United States Patent

[11] 3,628,054

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Hamanatsu-shi, Shizuoka-ken, Japan
[32] Priorities Feb. 13, 1969
[33] Japan
[31] 44/10866;
Feb. 13, 1969, Japan, No. 44/10867; Feb. 13, 1969, Japan, No. 44/10868

[54] **FREQUENCY-DIVIDING CIRCUIT FOR SIGNALS OF SAWTOOTH WAVEFORM**
10 Claims, 22 Drawing Figs.

[52] U.S. Cl. **307/225,** 307/228, 307/271, 328/36, 328/39, 328/157, 328/181, 328/184, 330/147
[51] Int. Cl. **H03k 21/00**
[50] Field of Search 307/220, 225, 228, 271; 328/30, 36, 39, 157, 158, 181, 184, 185; 330/147

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Primary Examiner—Stanley T. Krawczewicz
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ABSTRACT: A frequency-dividing circuit for signals of sawtooth waveform, comprising: a buffer transistor to the base of which an input sawtooth wave and an output square wave of a square-wave frequency divider are applied in their states of equal peak amplitude through mixing resistors having equal value, and a mixing circuit for obtaining an output of a frequency-divided sawtooth wave from the emitter of said buffer transistor, a compensating DC voltage being superposed at any point of the circuit so that the lower ends of the mixed signal appearing at said base are offset from said emitter potential by a voltage value which is greater than the forward voltage drop between the base and the emitter of the transistor thereby to cause said buffer transistor to perform a perfect class "A" amplifying operation. Furthermore, modifications of the circuits mentioned above are described.

