*, **141***a* and **143***a* have approximately the same amplitude and the modified tone signals **140***a*, **142***a* and **144***a* have approximately the same amplitude, and the modified tone signals **139***a*, **141***a* and **143***a* have amplitudes larger than those of the modified tone signals **140***a*, **142***a* and **144***a*.

The frequency spectrum shown in FIG. 21 behaves as a multitone signal even though it has a different tone color from that of the original mixed tone having the frequency spectrum shown in FIG. 19. In this case, a tone forming system including tone forming circuits modifies a mixed tone signal according to this invention to produce a more effective multitone signal such as a multitone signal having a frequency spectrum, as shown in FIG. 21, which is similar to the frequency spectrum shown in FIG. 10. It is also possible to convert such a more effective multitone signal to acoustic multitone by causing a sound system having frequency characteristics shown in FIG. 20 to modify the mixed-tone signal having a frequency spectrum as shown in FIG. 19.

It will be understood from the preceding description that in the novel tone signal mixing method, the multitone effect is successfully obtained even while using a single-pole keyswitch such as keyswitches **31, 32, 33** . . . **36** shown in FIG. 2. In addition, this method can produce various tone colors by simply changing the frequency characteristics of the tone forming circuits without losing said multitone effect.

A conventional electronic musical instrument requires a number of multipole keyswitches to produce said multitone effect because in a conventional electronic musical instrument, many tone signals generated by a tone generator system are combined after switching said many tone signals by means of the multipole keyswitches. The multipole keyswitches of a conventional electronic musical instrument are generally very complicated and consequently very expensive. Substitution of a single-pole keyswitch for the multipole keyswitch usually used in the conventional instrument can greatly reduce the cost of the electronic musical instrument in accordance with the invention. Moreover, inexpensive fixed resistors facilitate mixing said many tone signals having the fundamental frequencies in a 2^n order in accordance with the invention.

The novel concept according to the invention can produce enormous advantages when it is embodied to the arrangement depicted in FIG. 22. The same reference numbers as have been used in previous figures designate the same components in this and subsequent figures.

Referring to FIG. 22, two kinds of tone signals are employed, one of said two kinds of tone signals being a single-tone signal which produces only one pitch sensation, and the other one being a multitone signal which produces many pitch sensations in accordance with the invention.

A mixed tone signal switched by a keyswitch **145** corresponding to key C_4 is produced by mixing, in a special mixing ratio for producing a multitone signal according to the invention, four tone signals generated by frequency dividers **12, 13, 14** and **16**, excluding frequency divider **15**, by means of mixing resistors **151, 152, 153, 154**, having appropriate resistances and forming tone signal mixing network **77***a*.

A mixed tone signal switched by a keyswitch **146** corresponding to key B_3, a mixed tone signal switched by a keyswitch **147** corresponding to key $C_3\#$, a mixed tone signal switched by a keyswitch **148** corresponding to key C_3, a mixed tone signal switched by a keyswitch **149** corresponding to key B_2, a mixed tone signal switched by a keyswitch **150** corresponding to key $C_2\#$ and so on, are produced by mixing the tone signals generated by frequency dividers **19, 20, 21** and **23**, excluding frequency divider **22**, frequency dividers **25, 26, 27** and **29** excluding frequency divider **28**, frequency dividers **13, 14, 15** and **17**, excluding frequency divider **16**, frequency dividers **20, 21, 22** and **24**, excluding frequency divider **23**, frequency dividers **26, 27, 28** and **30**, excluding frequency divider **29**, and so on, respectively, by means of mixing resistors **162, 163, 164, 165**, mixing resistors **166, 167, 168, 169**, mixing resistors **170, 171, 172, 173**, mixing resistors **174, 175, 176, 177**, mixing resistors **178, 179, 180, 181** and so on, respectively, all of which have appropriate resistances, in the same way as said mixing tone signal for keyswitch **145** is produced, as explained above.

The tone signal from a frequency divider **15** is not mixed into the mixed tone signal switched by keyswitch **145**, but instead is directed to a keyswitch **155** through resistor **161** forming part of the tone signal mixing system **2** so as to give a special tone color to said mixed tone signal. Said special tone color gives said mixed tone signal at least two pitch sensations, because said mixed tone signal is made up of the tone signals excluding the one tone signal from the frequency divider **15** which has a pitch between the lowest pitch tone signal from the frequency divider **16** and the highest pitch tone signal from a frequency divider **12**. The tone signal derived directly from said frequency divider **15** does not contain even order harmonics. Such a tone signal having no even order harmonics has a particular tonal quality, such as a tone from a woodwind instrument, which produces a greater contrast with the mixed tone signal.

Tone signals from frequency dividers **22, 28, 16, 23, 29**, and so on, are directed to keyswitch **156** corresponding to key B_3, keyswitch **157** corresponding to key $C_3\#$, keyswitch **158** corresponding to key C_3, keyswitch **159** corresponding to key B_2, keyswitch **160** corresponding to key $C_2\#$, and so on, respectively, through respective resistors **191, 192, 193, 194, 195** and so on in the same way as for said tone signal for keyswitch **155**, as explained above.

