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ELECTRONIC MUSICAL APPARATUS IMPROVED IN A MUSICAL TONE GENERATING CIRCUIT
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FIG. 1

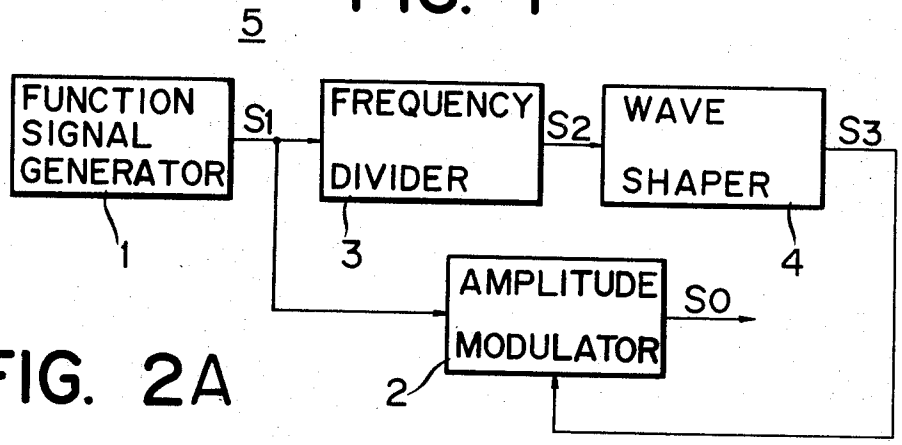


FIG. 2A

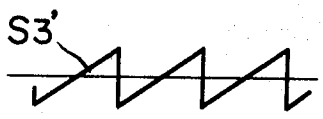


FIG. 2B

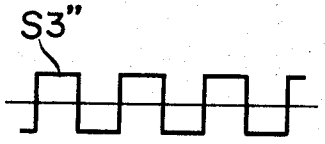


FIG. 2C

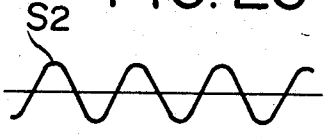


FIG. 3A

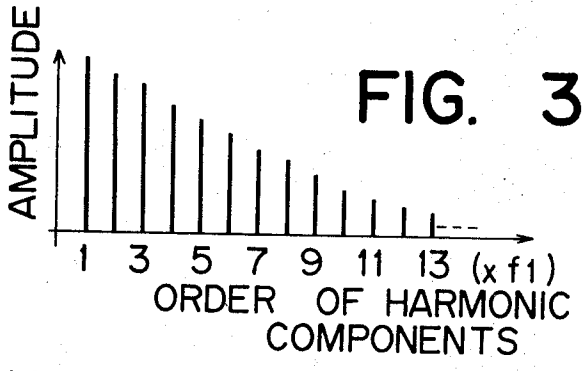


FIG. 3B

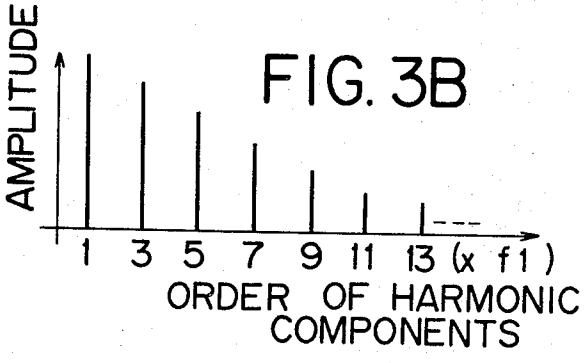
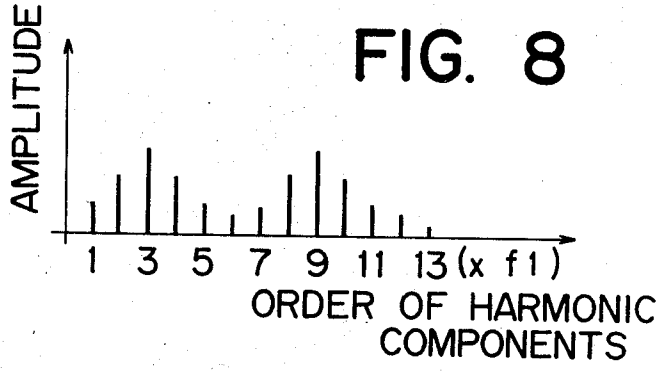