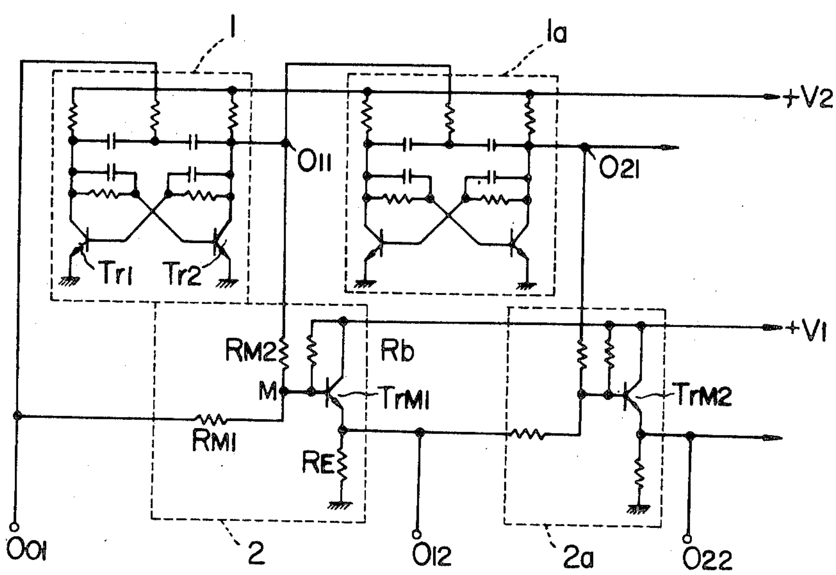

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FIG. 1

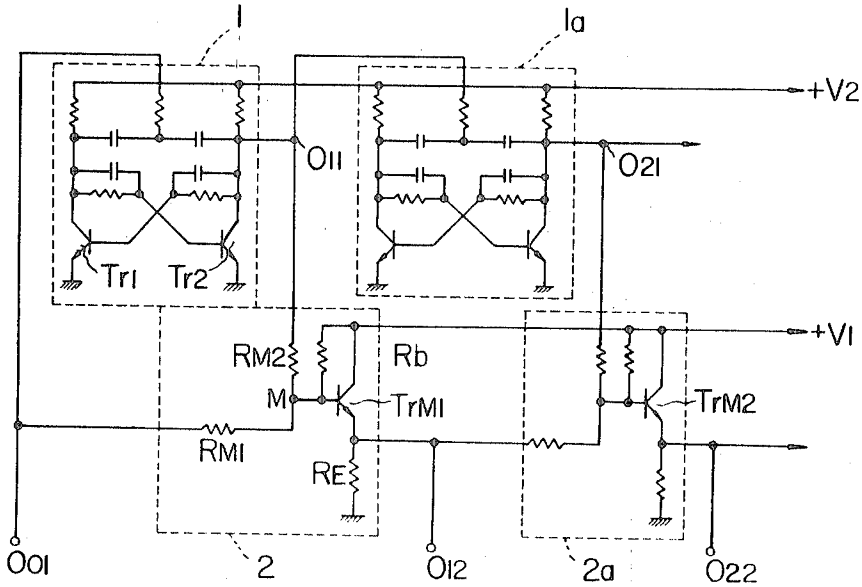

FIG. 3

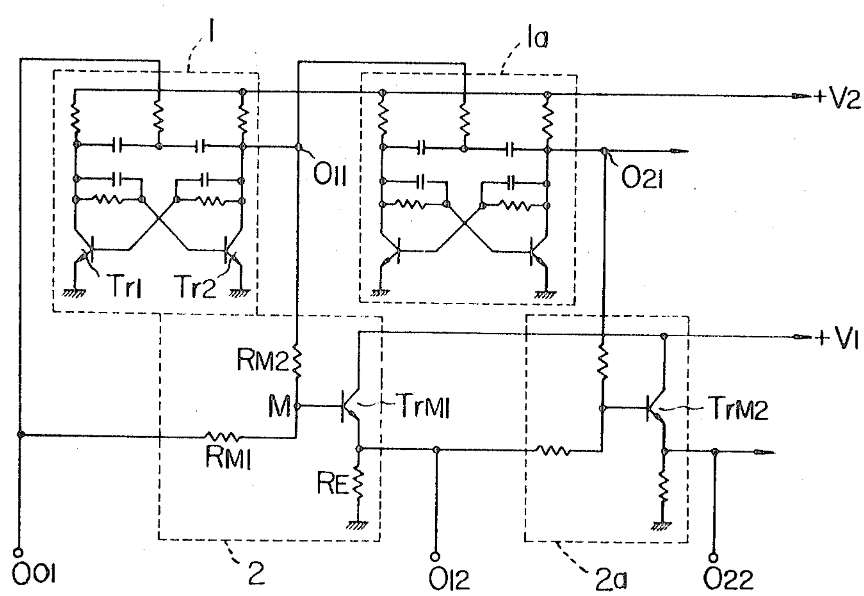

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FIG. 2(a)

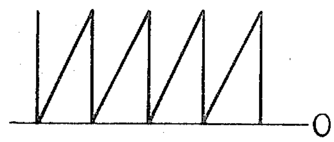


FIG. 2(b)

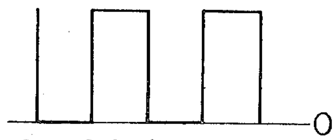


FIG. 2(c)

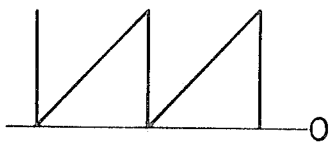


FIG. 2(d)

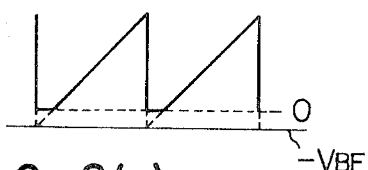


FIG. 2(e)

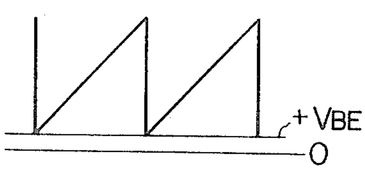


FIG. 2(f)

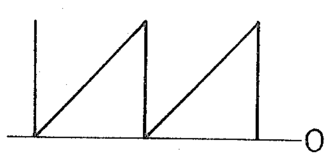


FIG. 4(a)

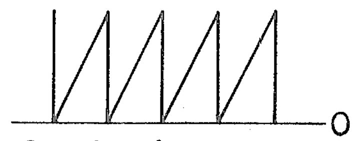
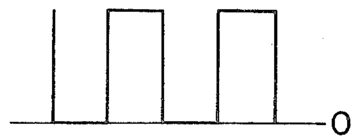


FIG. 4(b)



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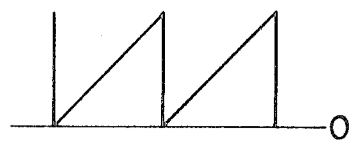

FIG. 4(d)

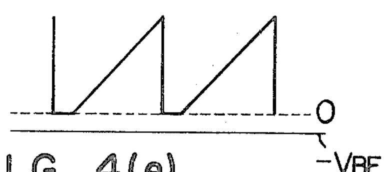

FIG. 4(e)

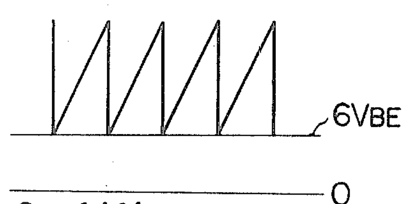

FIG. 4(f)