The mixed tone signals from keyswitches **145, 146**, . . . **150** are combined and are fed to the tone forming circuits **196, 197** and **198**, through tone switches **199, 200** and **201** of tone forming system **4** for the purpose of producing desired tone colors. On the other hand, the tone signals from keyswitches **155, 156**, . . . **160** are combined and are fed to the tone forming circuits **202** and **203** through tone switches **204** and **205** of said tone forming system **4** to obtain different tone colors.

In an electronic musical instrument having such an arrangement, the tone signals obtained from keyswitches **145, 146**, . . . **150** are multitone signals. On the other hand, however, the tone signals obtained from keyswitches **155, 156, . . . 160** are single-tone signal in which only one pitch sensation is observed. When the key C_4 is depressed, the double pole keyswitch consisting of said keyswitches **145** and **155** is actuated and simultaneously switches said multitone signal and said single-tone signal. The novel electronic musical instrument according to the invention, therefore, can produce many kinds of tone colors.

A more preferred embodiment of the invention is shown in FIG. 26. FIG. 23, FIG. 24 and FIG. 25 will be discussed initially to facilitate an understanding of the embodiment shown in FIG. 26.

Referring to FIG. 23, a tone signal **207** having a smaller amplitude and a higher frequency than a tone signal **206** is mixed with tone signal **206**. The mixed tone signal made up of said tone signals **206** and **207** is used as a single-tone signal which produces one pitch sensation of an 8 foot voice.

The expression "8 foot voice" is part of the terminology in the pipe organ art and is defined as the length of the pipe corresponding to the lowest key of the keyboard. Therefore, tone signals used to produce the sound of an 8 foot voice produce acoustic tones having the same pitch as the notes written in the five-line staves of the music. Tone signals used to produce the sound of a 16 foot voice produce acoustic tones having a pitch lower by one octave than that of the notes written in the staves of the music and the tone signals used to produce the sound of a 4 foot voice produce acoustic tones having a pitch higher by one octave than that of the notes written in the staves of the music, and so on.

Referring to FIG. 24, tone signals **208, 209** and **210** have amplitudes larger than the amplitudes of tone signals **211, 212** and **213** and are separated by two octaves from each other. Tone signals **211, 212** and **213** have frequencies corersponding to second order harmonics of tone signals **208, 209** and **210**, respectively. This mixed tone signal is considered to be a multitone signal which provides three pitch sensations corresponding to tone signals **208, 209** and **210**, and in which the lowest tone signal **208** is used to produce a 4 foot voice, and tone signal **209** is used to produce a 1 foot voice, and so on.

Referring to FIG. 25, tone signals **214, 215** and **216** have amplitudes larger than the amplitudes of tone signals **217, 218, 219** and **220** and tone signals **214** and **215** are separated by three octaves and tone signals **215** and **216** are separated by two octaves. Tone signals **217, 218, 219** and **220** are mixed with said tone signals **214, 215** and **216** so as to produce tone signal having the frequency spectrum of FIG. 25. This mixed tone signal is considered to be another multitone signal which provides three pitch sensations corresponding to tone signals **214, 216** and **217**, and in which the lowest tone signal **214** is used to produce a 16 foot voice, and tone signal **215** is used to produce a 2 foot voice, and so on.

These three kinds of tone signals are produced in an electronic musical instrument, the circuit diagram of a typical part of which is shown in FIG. 26 where a three-pole keyswitch switches said three kinds of tone signals at the same time. One mixed tone signal or any combination of said three kinds of mixed tone signals can be used by using a tone forming system **4** having tone switches **246, 247, . . . 250** and tone forming circuits **241, 242, . . . 245.** The combination of said three kinds of mixed tone signals comprising one single-tone signal and two multitone signals produces a tone in which all harmonics have about the same amplitude so as to produce a very effective tone color. Said very effective tone color provides many pitch sensations corresponding to the pitches of the 16 foot voice, 8 foot voice, 4 foot voice, 2 foot voice, 1 foot voice, and so on.

Referring to FIG. 26, frequency dividers **221** and **222** are added after frequency divider **17** in the tone generator chain of oscillator **9** so as to divide successively the frequency of tone signal from frequency divider **17.** Tone signals produced in frequency dividers **17** and **221** are mixed in mixing resistors **224** and **225** having appropriate resistance values to achieve the amplitude relation shown in FIG. 23, and are then fed to a keyswitch **223** corresponding to key C_3. Tone signals produced in frequency dividers **12, 13, . . . 17** are mixed in mixing resistors **227, 228, . . . 232** having appropriate resistance values to achieve the amplitude relation shown in FIG. 24 and are fed to a keyswitch **226** corresponding to said key C_3. Tone signals produced in frequency dividers **13, 14, . . . , 17, 221** and **222** are mixed in mixing resistors **233, 234, . . . , 239** having appropriate resistance values to achieve the amplitude relation shown in FIG. 25 and are fed to a keyswitch **240** corresponding to said key C_3. After being switched by the three pole keyswitch consisting of keyswitches **223, 266** and **240**, these three kinds of mixed tone signals are fed to tone forming circuits **241, 242, . . . 245** through tone switches **246, 247 . . . , 250** to obtain the desired tone colors. In the novel electronic musical instrument having such an arrangement, a mixed tone signal obtained from keyswitch **223** is a single-tone signal in which only one pitch sensation is observed. On the other hand, however, mixed tone signals obtained from key switches **226** and **240** are multitone signals in which many pitch sensations are observed. Further, the mixed tone signals obtained from keyswitches **223, 226** and **240** differ from each other in the voice which they sound, such as a 16 foot voice, 8 foot voice, 4 foot voice, and so on. This makes it posible to provide an electronic musical instrument with many advantages, such as the advantages that the tonal quality as well as the length of the voices can be changed greatly.