FIG. 8



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FIG. 6

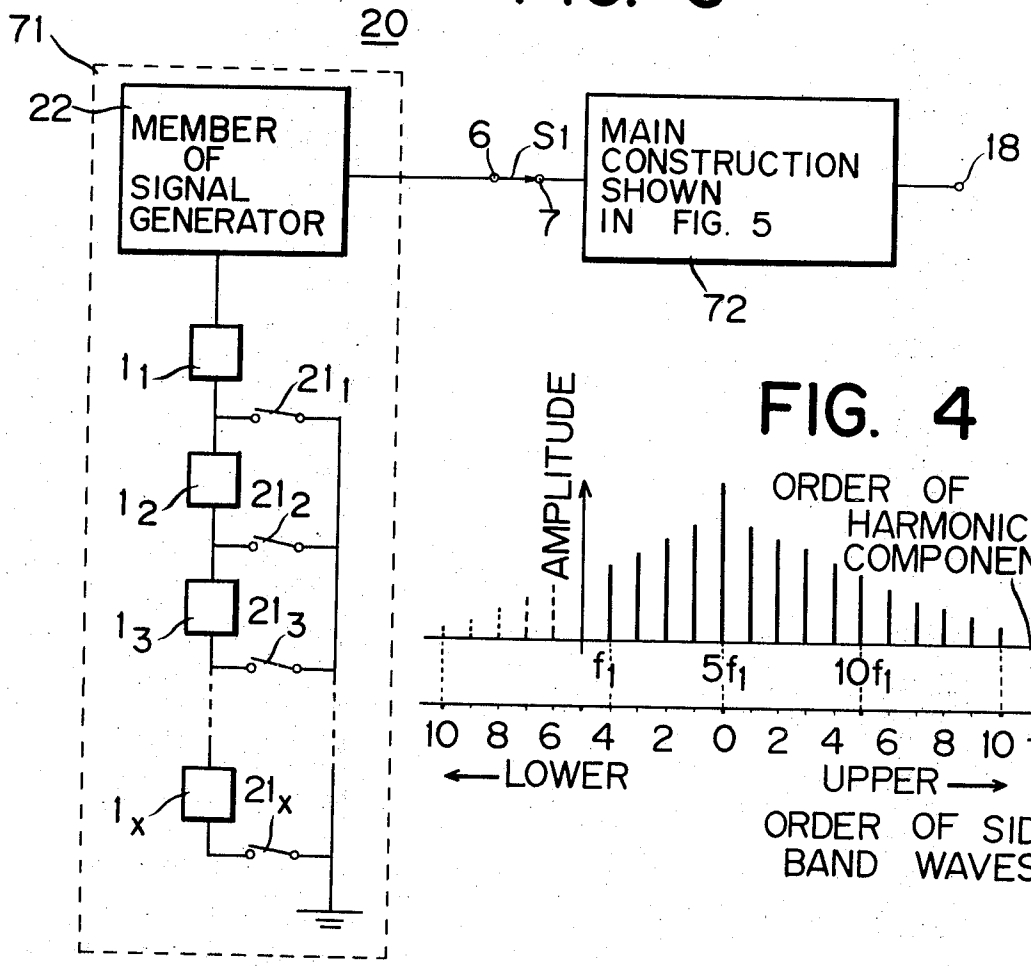


FIG. 4

FIG. 10

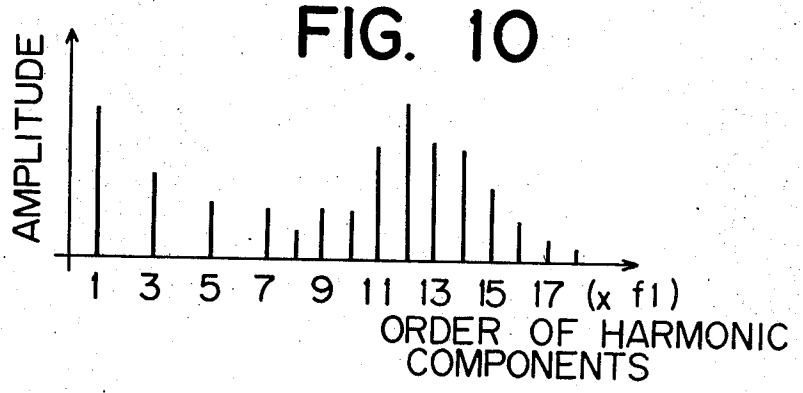


FIG. 5

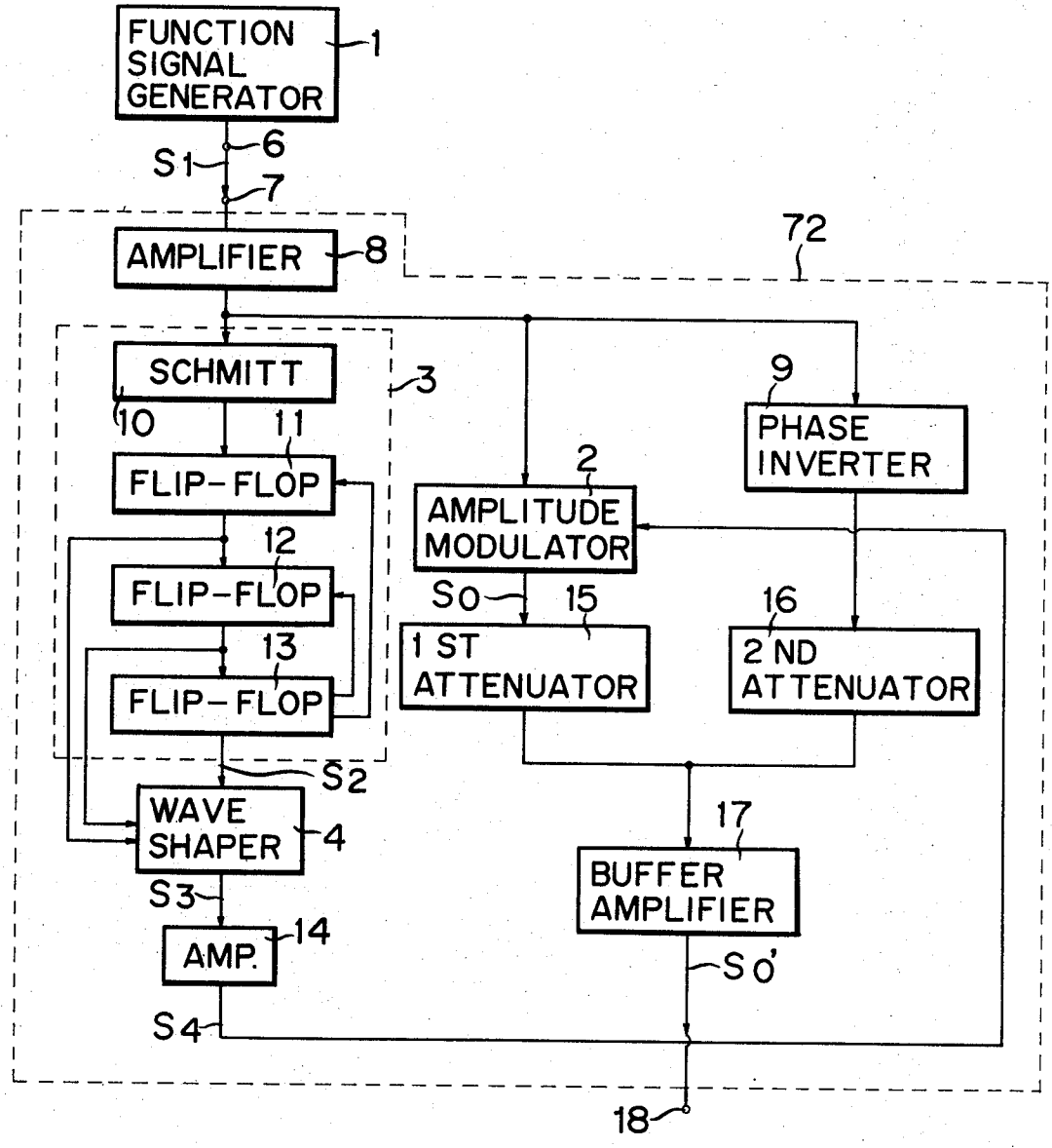
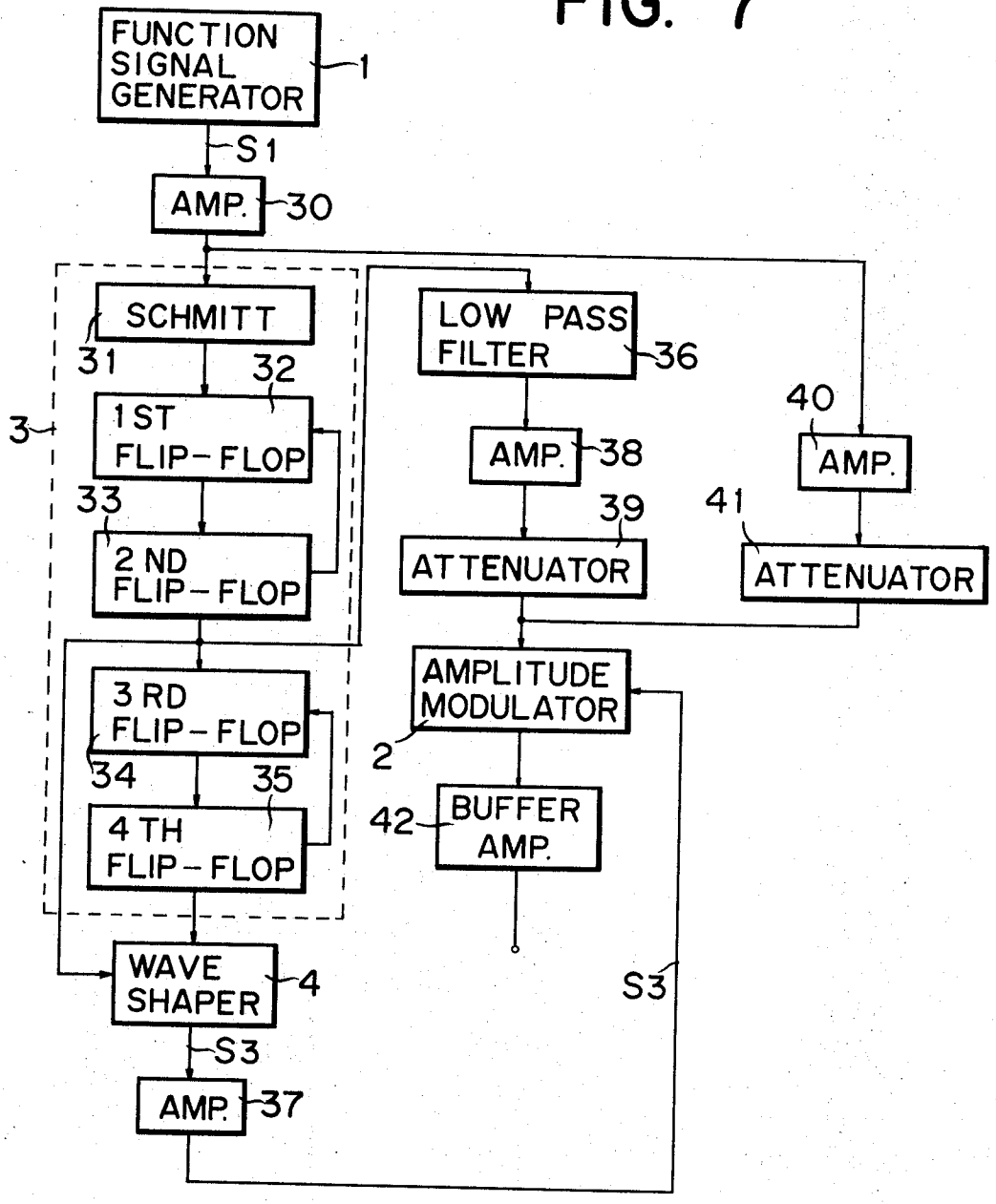