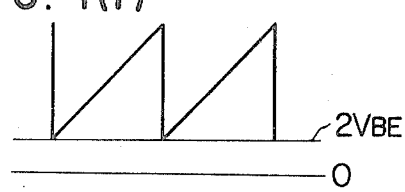

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FIG. 5

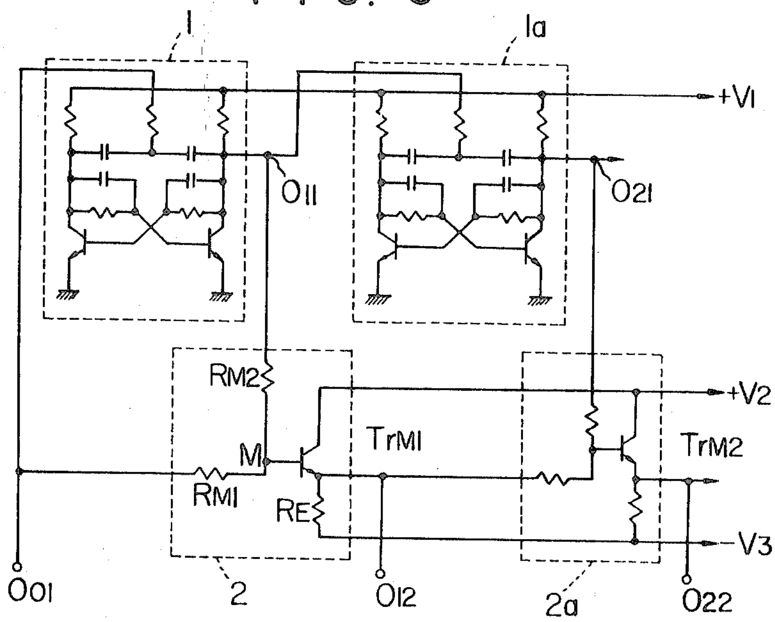

FIG. 6(a)

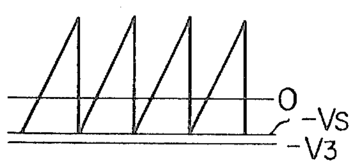

FIG. 6(b)

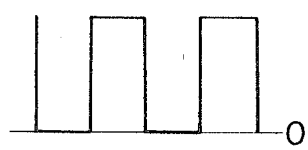

FIG. 6(c)

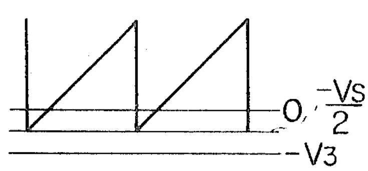

FIG. 6(d)