The different types of multitone signals described thus far have been produced by mixing tone signals having fundamental frequencies in a 2^n order. On the other hand, the single-tone signals have been produced either by mixing tone signals to produce a tone signal with a frequency spectrum as shown in FIG. 8 or FIG. 23 or by producing an unmixed tone signal having a frequency spectrum as shown in FIG. 5. Thus, all of the tone signals can initially be classified into two groups i.e. mixed tone signals and unmixed tone signals. Said mixed tone signals are subdivided into two groups i.e. multitone signals and single-tone signals, but all of said unmixed tone signals are single-tone signals Hereinafter, all of said single-tone signals referred to will be unmixed tone signals rather than said single-tone signals produced from a mixed tone signal.

In order to produce still another multitone signal, it will be apparent that there is no need to restrict the arrangement of tone signals so that the fundamental frequencies are in a 2^n order. Other musical relations can be used, such as musically perfect fifth or a musical third, by using the circuit arrangements as seen in FIG. 27 and FIG. 28.

Referring to FIG. 27, the tone generator chain which consists of a frequency oscillator **251** and frequency dividers **252, 253, . . . 256** and which corresponds to musical note G is shown in full lines. A mixed tone signal is supplied to a keyswitch **257** corresponding to key C_4, the main part of said mixed tone signal being supplied from frequency dividers **12, 13, . . . 16** through mixing resistors **258, 259, 260, 262** and **263,** having appropriate resistance values.

A further tone signal produced in frequency divider **254** is mixed with said main part of the mixed tone signal supplied to said keyswitch **257** through high frequency filtering means **264** and mixing resistor **261.** The further tone signal produced in frequency divider **254** is in the relationship of a musical fifth with respect to the tone signal produced in frequency divider **15.**

A mixed tone signal is supplied to keyswitch **265** corresponding to key C_3 and the main part of said mixed tone signal is supplied from frequency dividers **13, 14, . . . 17** through mixing resistors **266, 267, 268, 270** and **271,** having appropriate resistance values. The remainder of said mixed tone signal is supplied from a frequency divider **255** which produces a tone signal in a musical fifth relationship with the tone signal produced in frequency divider **16**, and is passed through high frequency filtering means **272** and mixing resistor **269**. Said high frequency filtering means **264** and **272** are used to avoid unfavorable beats generated as a result of interaction between frequency components of the tone signals generated by the tone generator chain corresponding to musical note C and high frequency components of the tone signal generated by the tone generator chain corresponding to musical note G. The tone signals switched by keyswitches **257** and **265** are combined and are fed to tone forming circuits **273**, **274**, . . . **277** so as to obtain the desired tone colors which are selected by tone switches **278**, **279**, . . . **282**.

Referring to FIG. 28, the tone generator chain which consists of frequency oscillator **283** and frequency dividers **284**, **285**, . . . **288** corresponding to musical note E is shown in full lines. The main part of a mixed tone signal supplied to keyswitch **290** corresponding to key C_4 is supplied from frequency dividers **12**, **13**, . . . **16** through mixing resistors **291**, **292**, **294**, **296** and **297** having appropriate resistance values. Another part of said mixed tone signal is supplied from a frequency divider **254** which produces a tone signal which is in a musical fifth relationship with respect to the tone signal generated by frequency divider **15**. The remainder of said mixed tone signal is supplied from frequency divider **285** which produces a tone signal which is in a musical third relationship with respect to the tone signal produced by frequency divider **14**. Said another part and said remainder are mixed with the main part of the mixed tone signal through high frequency filtering means **299** and a mixing resistor **295** and high frequency filtering means **298** and a mixing resistor **293**, respectively. The main part of the mixed tone signal supplied to keyswitch **300** corresponding to key C_3 is supplied from frequency dividers **13**, **14**, . . . **17** through mixing resistors **301**, **302**, **304**, **306** and **307** having appropriate resistance values. Another part of the mixed tone signal is supplied from frequency divider **255** which produces a tone signal which is in a musical fifth relationship with respect to the tone signal generated by frequency divider **16**. The remainder of said mixed tone signal is supplied from frequency divider **286** which produces a tone signal which is in a musical third relationship with respect to the tone signal generated by frequency divider **15**. Said another part and said remainder are mixed with the main part of the mixed signal through high frequency filtering means **309** and a mixing resistor **305** and high frequency filtering means **308** and a mixing resistor **303**, respectively. These mixed tone signals switched by keyswitch **290** and **300** are combined and are fed to tone forming circuits **273**, **274**, . . . **277** so as to obtain desired tone colors which are selected by tone switches **278**, **279**, . . . **282**. In the same manner as said high frequency filtering means **264** and **272** shown in FIG. 27, said high frequency filtering means **298**, **299**, **308** and **309** are provided to avoid unfavorable beats by filtering out higher frequency components of the input tone signals supplied to said high frequency filtering means.