FUNCTION SIGNAL GENERATOR
1
S1
6
7
AMPLIFIER
8
72
SCHMITT
3
10
11
FLIP-FLOP
12
FLIP-FLOP
13
FLIP-FLOP
S2
WAVE SHAPER
4
S3
AMP.
14
S4
2
AMPLITUDE MODULATOR
S0
15
1 ST ATTENUATOR
9
PHASE INVERTER
16
2 ND ATTENUATOR
17
BUFFER AMPLIFIER
S0'
18

FIG. 7


FUNCTION SIGNAL GENERATOR
1
S1
AMP.
30
SCHMITT
31
32
3
1ST FLIP-FLOP
33
2 ND FLIP-FLOP
3 RD FLIP-FLOP
34
35
4 TH FLIP-FLOP
WAVE SHAPER
4
S3
AMP.
37
LOW PASS FILTER
36
AMP.
38
39
ATTENUATOR
40
AMP.
41
ATTENUATOR
AMPLITUDE MODULATOR
2
42
BUFFER AMP.
S3

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FIG. 9

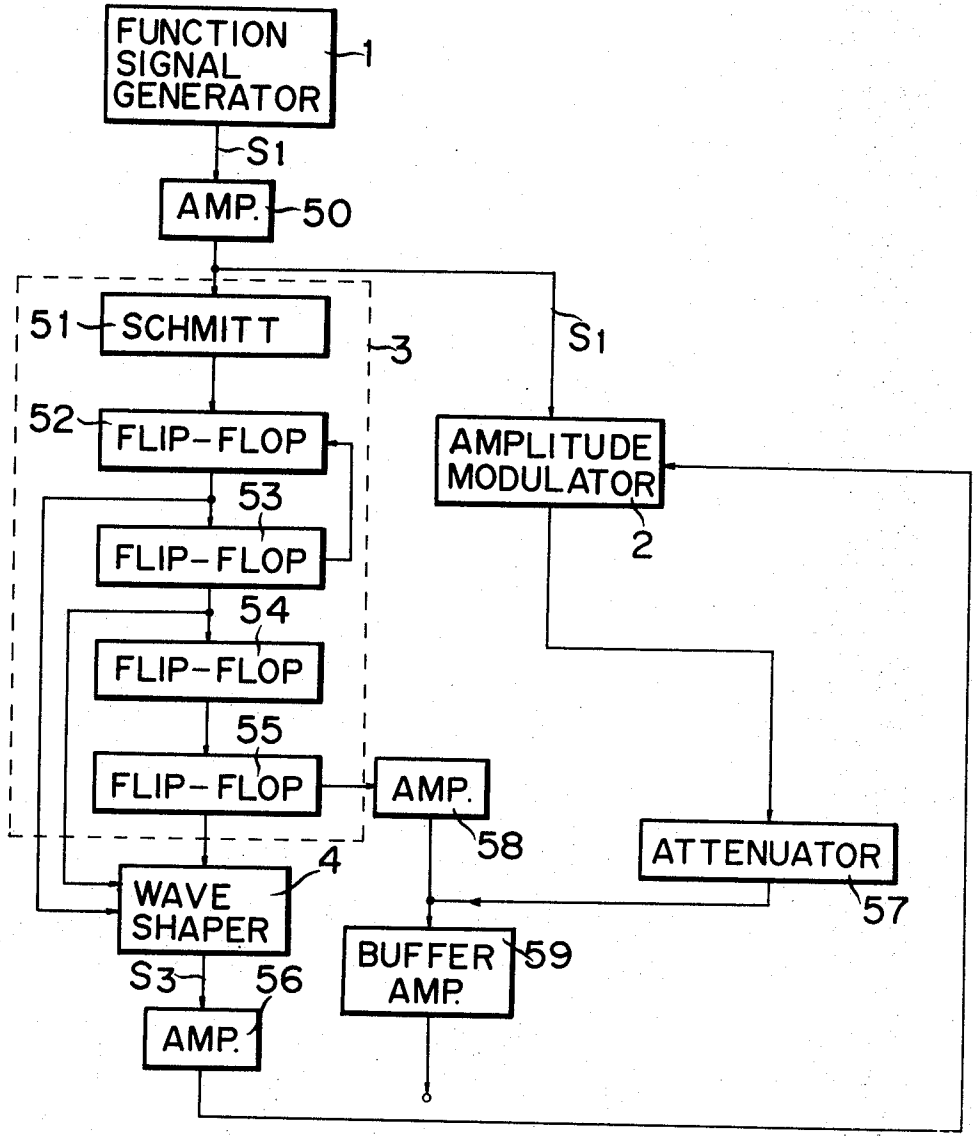
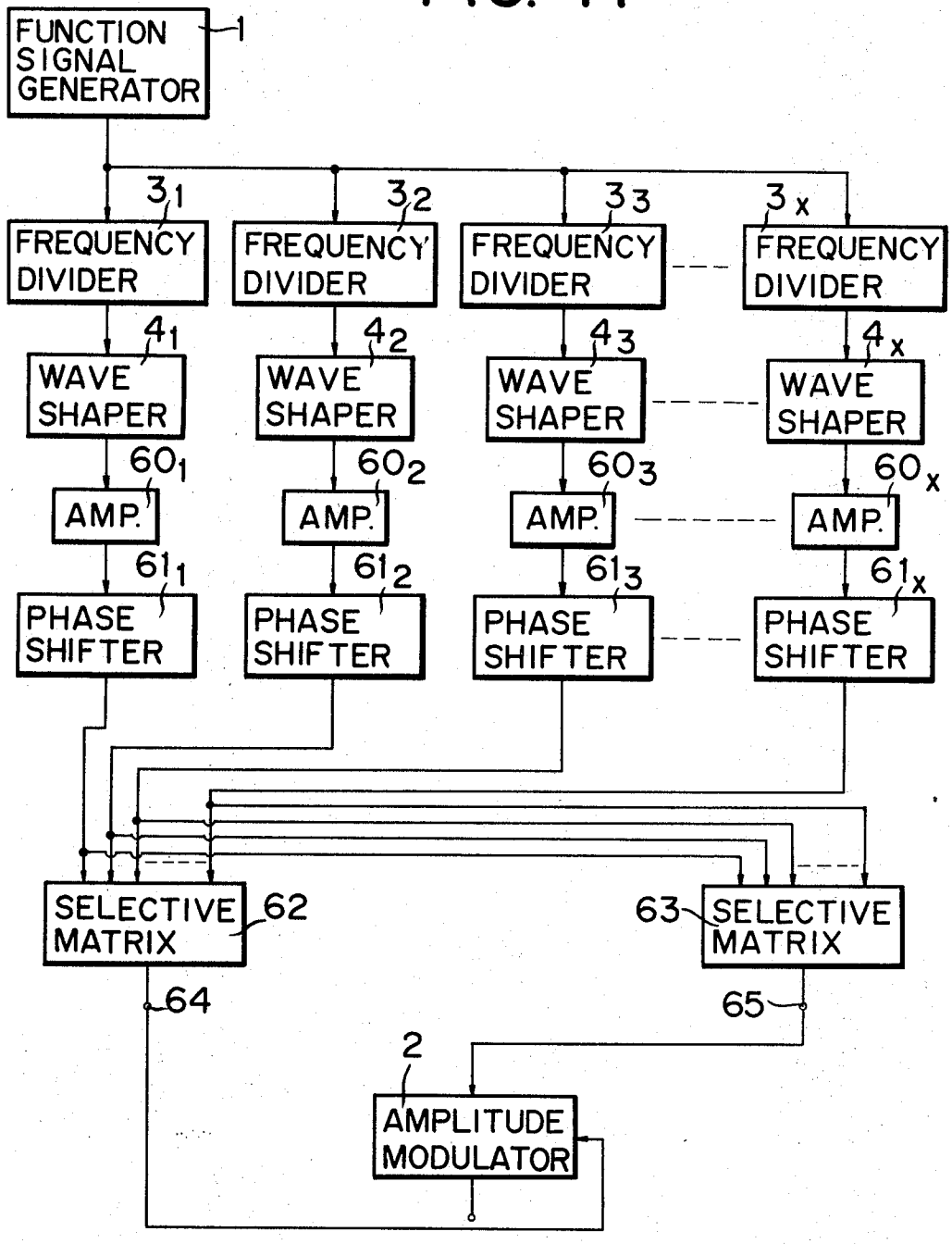