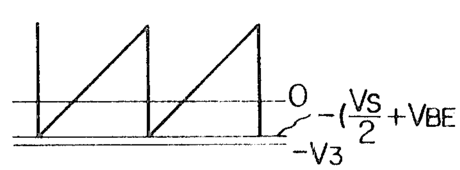

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FIG. 7

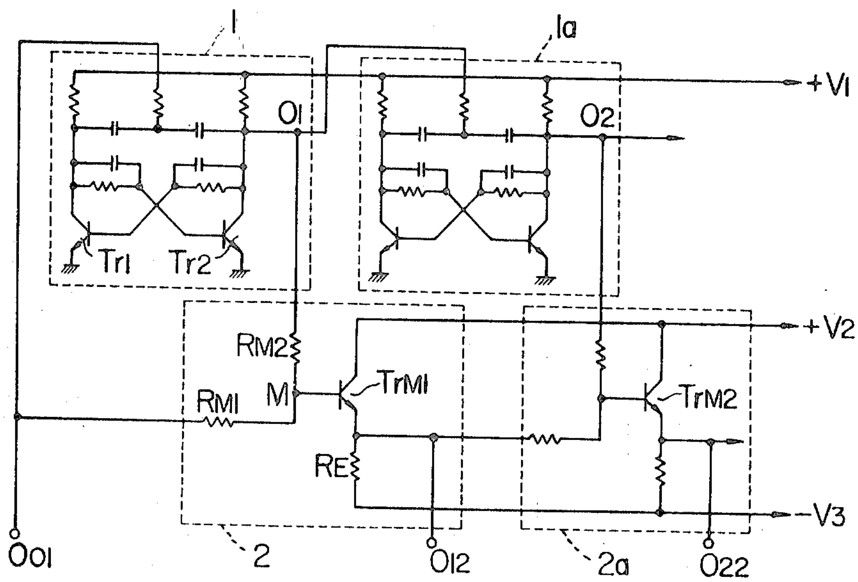

FIG. 9

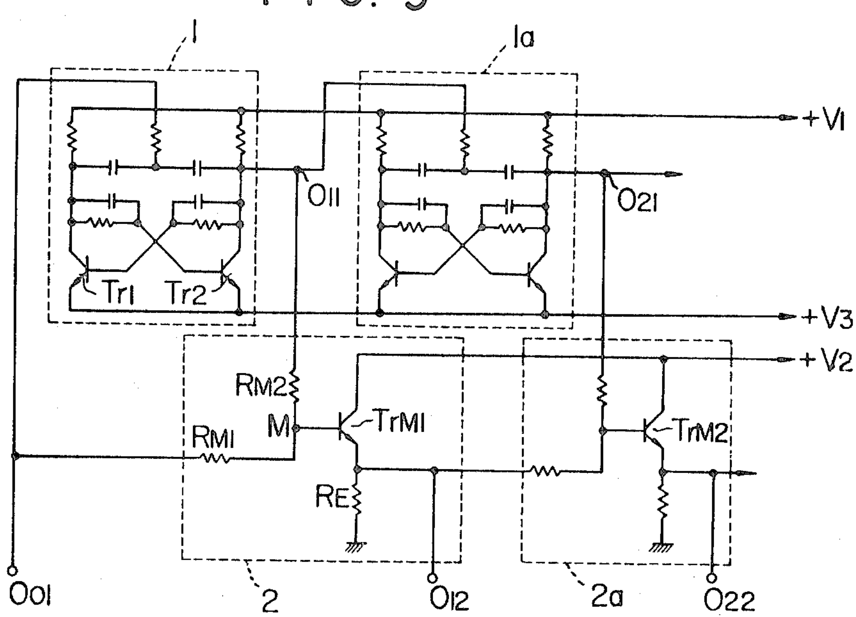

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FIG. 8

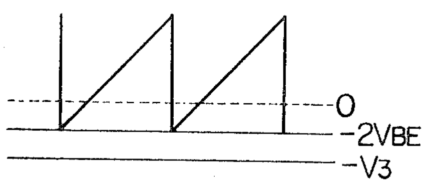


FIG. 10(a)

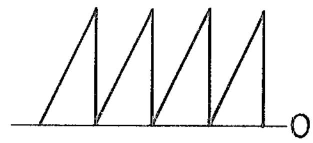
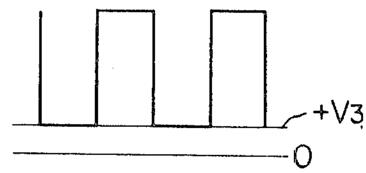


FIG. 10(b)



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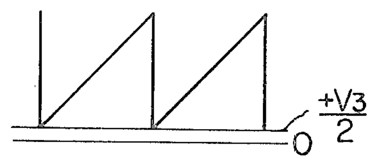
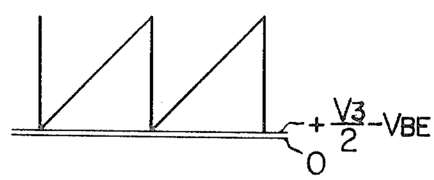


FIG. 10(d)



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FREQUENCY-DIVIDING CIRCUIT FOR SIGNALS OF SAWTOOTH WAVEFORM

BACKGROUND OF THE INVENTION

The present invention relates to a frequency-dividing circuit for signals of sawtooth waveform in which a frequency-divided sawtooth wave can be obtained by mixing a square wave and a sawtooth wave, and more particularly relates to frequency-dividing circuits for signals of sawtooth waveform, which can be connected in cascade from a point of view of direct current.

Hitherto, a frequency-dividing circuit constructed by connecting a plurality of flip-flop circuits or a plurality of blocking oscillators in cascade has been conventionally used as a frequency divider for use in electronic musical instruments. However, the conventional frequency dividers mentioned above have various disadvantages as well as various advantages. That is, since the frequency divider utilizing flip-flop circuits can carry out frequency-dividing operation within a broad frequency range having no limitation, it is very easy to manufacture said frequency divider in the case when a plurality of the frequency dividers are to be used, but since their output waves are of square form and contain only harmonic frequencies of odd order without containing harmonic frequencies of even order, said output waves are incomplete for practical use as a sound source in electronic musical instruments.

On the other hand, an output wave of a frequency divider comprising cascaded blocking oscillator circuits is of sawtooth waveform, so that said output wave has all of harmonic components, thus causing favorable production of timbres of any musical instrument, which means that said frequency divider is ideal as the sound source. However, the blocking oscillator circuit itself is liable to produce a self-running oscillation of a particular frequency in the case when any synchronizing means is not applied thereto, that is, said circuit includes therein a time-constant circuit the time constant of which is determined by a capacitance, a resistance, characteristics of active elements, bias voltage, power source voltage, and the like. Accordingly, the blocking oscillator circuit is affected by fluctuation of the above-mentioned values of various elements and variation of voltages and temperature, whereby frequency of the free-running oscillation is liable to be varied. Furthermore, when the blocking oscillator circuit is used as one-half frequency divider by applying synchronization thereto, frequency of the input synchronous signal is required to be higher than double value and lower than triple value of its free-running oscillation frequency, so that its operating frequency is limited. Accordingly, for the purpose of obtaining a desired operation frequency, values of the circuit elements such as capacitors and resistors should be selected to be matched with said desired frequency, and in the case of using the frequency divider as a sound source circuit of any musical instrument, elements of the circuit should be individually designed so as to be mutually different from elements of other circuits in order to cover frequency range over several octaves, thus causing difficulty of manufacture of the circuits. Furthermore, as sound frequency approaches bass region, larger time constant is required. In this case, capacitor of a larger capacitance is required, thus causing higher cost and bulkiness of the circuit.