In the cases shown in FIGS. 27 and 28, said tone signals having a musical relationship different from a 2^n order are added to the aforesaid multitone signals. When another tone signal having a musical fifth relationship with respect to any one of the tone signals having the fundamental frequencies in a 2^n order is added to a multitone signal, said another tone signal and any one of tone signals have fundamental frequencies in a relation of 3:2. Therefore, a tone signal having frequency 1 corresponding to the difference between the two tone signals in said ratio of 3:2 is produced and observed. The tone with the frequency 1 intensifies the pitch sensation of the tone signal which is mixed into said multitone signal and which has a fundamental frequency that corresponds to said difference frequency 1. When another tone signal having a musical third relationship with respect to any one of the tone signals having fundamental frequencies in a 2^n order is added to a multitone signal, said another tone signal and any one of the tone signals have fundamental frequencies in a relationship of 5:4. Therefore, a tone signal having a frequency 1 corresponding to the difference between the two tone signals in said ratio of 5:4 is produced and observed. The tone with the frequency 1 intensifies the pitch sensation of the tone signal corresponding to said difference frequency 1 in a manner similar to that described above. Even though said another tone signal which is added can intensify any one of the pitch sensations produced by a multitone signal, it is necessary to provide said another tone signal at a comparatively small amplitude in accordance with the invention, because when said another tone signal has a comparatively large amplitude, the plurality of pitch sensations of said multitone signal is lost. In the cases shown in FIG. 27 and FIG. 28, it is, of course, possible to use one or more added other tone signals which are consonant, such as by being in a musical perfect fifth or in a musical third relationship, with the tone signals having fundamental frequencies in a 2^n order.

FIG. 29 and FIG. 30 illustrate examples of high frequency filtering means consisting of a resistor **311** and a capacitor **312**, and consisting of an inductor **313** and a capacitor **314**, respectively.

A conventional electronic musical instrument usually has a number of tone generators greater than the number of keyboard keys in the keyswitch system because the number of signals supplied by one key in said keyswitch system is greater than one. Such a construction is complicated and expensive. The novel electronic musical instrument according to the invention has a reduced number of tone generators, and consequently it has advantages over a conventional electronic musical instrument not only with respect to tonal quality but also with respect to simplicity of construction.

According to the invention, the multitone effect can be achieved by using a fewer number of tone generators than is used in a conventional electronic instrument.

Referring to FIG. 31, a mixed tone signal supplied to a keyswitch **315** corresponding to key C_4 is supplied from frequency dividers **12**, **13** . . . **16** through mixing resistors **319**, **320**, . . . **323** having appropriate resistance values so as to be mixed in a special mixing ratio to obtain a multitone signal according to the invention. A mixed tone signal is supplied to a keyswitch **316** corresponding to a key C_3 from frequency dividers **13**, **14**, . . . **17** through mixing resistors **324**, **325**, . . . **328**, having appropriate resistance values so as to be in the same mixing ratio as said mixed tone signal for said key C_4. A mixed tone signal is supplied to a keyswitch **317** corresponding to a key C_2 from frequency dividers **14**, **15**, **16** and **17** through mixing resistors **329**, **330**, **331** and **332**, having appropriate resistance values and is partly supplied from a means **343** for producing a difference tone signal from a mixture of the two tone signals from frequency dividers **17** and **256**, said two tone signals being supplied to means **343** through resistors **340** and **339**. A mixed tone signal is supplied to a keyswitch **318** corresponding to a key C_1 partly from frequency dividers **15**, **16** and **17** through mixing resistors **334**, **335** and **336**, having appropriate resistance values and is partly supplied from said means **343** and another means **344** for producing a difference tone signal from a mixture of the two tone signals from frequency dividers **17** and **257**, said two tone signals being supplied to means **344** through resistors **341** and **342**.