FIG. 11


FUNCTION SIGNAL GENERATOR
1
FREQUENCY DIVIDER
3_1
3_2
3_3
3_x
WAVE SHAPER
4_1
4_2
4_3
4_x
AMP.
60_1
60_2
60_3
60_x
PHASE SHIFTER
61_1
61_2
61_3
61_x
SELECTIVE MATRIX
62
63
64
65
AMPLITUDE MODULATOR
2

United States Patent Office

3,532,799

Patented Oct. 6, 1970

3,532,799

ELECTRONIC MUSICAL APPARATUS IMPROVED IN A MUSICAL TONE GENERATING CIRCUIT

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Filed Apr. 15, 1968, Ser. No. 721,381
Claims priority, application Japan, Apr. 17, 1967, 42/24,007
Int. Cl. G10h *3/00, 1/02, 1/06*
U.S. Cl. 84—1.12 10 Claims

ABSTRACT OF THE DISCLOSURE

An electronic musical apparatus improved in a musical tone generating circuit which comprises a means for generating periodic functional signals corresponding to the musical tones to be regenerated, a means for dividing the frequency of said signals so as to shape the waves of these signals into those of signals having a harmonic structure corresponding to that of said musical tones and a means for modulating the amplitude of the periodic functional signals thereby to obtain musical signals having a desired harmonic structure.

The present invention relates to an electronic musical instrument improved in a musical tone generating circuit and more particularly to an apparatus for electrically synthesizing musical signals thereby to regenerate desired musical tones.

Generally, the ones produced by various musical instruments consist of a harmonic structure containing specific harmonic components, so that these musical instruments respectively have characteristic timbers. To synthesize desired musical tones, therefore, the conventional electronic musical apparatus involved the steps of generating square wave signals, saw tooth wave signals or triangular wave signals and the like which abounded with harmonic components, and thereafter causing these special musical signals to pass through a filter circuit wherein a special property of allowing for the passage of certain frequencies was built up so as to match the musical harmonic structure peculiar to the tones of musical instruments. However, a filter circuit having such a special property of selectively passing certain frequencies was of a complicated construction. Moreover, to obtain musical tones of different harmonic structures, it was necessary to set up a large number of these complicated filter circuits.

Since the aforesaid frequency passing property previously provided for the filter circuit was fixed, there was the drawback that where the frequency of musical signals to be impressed on the filter circuit was changed in order to obtain different musical intervals for certain musical tones, then the harmonic structure of these tones was also subject to variation. Consequently, there were encountered considerable difficulties in obtaining timbers of the same family with the same harmonic structure maintained over a broad range of auditory frequency.

There was indeed already proposed an apparatus for synthesizing musical tones which was capable of obtaining the same harmonic structure independently of variations in the musical intervals. With such apparatus, however, the provision of only a filter circuit was not sufficient, so that signals of sinusoidal functional waves corresponding respectively to the harmonic components were mixed after their frequency and amplitude were adjusted so as to match desired harmonic structures. This apparatus enabled signals of such frequency as falling

within the auditory range of the keyboard tones to be directly used as harmonic components of musical tones included in the low auditory range of the keyboard tones. However, to obtain the harmonic components of musical tones in a high auditory range, it was further required to generate signals 2 to 3 octaves higher. Consequently the apparatus had the drawbacks that it was necessary not only to prepare a large number of signal-generating circuits, but also to provide each keyboard with a sufficient number of contact means to match the number of harmonic components, and that the entire arrangement was exceedingly complicated. Furthermore, the apparatus also raised problems with respect to the accuracy of producing musical tones and cost of manufacture.