SUMMARY OF THE INVENTION

It is an essential object of the invention to provide a frequency-dividing circuit for signals of sawtooth waveform having no such disadvantages of the conventional frequency-dividing circuits as mentioned above, and more particularly to provide a frequency divider favorably adapted to produce a sound source for any electronic musical instrument.

It is another object of the invention to provide a frequency-dividing circuit for signals of sawtooth waveform, which produces a frequency-divided sawtooth wave by mixing a square wave from a square-wave frequency-dividing circuit and a sawtooth wave at a mixing circuit, disposing large amplitude signals without distortion.

It is a further object of the invention to provide frequency-dividing circuits for signals of sawtooth waveform, which can be connected in cascade to each other from a point of view of direct current, and are simple in their construction.

It is a further object of the invention to provide frequency-dividing circuits for signals of sawtooth waveform which can be easily connected in cascade without using DC blocking capacitor and bias resistor of the transistor.

It is still a further object of the invention to provide a frequency-dividing circuit for signals of sawtooth waveform, said circuit being more particularly adapted for various integrated circuits of any electronic musical instrument.

The foregoing and other objects of the invention have been attained by a frequency-dividing circuit comprising a buffer transistor to the base of which an input sawtooth wave and an output square wave of a square-wave frequency divider are applied in their states of equal peak amplitude through mixing resistors having equal value; and a mixing circuit for obtaining an output of a frequency-divided sawtooth wave from the emitter of said buffer transistor, characterized in that a means is provided for causing superposition of a compensating DC voltage at any portion of the circuit in such a manner that the lower ends of the mixed signal appearing at the base is offset from the emitter potential by a voltage value sufficient to compensate a base-to-emitter forward voltage which means the forward voltage drop between the base and the emitter, thereby causing said buffer transistor to perform a perfect class "A" amplifying operation.

The features and function of the invention will become more apparent and more readily understandable by the following description and the appended claims when read in connection with the accompanying drawings, in which same or equivalent members are designated by the same numerals and characters.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit connection diagram showing an embodiment of the invention;

FIGS. 2(*a*) to 2(*f*) are waveform diagrams showing the signal relationships in the circuit shown in FIG. 1;

FIG. 3 is a circuit connection diagram showing a second embodiment of the invention;

FIGS. 4(*a*) to 4(*f*) are waveform diagrams showing the signal relationships in the circuit shown in FIG. 3;

FIG. 5 is a circuit connection diagram showing a third embodiment of the invention;

FIGS. 6(*a*) to 6(*d*) are waveform diagrams showing the signal relationships in the circuit shown in FIG. 5;

FIG. 7 is a circuit connection diagram showing a fourth embodiment of the invention;

FIG. 8 is a waveform chart illustrating the operation of the circuit shown in FIG. 7;

FIG. 9 is a circuit connection diagram showing a fifth embodiment of the invention; and

FIGS. 10(*a*) to 10(*d*) are waveform diagrams illustrating the signal relationships in the circuit shown in FIG. 9.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIGS. 1 and 2, a sawtooth wave shown in FIG. 2(*a*) is applied to a square-wave frequency-dividing circuit 1 comprising transistors Tr_1 and Tr_2 from its input terminal O_{01}, whereby a square wave shown in FIG. 2(*b*) is derived from output terminal O_{11} of said circuit 1. When the transistor Tr_2 in the output side of said frequency-dividing circuit 1 is in conductive state, the output voltage is equal to a saturation voltage of said transistor and is nearly zero, but when the transistor Tr_2 is in cutoff state, the output voltage comes to have a voltage nearly equal to that of normal source voltage $+V_2$, and this alternating operation produces square wave having a considerable large amplitude.

Assuming that the sawtooth wave in FIG. **2**(*a*) from the terminal 0_{01} and the square wave from the square-wave frequency-dividing circuit **1** are made same in their peak amplitudes and mixing resistors R_{M1} and R_{M2} of a mixing circuit **2** comprising a buffer transistor Tr_{M1} having a high input impedance are set to same value respectively, a sawtooth wave shown in FIG. **2**(*c*) having a frequency of *f*/2 (*f*: original frequency) and same peak amplitude as that of said former waves is obtained at the connection point M. This output sawtooth wave is applied to the base of the buffer transistor Tr_{M1} having a high input impedance, whereby an output wave is derived from the emitter 0_{12} of said transistor Tr_{M1}. Although the emitter of the transistor Tr_{M1} is connected through an emitter resistor R_E to the ground, the transistor Tr_{M1} does not perform class "A" amplifying operation below the base-to-emitter forward voltage V_{BE} which is the nonconducting forward voltage between the base and the emitter, which results in that an imperfect sawtooth wave with its under side shown by a dotted line cut is obtained, as shown in FIG. **2**(*d*). In the case when silicon transistor is used as the transistor Tr_{M1}, the above-mentioned voltage is about 0.6 volt. Even if such a frequency-divided imperfect sawtooth wave is applied to a mixing circuit **2***a* of the succeeding stage, a perfect sawtooth wave can not be obtained from the terminal 0_{22}, so that, the above-mentioned frequency-dividing stages cannot be connected in cascade one after another.