In order to clarify the concept of difference tone signal, a method of mixing two tone signals to produce a difference tone signal will be described. In FIG. 31, a tone signal produced in frequency divider **17** corresponding to musical note C and a tone signal produced in a frequency divider **256** corresponding to musical note G have fundamental frequencies in a ratio of 2:3. When the tone signal generated by frequency divider **17** and the tone signal generated by frequency divider **256** are passed through mixing resistors **340** and **339** and are fed to the aforesaid means **343** for producing a difference tone signal, a difference tone singal having a frequency corresponding to a difference 1 between the two tone signals which are in said ratio of 2:3 is produced by said means **343**, which can be a non-linear network, for example. Said difference tone signal from said nonlinear network **343** will be lower in pitch by one octave than said tone signal generated by frequency divider **17** because the fundamental frequencies of the signal from the means **343** and the signal from frequency divider **17** are in a ratio of 1:2. Another difference tone signal can be produced by the aforesaid means **344** in a similar manner. The tone signal generated by frequency divider **17** corresponding to musical note C and the tone signal generated by frequency divider **257** corresponding to musical note G have fundamental frequencies in a ratio of 4:3 and are fed through mixing resistors **341** and **342** to said means **344**. A difference tone signal having a frequency corresponding to a difference 1 between the two tone signals in said ratio of 4:3 is produced. Said difference tone signal from said means **344** is, however, two octaves lower in a pitch than said tone signal generated by frequency divider **17** because the fundamental frequencies of the signal from the means **344** and the signal from frequency divider **17** are in a ratio of 1:4.

Even though a non-linear network, such as a diode **345** and a resistor **347**, or a diode **346** and a resistor **348** as shown in FIG. 32 and FIG. 33, respectively, is used as the means for producing the difference tone signal from the mixture of tone signals, it is possible to recognize a difference tone signal subjectively when a non-linear network is not used because one can discern subjectively the difference pitch between said two tone signals and can hear a sound corresponding to said difference pitch. The network for producing the difference tone has a filter comprising, for example, a resistor **349** and a capacitor **350** in the network of FIG. 32 or an inductor **351** and a capacitor **352** in the network FIG. 33. The unfavorable disconsonant high frequency components can be reduced by using such a filter, said filter filtering out high frequency components from the mixture of tone signals or from a difference tone signal from said non-linear network.

As a practical matter, each of the difference tone signals produced from a mixture of tone signals deviates in pitch from a pitch corresponding exactly to a musical note, because the tone signals used in an electronic musical instrument are tuned on an equal tempered musical scale. The ratio of the fundamental frequency of the aforesaid C note to that of the aforesaid G note is not exactly 2:3 as explained previously but rather is:

$$1:\sqrt[12]{2^7}\doteqdot 2:2.9966 \text{ or } 2:\sqrt[12]{2^7}\doteqdot 4:2.9966$$

respectively. Therefore, a difference tone signal derived from the mixture of said two tone signals has a pitch corresponding to a frequency difference of 0.9966 between frequencies 2 and 2.9966, or to a frequency difference of 1.0034 between frequencies 4 and 2.9966.

It is difficult for a conventional electronic musical instrument to sound said difference tone signals having a deviated pitch and normal tone signals having a pitch exactly equal to that of a note corresponding to a key of a keyboard individually and to produce the same tone response for each such tone. However, a mixed tone signal according to the invention formed by mixing one or two difference tone signals having a deviated pitch and a comparatively low frequency with three or more normal tone signals having an exact pitch and a comparatively high frequency will be very similar with respect to tone respones such as tone colors, to a mixed tone signal formed by mixing only normal tone signals having an exact pitch and ranging from a comparatively low frequency to a high frequency. This is because said one or two difference tone signals having deviated pitch are masked by said three or more normal tone signals in said mixed tone signal, according to the invention, which have an exact pitch. Therefore, said difference tone signals can be easily used by mixing them with normal tone signals in accordance with the invention. Consequently, the invention makes it possible to reduce the number of tone generators by employing said difference tone signals.

Tone signals from keyswitches **315**, **316**, **317** and **318** are combined and are fed to tone forming circuits **273**, **274**, . . . , **277** through tone switches **278**, **279** . . . , **282** for obtaining desired tone colors. The means **343** and **344** shown in FIG. 31 for producing difference tone signal includes a non-linear element such as diode and vacuum tube and high frequency filtering means for suppressing higher harmonics of difference tone signals generated therein.

Referring to FIG. 32 and FIG. 33 showing examples of difference tone producing means, said means comprise diodes **345** and **346** connected in parallel with resistors **347** and **348**, respectively, and further include high frequency filtering means. The said high frequency filtering means consist of resistor **349** and capacitor **350**, and an inductance **351** and capacitor **352**, respectively. By using this method of mixing difference tone signals with normal tone signals, one can obtain the same tone color over the whole musical note range of a keyboard.

The method of mixing such signals can be modified to be much simpler, which results in a low cost instrument.

Referring to FIG. 34, tone signals generated by a chain comprising a frequency oscillator **353** and four frequency dividers **354**, **355**, **356** and **357** and a tone signal generated by a frequency divider **358** and having a frequency which is higher by a musical fifth than the frequency of the tone signal generated by frequency divider **357** are supplied to keyswitches **359**, **360**, . . . **363** which are in a one octave relationship to each other.