Accordingly, the main object of the present invention is to provide an electronic musical apparatus whose musical tone generating circuit is so improved as to produce timbers of the same family for each musical interval without using a filter circuit.

Another object of the invention is to provide an electronic musical apparatus improved in a musical tone generating circuit which is capable of obtaining a fixed harmonic structure over a broad range of auditory frequency.

Another object of the invention is to provide an electronic musical apparatus improved in a musical tone generating circuit which enables a harmonic structure to be freely varied over a broad range.

Still another object of the invention is to provide an electronic musical apparatus which is of sufficiently simple construction to minimize the requirements of circuit elements.

Further objects and advantages will be apparent from the following description for which reference is made to the appended drawings in which:

FIG. 1 is a schematic diagram of the construction of an electronic musical apparatus improved in a musical tone generating circuit according to an embodiment of the present invention;

FIGS. 2A, 2B and 2C present the wave forms of signals by way of illustrating the functional operation of the apparatus of the invention;

FIGS. 3A and 3B indicate the harmonic spectra of signal wave forms similarly to illustrate the working of said apparatus;

FIG. 4 shows the harmonic structure of reed family musical tones synthesized by the apparatus of the invention;

FIG. 5 is another embodiment of the invention, schematically showing the construction of a means for synthesizing reed family musical tones;

FIG. 6 schematically shows the construction of an electronic organ according to another embodiment of the invention;

FIG. 7 indicates the composition of a musical tone generating circuit according to still another embodiment of the invention;

FIG. 8 is a diagramatic representation of the harmonic structure of musical signals synthesized by the means of FIG. 7;

FIG. 9 represents the composition of a musical tone generating circuit according to a further embodiment of the invention;

FIG. 10 shows the harmonic structure of musical signals synthesized by the means of FIG. 9; and

FIG. 11 indicates the composition of a musical tone generating circuit according to a still further embodiment of the invention.

There will now be described by reference to these figures the principle on which the apparatus of the present invention is based and the various aspects in which the

apparatus is applied. The apparatus of the present invention characteristically comprises the steps of generating periodic functional signals with a prescribed frequency so as to synthesize musical signals having a desired harmonic structure for a given musical interval, dividing the frequency of the periodic functional signals so as to conform it to the fundamental frequency corresponding to the musical interval, shaping the waves of the signals, whose frequency is thus divided, into those containing harmonic components corresponding to the harmonic structure and modulating the amplitude of the periodic functional signals with the signals whose waves are thus shaped, thereby to produce the aforementioned musical signals.

There will now be described by reference to FIG. 1 the basic construction of an apparatus of the present invention. The reference numeral **1** is a generator of periodic functional signals comprising a circuit for generating periodic functional signals, for example, signals of a sinusoidal functional wave having a certain frequency corresponding to musical tones to be regenerated. Periodic functional signals such as square wave signals, saw tooth wave signals, etc. may be properly selected in accordance with the harmonic structure of musical tones to be regenerated. The output signals from the generator **1** are divided in two groups. One group is supplied to an amplitude modulator **2** so as to be modulated, while the other is transmitted to a frequency divider **3**. The ratio $1/n$ in which the frequency is divided by the frequency divider **3** is so set as to obtain a signal S_2 of such divided frequency as will have an equivalent frequency to the fundamental frequency f_1 of a musical signal S_0 to be regenerated. While the signals S_1 and S_2 are not theoretically required to be in the ratio expressed in integers, the division of frequency is preferably carried out in a manner to obtain such ratio in consideration of the nature of the frequency divider. The output signal S_2 of divided frequency from the frequency divider **3** is transmitted to the following wave shaper **4**, where the wave form of said signal S_2 is shaped into that of a signal S_3 which has the fundamental frequency f_1 and contains harmonic components corresponding to the harmonic structure of the musical signal S_0. The signal S_3 whose wave form has thus been shaped by the wave shaper **4** is then transferred to the amplitude modulator **2** so as to modulate the amplitude of the aforementioned period functional signal S_1, so that there is obtained the desired musical signal S_0 as an output from the amplitude modulator **2**.

There will be further detailed the operation of the musical tone generating circuit of the present invention constructed in the aforementioned manner. To ease explanation, the periodic functional signal S_1 is taken to be a signal of a sinusoidal functional wave solely consisting of a monofrequency component, which may be expressed by the undermentioned formula. Namely, the signal generator **1** is assumed to generate a signal of the following formula.

$$S_1=Ac\cos(n\omega t+\theta) \tag{1}$$

were:

Ac=amplitude

n=integers (reciprocals of the aforementioned ratio of divided frequencies)

ω=angular frequency (equivalent to $2\pi f_1$)

θ=phase angle.

The signal S_1 of a sinusoidal functional wave is introduced into the amplitude modulator **2** and frequency divider **3**. Since the ratio in which the frequency is divided by the frequency divider **3** is set at $1/n$ as described above, the sign S_2 of divided frequency obtained as an output will form a sinusoidal functional wave having a frequency f_1. The wave form of the signal S_2 having the divided frequency is shaped by the wave shaper **4**, and is formed into a signal S_3 having special type waves, for example, saw tooth waves, square waves, or triangular waves with the pulse-repetition frequency f_1. The signal S_3 produces harmonic components of frequency f_1 in accordance with the aforementioned special wave forms. Where the signal S_2 of a sinusoidal functional wave is changed by wave shaping, for example, into a signal S_3' of a saw tooth wave or a signal S_3'' of a square wave as shown in FIG. 2, the harmonic spectra of these signals S_3' and S_3'' will be as illustrated in FIGS. 3A and 3B respectively. It is well known that signals of a saw tooth wave, square wave or other special wave forms have their own peculiar harmonic spectra. Thus, if the wave shaper **4** comprises a saw tooth wave generating circuit, the spectrum of the signal S_3 will be as shown in FIG. 3A. Namely, the signal S_3 will progressively acquire larger harmonic components as $2f_1$, $3f_1$ . . . Nf_1 in relation to the fundamental frequency f_1 without missing any of these components on the way. As the order of harmonic components contained increases, the amplitude of those is reduced. Also where the sinusoidal functional wave of the signal S_2 is shaped into a square one, the spectrum of the signal S_3'' will obtain harmonic components of only odd orders as $3f_1$, $5f_1$ . . . in relation to the fundamental frequency f_1, as shown in FIG. 3B. Signals of other special wave forms will also have their own peculiar spectra. In any case, the signal S_3 contains various orders of harmonic components in relation to the fundamental frequency f_1 of the aforesaid signal S_2 of divided frequency. Thus the signal S_3 may generally be expressed by the following formula:

$$S_3=\sum_{m=1}^{N} Am\cos(m\omega t+\phi m) \tag{2}$$

where:

m=order of harmonic components contained

N=upper limit of orders.

While N theoretically represents the value up to an infinite (∞) order, there will be no difficulties for practical purposes if N is considered to denote orders of less than 100.

Am=amplitude of the signal containing mth harmonic components.