Accordingly, in the embodiment of FIG. **1** according to this invention, it is constructed that a resistor R*b* is connected between the base and collector of the transistor Tr_{M1} and a DC voltage nearly equal to said V_{BE} is superposed to the signal brought at the base of the transistor Tr_{M1}. That is, sawtooth wave shown in FIG. **2**(*e*) can be obtained by superposing a direct current component V_{BE} to sawtooth wave at the connection point M. By such organization, class "A" operation of the transistor Tr_{M1} can be surely obtained, whereby a perfect output sawtooth wave as shown in FIG. **2**(*e*) can be obtained.

Of course, the peak amplitude of the mixed resultant sawtooth wave shown in FIG. **2**(*e*) reduces by a smaller amount than that of each of the two signals before mixing, because of the load effect of the resistor R_b connected between the base and collector of the transistor Tr_{M1}. However, when a source voltage $+V_1$ for the collector of the transistor T_{M1} is selected sufficiently high and a value of the resistor R*b* is also selected sufficiently high, the above-mentioned reduction of the peak amplitude of the mixed resultant sawtooth wave becomes so small that it has no problem in practical use.

The emitter of the transistor Tr_{M1} is connected not only to the output terminal O_{12}, but also to one input side of the succeeding mixing circuit **2***a*, and output square wave at the terminal O_{11} is applied not only to the mixing circuit **2** as one input thereof, but also to the succeeding square-wave frequency-dividing circuit **1***a* as a trigger input thereof. In addition, output terminal O_{21} of the above-mentioned circuit **1***a* is connected to the other input side of the mixing circuit **2***a*. Since the mixing circuit **2***a* is constructed the same as the mixing circuit **2** and buffer transistor Tr_{M2} of the mixing circuit **2***a* performs normally class "A" operation, a frequency-divided perfect sawtooth wave can be obtained from the terminal O_{22} at the output side of the mixing circuit **2***a*. Furthermore, by connecting in cascade a plurality of frequency-dividing stages, each being composed of a set of square-wave frequency-dividing circuit (**1**, **1***a*...or) and a mixing circuit (**2**, **2***a*...), the desired frequency-divided sawtooth waves can be easily obtained from the output terminal of each frequency-dividing stage.

Referring to the embodiment shown in FIG. **3**, a DC voltage is superposed to an input sawtooth wave in response to the number of frequency-dividing stages connected in cascade so as to obtain surely class "A" operation of buffer transistors in the mixing circuits to be connected in cascade. When two frequency-dividing stages are connected in cascade as shown in FIG. **3**, a sawtooth wave obtained by superposition of a pure sawtooth wave and a positive DC voltage corresponding to six times as large as the base-to-emitter forward voltage V_{BE} between the base and the emitter of the buffer transistor Tr_{M1}, said voltage V_{BE} corresponding to minimum voltage adapted to operate said transistor, is applied to the input terminal O_{01} as shown in FIG. **4**(*e*). Accordingly, class "A" operation of the buffer transistor TrM1 is established, thereby a frequency-divided sawtooth wave shown in FIG. **4**(*f*) can be obtained from the emitter of the buffer transistor Tr_{M1} when a sawtooth wave at the terminal O_{01} and a square wave from the square-wave frequency-dividing circuit **1** are mixed in the mixing resistors R_{M1} and R_{M2}. When the frequency-divided sawtooth wave thus obtained is applied to one input terminal of the succeeding mixing circuit **2***a* and is mixed with a square wave from the succeeding square-wave frequency-dividing circuit **1***a* to produce a desired frequency-divided sawtooth wave, class "A" operation of the buffer transistor Tr_{M2} is similarly established, because the minimum voltage of the above-mentioned resultant sawtooth wave is larger than the voltage V_{BE} of the buffer transistor Tr_{M2}, whereby a perfect frequency-divided sawtooth wave can be obtained from the terminal O_{22}. Although the foregoing description relates to the embodiment using two frequency-dividing stages, class "A" operation of the buffer transistor in each frequency-dividing stage can be surely obtained by applying a sawtooth wave superposed with a DC voltage $2(2^n-1)V_{BE}$ to the terminal O_{01} in the case when the number of the frequency-dividing stages is *n*, whereby perfect sawtooth waves can be obtained from their output terminals, respectively.