Two tone signals which are in octave relationship with each other, i.e., which have the fundamental frequencies in a 2^n order are generated by a frequency oscillator **353** and produced in frequency divider **354**, respectively, and are mixed by mixing resistors **R1** and **R2**, respectively, and then are fed to a key switch **359**. With only these two tone signals it is difficult to produce an effective multitone signal due to a lack of frequency components contained therein. The difficulty can be overcome by intensifying the higher harmonic components of the tone signal which is generated by the frequency oscillator **353** and which includes at least a second harmonic. A capacitor C_1 can be used to intensify said higher harmonic components by being connected in parallel with resistor **R1**. Three tone signals which are in octave relationship to each other are generated by frequency oscillator **353**, and produced in frequency dividers **354** and **355** respectively, and are mixed by mixing resistors **R3**, **R4** and **R5**, respectively, and then fed to keyswitch **360**. A capacitor C_2 is also provided to intensify the higher harmonic components of the tone signal generated by the frequency oscillator **353** in a manner similar to that of capacitor C_1. Four tone signals which are in octave relationship to each other are generated by the frequency oscillator **353** and produced in frequency dividers **354**, **355** and **356** respectively, and are mixed by mixing resistors **R6**, **R7**, **R8** and **R9**, respectively, and are fed to a keyswitch **361**. Five tone signals are in octave relation to each other, are generated by frequency oscillator **353**, and produced in frequency dividers **354**, **355**, **356** and **357** respectively, and are mixed by mixing resistors **R10**, **R11**, . . . **R14**, respectively, and are fed to keyswitch **362**. Since there are at least four tone signals in said last two mixed tone signals, no shunt capacitor is needed.

Finally, a mixed tone signal supplied to a keyswitch **363** is partly generated in frequency oscillator **353** and produced in frequency dividers **355** and **356** respectively, and mixed by mixing resistors **R15**, **R16** and **R17**, respectively, and the remainder produced in a non-linear network described hereinafter. A tone signal lower by one octave than that produced in frequency divider **357** cannot be obtained from the tone generator chain **353, 354, 355, 356, 357** of FIG. 34. Therefore, this tone signal is synthesized as a difference tone signal by means of a non-linear network. A tone signal generated by a frequency divider **357** and a tone signal generated by a frequency divider **358** which has a frequency which has a musical fifth relationship with respect to said tone signal generated by a frequency divider **357** are mixed by resistors **R19** and **R20**, respectively, and are fed to a non-linear network consisting of resistor **R21**, diode D and capacitor C_3 so as to generate a difference tone signal. Said difference tone signal is mixed by a mixing resistor **R18** with the other tone signals generated by the frequency oscillator **353** and produced in frequency dividers **355** and **356**, respectively, and the mixed tone signal is fed to keyswitch **363**. Each of the mixed tone signals fed to the respective keyswitches **359, 360, . . . , 363** is grounded to a common ground through resistors **R22, R23, . . . , R26**, respectively.

In the embodiment shown in FIG. 34, the fundamental frequencies and amplitudes of all tone signals are combined in the aforesaid manner to produce multitone signals in accordance with the invention. An example of the values of the resistors and capacitors for the embodiment is shown in Table 1 and Table 2.

In Table 2, the systems for the F♯–A♯ notes and the B–E notes do not contain components C_1, R1, R2 and R22, because in the F_1–F_5 scale keyboard having a four octave musical range, there are five F note keys, i.e. F_1, F_2, F_3, F_4 and F_5, but the group of keys for the other notes comprises only four keys. For example, the F♯ keys comprise F_1♯, F_2♯, F_3♯ and F_4♯, and the G keys comprise G_1, G_2, G_3 and G_4, and so on.

Referring to FIG. 35 illustrating the frequency spectrum of a mixed tone signal fed to the keyswitch **359** shown in FIG. 34, the frequency component **364** is the fundamental frequency component of the tone signal produced in the frequency divider **354** shown in FIG. 34 and the frequency component **365** is the fundamental frequency component of the tone signal generated by frequency oscillator **353** shown in FIG. 34. The frequency component **366** is a second harmonic component of the tone signal generated by said frequency oscillator **353** shown in FIG. 34, said second harmonic component being intensified by said capacitor C_1 shown in FIG. 34. The frequency spectrum shown in FIG. 35 is considered to be that of a multitone signal, because it includes three frequency components **364, 365** and **367**, and the component **364** has an amplitude larger by at least three db than that of the adjacent frequency component **365** forming part of said frequency spectrum and which in turn has a higher frequency than that of said component **364**, and the other component **366** has an amplitude larger by at least three db and a frequency higher than that of the adjacent frequency component **365**.

A multitone signal can also be produced by mixing three tone signals having their fundamental frequencies in a 2^n order in such a way that said three tone signals have their amplitudes and relative frequencies corresponding to those of said three frequency components **364, 365** and **366** shown in FIG. 35. One of said three tone signals corresponding to said three frequency components **364, 365** and **366** has a fundamental frequency midway between the other two and has an amplitude smaller than the amplitudes of the other two tone signals. In this case, it is most favorable for obtaining a good multitone signal when said one tone signal midway between the other two has an amplitude lower by at least three db than the amplitude of the other two tone signals so as to produce two pitch sensations in said multitone signal.