ϕm=phase angle of the signal containing mth harmonic components.

The amplitude modulator **2** is formed from a very common type of amplitude modulating circuit. When the aforesaid signal S_3 modulates the amplitude of the signal S_1 which should be modulated then there will be obtained a musical signal S_0 as represented by the following formua:

$$\begin{aligned} S_0&=Ac\left\{1+\sum_{m=1}^{N} Km\cdot\cos(m\omega t+\phi m)\right\}\cdot\cos(n\omega t+\theta)\\ &=Ac\cos(n\omega t=\theta)+Ac\sum_{m=1}^{N}\frac{Km}{2}\cos\{(n+m)\omega t+\theta+\phi m\}\\ &\quad+Ac\sum_{m=1}^{N}\frac{Km}{2}\cos\{(n-m)\omega t+\theta-\phi m\} \end{aligned} \tag{3}$$

where:

Km=degree of amplitude modulation. There is a relation

$$Km=k\frac{Am}{Ac}$$

(where k represents a ratio constant).

Because of $\omega=2\pi f_1$, the harmonic spectrum of a musical signal S_0 forms side bands around nf_1, as seen from Formula 3, in accordance with the harmonic spectrum of the signal S_3, thus enabling desired harmonic structures to be obtained in accordance with the harmonic structure of the signal S_3 with the frequency f_1 as the fundamental one.

For better understanding, there will be described more concretely the case where reed family musical sounds, for example, those of an oboe are practically synthesized. The harmonic structure of reed family musical tones gen-

erally has a single peak at a specific order of a harmonic component. Therefore, the harmonic structure of the desired musical signal S_0 is deemed to be as shown in FIG. 4. Namely, said harmonic structure has a single peak at the nth order (nf_1), for example, fifth order $5f_1$ in relation to the fundamental frequency f_1. In this case, it is assumed that the periodic functional signal generator **1** generates a signal S_1 of a sinusoidal functional wave having a frequency $5f_1$, that the ratio in which the frequency is divided by the frequency divider **3** is set at 1/5 and that the wave shaper **4** consists of a saw tooth wave synthesizer for shaping a sinusoidal functional wave into a saw tooth wave. Then the signal S_1 having a frequency $5f_1$ is reduced to a signal S_2 having a frequency f_1 due to frequency division by the frequency divider **3** wherein the ratio of frequency division is set at 1/5 as mentioned above. The signal S_2 of divided frequency is shaped by the wave shaper **4** into a saw tooth wave signal S_3 having a pulse-repetition frequency f_1. The signal S_1 is modulated in amplitude by said signal S_3 in the amplitude modulator **2** to produce the desired musical signal S_0. The peak of the harmonic spectrum of the musical signal S_0 corresponds to the frequency $5f_1$ of the amplitude modulated signal, and the attenuating property of upper and lower side bands agrees with that observed in the spectrum of the saw tooth wave signal S_3. Namely, said upper and lower side bands displays a corresponding pattern to the harmonic component of the modulating signal S_3. While the upper side bands theoretically involve an infinite degree of a harmonic component, the harmonic component which exceeds one hundredth order may be neglected for practical purposes. On the other hand, the lower side band in the fourth order contains a frequency up to f_1. As shown in FIG. 4, the lower side bands in the 6th to 9th order from the frequency $5f_1$ of the signal S_1 are vectorially superposed on the lower side bands in the 4th to 1st order. Also the lower side band in the 10th order is superposed on the signal S_1 and the lower side bands in the 11th and subsequent orders are superposed by turns on the upper side bands in the 1st and subsequent orders so as to be vectorially added. This will be more apparent by reference to Formula 3. It may be generalized that in the case of $m>n$, some of the side bands are vectorially added by superposition. Namely, the lower side bands in the order of m_1 from the carrier wave (provided $n<m<2n$) agree in frequency with the lower side bands in the order of $(2n-m_1)$ to be vectorially superposed thereon. And the lower side bands in the order following $2n$, namely those in the order $2n+m_2$ (provided $m_2 \geqq 1$) are superposed on the upper side bands in the order of m_2. Strictly speaking, therefore, the spectrum of FIG. 4 is not perfectly symmetrical relative to the frequency $5f_1$. For practical purposes, however, the spectrum may be deemed symmetrical.

As seen from the spectrum of FIG. 4, the aforementioned arrangement produces the harmonic structure of reed family musical tones having a single peak at the fifth order $5f_1$ of a harmonic component with the frequency f_1 as the fundamental one, so that the output from the amplitude modulator **2** forms a musical signal S_0 adapted for reed family musical instruments.

As mentioned above, the present invention enables musical tones of a desired harmonic structure to be synthesized in accordance with the harmonic spectrum of the signal S_3 even without particularly providing a filter circuit. Also if the frequency of the periodic functional signal issued by the generator **1** thereof is varied, then it will be possible to synthesize musical signals having a similar harmonic structure to that of FIG. 4 with a $1/n$ fraction of the aforesaid frequency taken as the fundamental frequency. For instance, if $5 \times f_1 = 5 \times 440$ Hz., then the fundamental frequency will be 440 Hz., and there will be obtained a harmonic structure having a single peak at the fifth order 5×440 Hz. of a harmonic component. Where $5 \times f_1$ changes to 5×880 Hz., then the fundamental frequency will be 880 Hz. and there will appear a harmonic structure having a single peak at the fifth order 5×880 Hz. of a harmonic component. Therefore, the harmonic structure itself remains fixed even though musical intervals may vary, thus enabling timbers of the same family to be obtained over a broad range of auditory frequency. Moreover, the order of harmonic components containing a single peak may be varied to any desired extent by changing the ratio of frequency division carried out by the frequency divider **3**.

FIG. 5 is a diagram of a more practical type of apparatus for synthesizing reed family musical tones. It involves new members added to the apparatus shown in FIG. 1. The same parts or functions of FIG. 5 as those shown in FIG. 1 are denoted by the same numerals and description thereof is omitted.