Referring to an embodiment shown in FIG. **5**, square-wave frequency-dividing circuit **1** consisting of a flip-flop circuit is caused to operate by a positive source voltage $(+V_1)$ and the ground potential. The collector of the buffer transistor Tr_{M1} in the mixing circuit **2** is connected to a positive source voltage $(+V_2)$ and the emitter thereof is connected through an emitter resistor R_E to an emitter source voltage $(-V_3)$ biased negatively with respect to the ground potential.

Assuming that, in the circuit shown in FIG. **5**, a DC voltage $(-V_S)$ biased negatively is superposed to a sawtooth wave at the input terminal 0_{01} as shown in FIG. **6**(*a*) and the resultant sawtooth wave thus obtained is mixed with a square wave shown in FIG. **6**(*b*) and obtained from the square-wave frequency-dividing circuit **1** in the mixing resistors R_{M1} and R_{M2} having same value respectively, a negative DC voltage superposed sawtooth wave as shown in FIG. **6**(*c*) comes to a value of $-V_s/2$ at the base of the transistor Tr_{M1}, because a mixing loss is one-half. On the other hand, since a negative DC voltage corresponding to an amount equal to the voltage V_{BE} between the base and the emitter of the transistor Tr_{M1} is superposed to the output wave at the emitter (at the output terminal O_{12}) of the transistor Tr_{M1}, the resultant negative DC voltage to be superposed to a frequency-divided sawtooth wave comes to $-(V_S/2+V_{BE})$ as shown in FIG. **6**(*d*).

Therefore, let it be assumed that the negative DC voltage $(-V_S)$ superposed to the sawtooth wave at the input terminal O_{01} is equal to $-2V_{BE}$, a negative DC voltage superposed to a frequency-divided sawtooth wave at the output terminal O_{12} comes to $-2V_{BE}$ also. That is, the negative DC voltages superposed to the sawtooth wave come to $-2V_{BE}$ respectively at both the input terminal 0_{01} and the output terminal O_{12}.

Accordingly, assuming that the emitter source voltage $(-V_3)$ of the buffer transistor Tr_{M1} is selected to a value equal to or more negative than the negative DC voltage $-2V_{BE}$ superposed to a frequency-divided sawtooth wave, the buffer transistor Tr_{M1} makes sure "A" operation, whereby a perfect sawtooth wave can be obtained from the emitter thereof.

Moreover, when the frequency-divided sawtooth wave thus obtained is applied to the base of the succeeding mixing circuit **2***a* as one input thereof and is mixed with a square wave from the succeeding square-wave frequency-dividing circuit **1***a*, thereby to derive a sawtooth wave of which frequency is further divided to one-half from the emitter of the buffer transistor Tr_{M2}, a DC voltage is to be superposed to the frequency-divided sawtooth wave thus obtained comes to

$-2V_{BE}$ also. Since this DC voltage ($-2V_{BE}$) is equal to the emitter source voltage ($-V_3$) of the buffer transistor Tr_{M2} or nearly equal to the ground potential, the similar class "A" operation can be obtained surely, whereby a perfect sawtooth wave can be obtained from the output terminal O_{22}.

Although the foregoing description relates to the embodiment using two frequency-dividing stages, it is apparent that class "A" operation of the buffer transistors in each frequency-dividing stage can be surely obtained in the case when one frequency-dividing stage is utilized or more than three are utilized.

Referring to an embodiment shown in FIG. 7, the circuit is constructed so that the emitter source voltage of the buffer transistor in the mixing circuit is biased more negatively than the ground potential. In the circuit of FIG. 7, the emitter of the buffer transistor Tr_{M1} in the mixing circuit 2 is connected through the emitter resistor R_E to the source voltage biased more negatively than the ground potential. As will be apparent from the foregoing description, a frequency-divided sawtooth wave superposed with a DC voltage ($-V_{BE}$) can be obtained at the emitter (at the output terminal O_{12}) of the transistor Tr_{M1} and similarly each of frequency-divided sawtooth waves, superposed DC voltages $-1.5V_{BE}$, $-1.75V_{BE}$,...respectively, having one-half frequency of the output frequency of the preceding frequency-dividing stage can be obtained successively at the output terminal of each frequency-dividing stage. Herein, assuming that each of the emitter source voltage ($-V_3$) of the buffer transistors is selected to be equal to $-2V_{BE}$ or more negative than $-2V_{BE}$, the buffer transistors in each of the frequency-dividing stages make sure class "A" operation, thereby perfect sawtooth waves can be obtained at each of the emitters of the buffer transistors as shown in FIG. 8.

Although the foregoing paragraph is described as to the embodiment wherein frequency-dividing stages are connected infinitely, it is apparent that when a number 'n' of the frequency-dividing stages are to be connected in cascade, a DC voltage to be superposed to frequency-divided sawtooth wave which is obtained from the output terminal of the nth frequency-dividing stage comes to $-2(1-½^n)V_{BE}$. Accordingly, the emitter source voltage of the buffer transistor may be selected to be equal to a value of $-2(1-½^n)V_{BE}$ or more negative than that of $-2(1-½^n)V_{BE}$.