Referring to FIG. 36 illustrating a frequency spectrum of one of the multitone signals according to the invention, two tone signals **367** and **368** have fundamental frequencies which are separated by two octaves and no tone signal is positioned between said two tone signals **367** and **368**. In this case, the frequency spectrum shown in FIG. 36 is similar to that obtained in the case where the frequency component **365** in the frequency spectrum of FIG. 35 is eliminated. In such a way, a multitone signal can be made by mixing two tone signals having the fundamental frequencies separated by two octaves.

The concept of the novel multitone signals according to the invention can be applied not only to the whole range of the keyboard of an electronic musical instrument, but also to a part of the keyboard in such a way that the tone signal mixing networks mix some of the tone signals generated by the tone generator system so as to produce said multitone signals for only a part of the keyboard.

In addition, the concept of the novel multitone signals according to the invention can be applied to an electronic musical instrument having two or more keyboards in such a way that some of said keyboards control said novel multitone signals and the other of said keyboards control conventional tone signals.

Furthermore, the concept of the novel multitone signals according to the invention can be applied to an electronic musical instrument in which each key of some part of the keyboard has a multipole switch. In such a case some of the keyswitches of said multipole keyswitch switch two or more different types of said novel multitone signals, such as the different types of said novel multitone signals which are shown in FIGS. 10–14, FIG. 24 and FIG. 25, and which are different from each other with respect to the fundamental frequency and amplitude of tone signals contained therein, and the other keyswitches of said multipole keyswitches switch one or more different types of conventional tone signals, such as the different types shown in FIG. 5 and FIG. 8.

While particular embodiments of the invention have been shown and described, it will be apparent to those skilled in the art that numerous modifications and variations can be made in the form and construction thereof without departing from the fundamental principles of the invention. It is, therefore, desired, by the following claims, to include within the scope of the present invention all similar and modified forms of the apparatus disclosed and by which the results of the invention can be obtained.

What is claimed is:

1. An electronic musical instrument comprising in combination: a tone generator system for generating tone signals capable of producing acoustic tones; a keyswitch system for switching said tone signals and including keyswitches actuated by depressing keys of keyboards; a tone forming circuit coupled to the output of said keyswitch system and which provides tone responses for said acoustic tones; a sound system which includes an amplifier and a sounding means and is coupled to the output of said tone forming circuit; and a tone signal mixing circuit which is coupled between said tone generator system and said keyswitch system and which includes a plurality of mixing networks for mixing at least some of said tone signals generated by said tone generator system so as to produce mixed tone signals at least some of which are multitone signals, each of said multitone signals being made up of a plurality of tone signals having their fundamental frequencies in a 2^n order and extending over a range of at least three octaves, each of at least some of said multitone signals including at least two tone signals, one of said two tone signals having an amplitude larger than that of an adjacent tone signal which is present in said each of at least some multitone signals and having a lower fundamental frequency than said adjacent tone signal, and another of said at least two tone signals having an amplitude larger than that of an adjacent tone signal which is present in said each of at least some multitone signals and having a higher fundamental frequency than said adjacent tone signal.

2. An electronic musical instrument as claimed in claim 1, wherein said mixing networks each comprise means for mixing said multitone signals are each made up of tone signals having their fundamental frequencies in a 2^n order and extending over a range of more than two octaves and including four octaves.

3. An electronic musical instrument as claimed in claim 1, wherein said mixing networks comprise impedance elements.

4. An electronic musical instrument as claimed in claim 3, wherein said impedance elements are fixed value resistors.

5. An electronic musical instrument as claimed in claim 3, wherein said impedance elements consist of fixed value resistors and fixed value capacitors connected in parallel therewith for intensifying high frequency components of tone signals.

6. An electronic musical instrument as claimed in claim 1, wherein at least some of said mixing networks for producing said multitone signals each include impedance elements having at least two different electric impedance values for producing a multitone tone signal in which the components have at least two different amplitudes.

7. An electronic musical instrument as claimed in claim 1, in which said mixing networks comprise means for mixing said tone signals so that each of at least some of said multitone signals includes tone signals having the lowest and the highest pitch fundamental frequencies in a 2^n order and excludes at least one tone signal having the fundamental frequency between said lowest and said highest pitch fundamental frequencies.

8. An electronic musical instrument as claimed in claim 1, in which said mixing networks comprise means for mixing said tone signals so that the pitch of said one of said at least two tone signals has a fundamental frequency different by at least two octaves from the fundamental frequency of said another of said at least two tone signals.

9. An electronic musical instrument as claimed in claim 1, in which said keyswitch system includes multipole keyswitches corresponding to at least some of the keys in the keyboards for switching said multitone signals and said signals other than said multitone signals at the same time to supply them to said tone forming circuit.

10. An electronic musical instrument as claimed in claim 1, in which said mixing networks comprise means for mixing said tone signals so that at least some of said multitone signals comprise at least two different types of multitone signals which have different amplitudes and different fundamental frequencies of said tone signals, and said keyswitch system includes multipole keyswitches corresponding to at least some of the keys in the keyboards for switching said different types of multitone signals to said tone forming circuit at the same time.