The periodic functional signal S_1 generated at the output terminal **6** of the generator **1** thereof is introduced through an input terminal **7** into an amplifier **8** so as to be amplified. The periodic functional signal S_1 thus amplified is transferred to an amplitude modulator **2**, frequency divider **3** and phase inverter **9** respectively. The frequency divider **3** is so arranged as to divide the frequency in the ratio of 1/5. Namely, the signal S_2 of a periodic functional wave is subjected to wave shaping by a Schmitt trigger circuit **10**. Then the signal S_1 is changed by frequency division into another signal containing a fundamental frequency f_1, namely, one-fifth of the frequency $5f_1$ originally possessed by the signal S_1, in flip-flop circuits **11**, **12** and **13** connected in series. The signals issued from the flip-flop circuits **11**, **12** and **13** are mixed so as to be synthesized into a symmetrical wave wherein the pulse widths are in the ratio of 1:4 (duty factor 4/5), and thereafter introduced into the wave shaper **4**. The wave shaper **4** is formed from a directional integration circuit and produces a saw tooth wave signal S_3 of a pulse-repetition frequency f_1. The signal S_3 is amplified into a saw tooth wave signal S_4 of constant amplitude by an amplifier **14** regardless of inputs applied. The signal S_4 is transmitted to the amplitude modulator to modulate the aforesaid signal S_1. Up to this point, the apparatus of FIG. 5 performs substantially the same operation as that of FIG. 1 excepting that amplification is involved in the interim step. Thus the amplitude modulator **2** produces a musical signal S_0 having such a harmonic structure as shown in FIG. 4. In the apparatus of FIG. 5, said signal S_0 is adjusted in amplitude by an attenuator **15**. On the other hand, the signal S_1 of a sinusoidal functional wave is inverted 180° in phase by a phase inverter **9**, and adjusted in amplitude by another attenuator **16**. The output signals from both attenuators **15** and **16** are synthesized and amplified by a buffer amplifier **17** to form the desired musical signal S_0'. The harmonic structure of the musical signal S_0' obtained at the output terminal **18** is almost the same as that of FIG. 4. In the apparatus of FIG. 5, however, the signal S_1 of a sinusoidal functional wave is added after phase inversion to the output signal from the amplitude modulator **2**, so that the value of the peak only consisting of the nth harmonics of the fundamental frequency f_1, for example, the fifth order $5f_1$ of a harmonic component can be adjusted. Thus the relative differences between the peak value having a harmonic component $5f_1$ and another peak value containing other orders of harmonic components are varied and as a result the harmonic structure of the aforementioned musical signal S_0' is changed to that extent. Therefore, there are synthesized reed family musical signals having a harmonic structure bearing greater similarity to the tones of the original musical instrument.

The apparatus of FIG. 5 can be used in constructing an electronic organ. There will now be described the electronic organ apparatus **20** by reference to FIG. 6. The same parts of FIG. 6 as those of FIG. 5 are denoted by the same numerals and description thereof is omitted. In the organ apparatus **20**, the main construction **72** includ-

ing the input terminal 7 and following members is quite the same as that of FIG. 5 and is briefly indicated in a block. Reference numeral 71 represents a periodic functional signal generator, which generates signals of a periodic functional wave having a frequency 5 times the frequencies of musical intervals A, A♯, B, C . . . A, for example, those of 440 Hz., 466 Hz., 493 Hz. . . . 880 Hz.

The signal generating circuit 71 is formed from a signal generating member 22, elements 1_1, 1_2 . . . 1_x for defining an oscillation constant comprising a coil, condenser, resistor, etc. and serially connected to said generating member 22, and switches 21_1, 21_2, 21_3 . . . 21_x, one end of which is respectively connected to one end of each of the aforementioned oscillation constant defining elements and the other end of which is grounded. These switches 21_1, 21_2 . . . 21_x are operated in an interlocking relation with the respective keyboards through an interlocking mechanism (not shown). If a keyboard having a musical interval B is pressed, a switch contact 21_3 is closed and there is supplied to the input terminal 7 a signal of a periodic functional wave having a frequency 5×493 Hz. as defined by the elements 1_1, 1_2 and 1_3 which are arranged to generate signals with a previously set constant. Then there is obtained from an output terminal 18 a musical signal of a B interval having a fundamental frequency 493 Hz. and a similar harmonic structure to that of FIG. 4. Also where another keyboard is pressed, there is obtained a musical signal having the same pattern of harmonic structure, though its fundamental frequency alone is varied in accordance with the required musical interval. The aforementioned electronic organ apparatus 20 has a very simple construction, because its major parts can be used in common over a broad range of musical intervals, only requiring the generation constant to be so set as to match each musical interval involved.

There will now be described by reference to FIGS. 7 and 8 a circuit for generating a string family musical signal having a multiple format type of harmonic structure, of concretely, for example, the case in which there is synthesized a musical tone having a harmonic structure wherein a peak is present at both the third order $3f_1$ of a harmonic component and the ninth order $9f_1$ in relation to the fundamental frequency f_1. Referring to FIG. 7, the periodic functional signal generator 1 generates a signal S_1 of a periodic functional wave having a frequency $9f_1$. After being amplified by an amplifier 30, the signal S_1 is conducted to a frequency divider 3. As illustrated, the frequency divider 3 comprises flip-flop circuits 32, 33, 34 and 35 serially connected to a Schmitt trigger circuit 31. The signal S_1 of a periodic functional wave is adjusted in the wave form by the Schmitt trigger circuit 31 and carried to the first to fourth flip-flop circuits 32, 33, 34 and 35. By feeding the output from the second flip-flop circuit 33 back to the first flip-flop circuit 32, the frequency of the signal S_1 is reduced to one-third of the original frequency, thus obtaining another signal having a frequency, $3f_1$. The signal thus obtained is transferred to a low-pass filter 36 as later described, and to the succeeding flip-flop circuits 34 and 35. The output of the fourth flip-flop circuit 35 is carried back to the third flip-flop circuit 34 to cause the aforesaid divided frequency to be further reduced to one-third. The output signal from the second flip-flop circuit 33 and that from the fourth flip-flop circuit 35 are mixed and supplied to a wave shaper 4 consisting of a directional integration circuit. The wave shaper generates a saw tooth wave signal S_3 of a pulse-repetition frequency f_1. The signal S_3 is transferred to an amplifier 37 to cause it to have a fixed amplitude.

On the other hand, the low-pass filter 36 has a property of passing only a signal of a low frequency range which does not exceed a certain upper limit. Thus the output signal from the second flip-flop circuit 33 whose frequency has already been reduced to one-third is introduced into a filter 36 to be shaped into a type containing large amounts of the third harmonics of the fundamental frequency f_1, namely, a harmonic component $3f_1$, and thereafter amplified to a fixed amplitude by another amplifier 38. The amplified signal is conducted to an attenuator 39. Also, that portion of the signal S_1 of a periodic functional wave which was separated from the output of the amplifier 30 is also amplified by another amplifier 40 and transmitted to another attenuator 41. Output signals from the attenuators 39 and 41 having frequencies $9f_1$ and $3f_1$ respectively are mixed and carried to the amplitude modulator 2, where these mixed signals are modulated in amplitude by the saw tooth wave signal issued from the amplifier 37. Then the amplitude modulator 2 generates a musical signal having a desired harmonic structure which contains a peak at both the third order $3f_1$ of a harmonic component and the ninth order $9f_1$. This signal is formed into the desired output signal after being amplified by a buffer amplifier 42. If the value of the fundamental frequency f_1 is varied by changing the frequency $9f_1$ of the signal S_1 then there will be realized musical tones having multiple formats of the desired musical interval.