11. An electronic musical instrument as claimed in claim 1, in which said mixing networks comprise means for mixing with each of at least some of said multitone signals other tone signals which are different from and consonant with said tone signals having fundamental frequencies in a 2^n order.

12. An electronic musical instrument as claimed in claim 11, in which said means for mixing said other tone signals include a filter for filtering out high frequency components of the said other tone signals.

13. An electronic musical instrument as claimed in claim 11, in which said means for mixing said other tone signals mix with said multitone signals other tone signals which are in a musical fifth relation with respect to any one of said multitone signals which have the fundamental frequencies in a 2^n order.

14. An electronic musical instrument as claimed in claim 11, in which said means for mixing said other tone signals mix with said multitone signals at least some other tone signals which are in a musical fifth relation with respect to any one of said multitone signals having the fundamental frequencies in a 2^n order, and mix additional other tone signals which are in a musical third relation with respect to any of said multitone signals having fundamental frequencies in a 2^n order relation.

15. An electronic musical instrument as claimed in claim 1, in which said mixing networks comprise means for mixing said tone signals and producing a difference tone therefrom and supplying said difference tone to at least some of said multitone signals as at least one tone signal thereof.

16. An electronic musical instrument as claimed in claim 15, in which said means for producing a difference tone signal from a mixture of tone signals comprises a filter for filtering out high frequency components of said mixture of tone signals.

17. An electronic musical instrument as claimed in claim 15, in which said means for producing a difference tone signal from a mixture of tone signals comprises a non-linear resistor and a filter for filtering out high frequency components of said difference tone signal.

18. An electronic musical instrument comprising in combination: a tone generator system for generating tone signals capable of producing acoustic tones; a keyswitch system for switching said tone signals and including keyswitches actuated by depressing keys of keyboards; a tone forming circuit coupled to the output of said keyswitch system and which provides tone responses for said acoustic tones; a sound system which includes an amplifier and sounding means and is coupled to the output of said tone forming circuit; and a tone signal mixing circuit which is coupled between said tone generator system and said keyswitch system and which includes a plurality of mixing networks for mixing at least some of said tone signals generated by said tone generator system so as to produce mixed tone signals at least some of which are multitone signals, each of said multitone signals being made up of a plurality of tone signals having their fundamental frequencies in a 2^n order, said each of said multitone signals having at least two acoustic frequency components which have fundamental frequencies two octaves apart and which have an amplitude larger by at least three db than the amplitude of another acoustic frequency component positioned between said two acoustic components, said another acoustic frequency component being higher by one octave than the lower frequency acoustic frequency component of said two acoustic frequency components.

19. An electronic musical instrument as claimed in claim 18, in which said mixing networks mix tone signals to produce at least some of said multitone signals each having three tone signals with their fundamental frequencies in a 2^n order and extending over a range of two octaves, and one of three tone signals having a frequency positioned at the octave midway between the octave positions of the other two and having an amplitude smaller by at least three db than the amplitudes of the other two.

20. An electronic musical instrument as claimed in claim 18, in which said mixing networks mix tone signals to produce at least some of said multitone signals each having two tone signals with their fundamental frequencies in a 2^n order and extending over a range of one octave, and to produce at least some of said multitone signals each having three acoustic frequency components with their frequencies in a 2^n order and extending over a range of two octaves, one of said three acoustic frequency components being positioned at the octave midway between the octave positions of the other two and having an amplitude smaller by at least three db than the amplitudes of the other two.

21. An electronic musical instrument as claimed in claim 18, in which said mixing networks mix tone signals to produce at least some of said multitone signals each having two tone signals with their fundamental frequencies

in a 2^n order and said two tone signals having the fundamental frequencies two octaves apart.

22. An electronic musical instrument comprising in combination: a tone generator system for generating tone signals capable of producing acoustic tones; a keyswitch system for switching said tone signals and including keyswitches actuated by depressing keys of keyboards; a tone forming circuit coupled to the output of said keyswitch system and which provides tone response for said acoustic tones; a sound system which includes an amplifier and a sounding means and is coupled to the output of said tone forming circuit; and a tone signal mixing circuit which is coupled between said tone generator system and said keyswitch system and which includes a plurality of mixing networks for mixing at least some of said tone signals generated by said tone generator system so as to produce mixed tone signals at least some of which are multitone signals, each of said multitone signals being made up of a plurality of tone signals having their fundamental frequencies in a 2^n order and extending over a range of at least three octaves, said tone forming circuit and said sound system comprising means for modifying the frequency characteristics of at least some of said multitone signals so as to produce acoustic multitones each including at least two acoustic tones, one of said two acoustic tones having an amplitude larger than that of an adjacent tone which is one component of said acoustic multitone and having a lower fundamental frequency than said adjacent tone, and another of said at least two acoustic tones having an amplitude larger than that of an adjacent acoustic tone which is one component of said acoustic multitone and having a fundamental frequency higher than that of said adjacent tone.

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