There will now be described by reference to FIGS. 9 and 10 the apparatus of the present invention for synthesizing musical tones of a harmonic structure which contains only odd harmonic components insofar as the low orders of said harmonic components are concerned, such, for example, as the musical tones of a clarinet. Referring to FIG. 9, the periodic functional signal generator 1 generates a signal S_1 of a sinusoidal functional wave having a frequency of, for example, $12f_1$ in relation to the fundamental frequency f_1. The signal S_1 is carried through an amplifier 50 to the succeeding frequency divider 3, where the signal S_1 of a frequency $12f_1$ is adjusted in the wave form by a Schmitt trigger circuit 51 and then transferred to flip-flop circuits 52, 53, 54 and 55 connected in series. Part of the output signal from the second flip-flop circuit 53 is sent back to the first flip-flop circuit 52 and so the frequency $12f_1$ is reduced to one-third by the first and second flip-flop circuits 52 and 53, thus obtaining a signal S_4 of a frequency $4f_1$. The signal S_4 of divided frequency is further reduced to one-fourth during transit through the third and fourth flip-flop circuits 54 and 55 to obtain another signal of a pulse-repetition frequency f_1. This signal and the output signal from the first and second flip-flop circuits 52 and 53 are mixed and supplied to a wave shaper 4 consisting of a directional integration circuit (not shown). From the wave shaper 4 is obtained due to directional integration a saw tooth wave signal S_3 of a pulse-repetition frequency f_1. The signal S_3 is amplified by an amplifier 56 to a fixed amplitude, and then transferred to an amplitude modulator 2 as a modulating signal. Since the amplitude modulator 2 is already supplied from an amplifier 50 with the signal S_1 of a sinusoidal functional wave having a frequency $12f_1$ so as to be modulated thereby, the amplitude modulator 2 generates a signal of a harmonic structure which contains a peak at the 12th order of a harmonic component in relation to the fundamental frequency f_1. The signal thus generated is conducted to an attenuator 57. On the other hand, another output signal issued from the aforesaid fourth flip-flop circuit 55 is a square wave signal of a pulse-repetition frequency f_1. The square signal is amplified by an amplifier 58. The square wave signal has a harmonic spectrum wherein a harmonic component only appears at the odd number of order as shown in FIG. 3B. Therefore when the square wave signal is mixed with the output signal from the attenuator 57 there will be obtained a musical signal of such a harmonic structure as shown in FIG. 10. The musical signal is amplified to a desired extent by an amplifier 59.

The apparatus of the present invention can synthesize not only musical signals of a very special harmonic structure as has been described up to this point, but also a

large variety of other musical signals at will. These other musical signals can be generated by an apparatus shown in FIG. 11. As illustrated, the apparatus is operated in the following manner. The periodic functional signal generator **1** generates a signal of a fixed frequency f. Said periodic functional signal is introduced into frequency dividers 3_1, 3_2 . . . 3_x wherein the ratio in which the frequency is divided is set at $1/n_1$, $1/n_2$ . . . $1/n_x$ respectively in terms of integers (where n_1 . . . n_x represent different integers with $n_1<n_2$). Output signals from frequency dividers 3_1, 3_2 . . . 3_x are supplied to wave shapers 4_1, 4_2 . . . 4_x. These wave shapers are not formed from the same type of circuit, but from a plurality of those types which can shape the aforesaid signal of divided frequency into one having a special wave form such as at least a saw tooth wave, square wave or triangular wave. Output signals from the wave shapers 4_1, 4_2 . . . 4_x are conducted to a plurality of circuits involving serially connected amplifiers 60_1, 60_2 . . . 60_x and phase shifters 61_1, 61_2 . . . 61_x respectively. These phase shifters enable the phase of output signals from the wave shapers 4_1, 4_2 . . . 4_x to be varied freely. The output signals from the phase shifters 61_1, 61_2 . . . 61_x are respectively supplied in parallel to the input terminal of the first and second selection matrices **62** and **63**. These selection matrices **62** and **63** are interlocked with a keyboard switch (not shown) and select only desirable signals from among those which are carried to the input terminals thereof, and conduct the selected signals to the output terminals **64** and **65** thereof. The signal issued from the output terminal **65** is transmitted to the amplitude modulator **2** and the signal taken out of the output terminal **64** is also transferred thereto as a signal modulating the amplitude of the signal from the aforesaid terminal **65**. From the amplitude modulator **2** is obtained a musical tone having a desired complicated harmonic structure. The signals entering the input terminals of the selection matrices **62** and **63** have their own specific harmonic spectra. Therefore, control of the keyboard switch enables a signal having a desired harmonic spectrum to be obtained from the output terminals **64** and **65** of the selection matrices **62** and **63**. Namely, amplitude modulation produces that type of harmonic structure in which side bands are formed around the respective harmonic components contained in the first signals in accordance with the harmonic spectra of the second signals modulating the amplitude of the first signals, thus synthesizing musical tones having various complicated harmonic structures.

As mentioned above, the present invention enables desired musical signals to be synthesized over a broad range of musical intervals using a simple construction. While the foregoing description relates to the synthesis of harmonic structures of tones of several musical instruments, it is needless to say that the tones of other musical instruments can be easily synthesized using the concept of the present invention. It will be understood that the aforementioned embodiments of the invention are offered only by way of illustration and that the apparatus according to the invention may be practised in various modifications. It will also be noted that these modification constitute part of the present invention, provided that they do not change the spirit and object of the invention, but fall within the scope of the patent claims.

What is claimed is:

1. An electronic musical apparatus comprising:

means for generating a periodic functional signal having at least one frequency nf equivalent to an integral multiple n of the fundamental frequency f of a desired musical signal to be regenerated;

means coupled to said generating means for producing a frequency divided signal having a frequency corresponding to the frequency of said periodic functional signal divided by a predetermined value;

wave shaping means coupled to said dividing means for changing the frequency divided signal into a wave shaped signal containing harmonic components corresponding to the harmonic structure of the musical signal to be regenerated; and

means for amplitude modulating a signal including the output signal from said generating means with said wave shaped signal to thereby produce said musical signal.

2. An electronic musical apparatus according to claim **1** wherein said predetermined value is an integer n equal to said integral multiple n.

3. An electronic musical apparatus according to claim **1** wherein said periodic functional signal is sinusoidal wave signal.

4. An electronic musical apparatus according to claim **3** wherein the said wave shaping means comprises means for shaping said frequency divided signal into a square wave.

5. An electronic musical apparatus according to claim **3** wherein said wave shaping means comprises means for shaping said frequency divided signal into a saw tooth wave.

6. An electronic musical apparatus according to claim **1** further comprising means for adding said periodic functional signal to the output signal from said amplitude modulating means.

7. An electronic musical apparatus according to claim **1** wherein said generating means includes means for generating a plurality of periodic functional signals, each having a different frequency, and means for selecting the periodic signal having a frequency corresponding to the desired musical signal to be regenerated.

8. An electronic musical apparatus according to claim **1** wherein said dividing means produces an intermediate signal having a frequency which corresponds to the frequency of said periodic functional signal divided by a second predetermined value.

9. An electronic musical apparatus according to claim **8** comprising means combining said periodic functional signal and said intermediate signal to produce a combined signal, and wherein said amplitude modulating means modulates said combined signal with said wave shaped signal.

10. An electronic musical apparatus according to claim **1** wherein said dividing means includes means for generating from said periodic functional signal a square wave signal having a pulse-repetition frequency equivalent to an integral multiple of the fundamental frequency of musical signal to be regenerated; and further comprising means mixing said square wave signal with the output signal from said amplitude modulating means.

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U.S. Cl. X.R.

84—1.21, 1.23