Referring to an embodiment shown in FIG. 9, the circuit is constructed so that a DC Voltage biased positively may be superposed to a frequency-divided square wave from a square-wave frequency-dividing circuit 1 so as to obtain surely class "A" operation of the buffer transistor in each of the mixing circuits connected by the desired numbers in cascade. In the circuit of FIG. 9, each of the square-wave frequency-dividing circuits 1 and 1a is connected between positive source voltages $+V_1$ and $+V_3$. The output of the above-mentioned square-wave frequency-dividing circuit 1 is equal to voltage having a value corresponding to sum of the source voltage $+V_3$ and saturation voltage of the transistor Tr_2 when the transistor Tr_2 in the output side of the square-wave frequency-dividing circuit 1 is in conductive state, but it comes to be nearly equal to the source voltage $+V_3$, because the above-mentioned saturation voltage is nearly equal to zero.

Assuming that, in this circuit, such a sawtooth wave at the input terminal O_{01} as shown in FIG. 10(a) and such a square wave from the square-wave frequency-dividing circuit 1 superposed with a positive DC voltage ($+V_3$) as shown in FIG. 10(b) are mixed through the mixing resistors R_{M1} and R_{M2} having same value respectively, such a frequency-divided sawtooth wave superposed with a positive DC voltage ($+V_3/2$) as shown in FIG. 10(c) can be obtained at the base of the transistor Tr_{M1}, because a mixing loss is one-half. On the other hand, since a negative DC voltage is superposed by the amount equal to the voltage V_{BE} between the base and the emitter of the transistor Tr_{M1} to the output wave at the emitter (at the output terminal 0_{12}) of the transistor Tr_{M1}, the resultant DC voltage superposed to a frequency-divided sawtooth wave comes to ($+V_3/2-V_{BE}$ as shown in FIG. 10(d).

Therefore, if the positive DC voltage ($+V_3$) to be superposed to the frequency-divided square wave is selected to be equal to $+2V_{BE}$, a DC voltage to be superposed to the frequency-divided sawtooth wave at the output terminal O_{12} comes to zero. That is, the DC voltages to be superposed to the sawtooth wave come to zero respectively at both the input terminal O_{01} and the output terminal O_{12}. Accordingly, when the source voltage ($+V_3$) of the square-wave frequency-dividing circuit is selected to a value equal to $2V_{BE}$, the buffer transistor Tr_{M1} makes sure class "A" operation, whereby a perfect sawtooth wave can be obtained from the emitter thereof.

Moreover, when the frequency-divided sawtooth wave thus obtained is applied to the succeeding mixing circuit 2a as one input thereof and is mixed with a square wave obtained from the succeeding square-wave frequency-dividing circuit 1a to and superposed with a positive DC voltage $2V_{BE}$, thereby to derive a sawtooth wave of which frequency is further divided to one-half from the emitter of the buffer transistor Tr_{M2}, a DC voltage to be superposed to the frequency-divided sawtooth wave thus obtained comes to zero. Accordingly, class "A" operation of the transistor Tr_{M2} is surely obtained, whereby a perfect sawtooth wave can be obtained from the output terminal O_{22} of the succeeding mixing circuit 2a. Furthermore, since there are small fluctuations in voltage V_{BE} of the transistors, it is preferable to set a source voltage ($+V_3$) of the square-wave frequency-dividing circuit to a voltage somewhat larger than $2V_{BE}$.

In the above-mentioned embodiment, a common source voltage ($+V_3$) to each of the square-wave frequency-dividing circuits is utilized as a means to superpose a positive DC voltage to frequency-divided square wave, but it is possible to connect each of the circuits through resistor or diode and the like to the ground without connecting each of the square-wave frequency-dividing circuits to the common source voltage ($+V_3$).

It will be appreciated that by the use of the system according to one of the above-mentioned embodiments of the invention it is possible to easily obtain a sawtooth wave frequency-dividing circuit composed of a plurality of a frequency-dividing stages which can be connected in cascade successively and to provide an improved sawtooth frequency-dividing circuit adapted for sound source of electronic musical instruments and more particularly adapted for integrated circuit thereof. It will be understood, of course, that these embodiments are presented only as exemplary to the invention, and many changes and modifications will become apparent to those skilled in the art.

What we claim is:

1. A circuit for producing signals of sawtooth wave having at least one stage comprising: a buffer transistor; at least two mixing resistors of equal value feeding at the base of the transistor an input sawtooth wave and a square wave of equal peak amplitude; a frequency mixing circuit including said buffer transistor and said resistors to mix the input sawtooth wave and square wave to produce a required sawtooth signal; a square-wave frequency-dividing circuit having an output thereof connected to one of said mixing resistors to feed said square wave into the frequency-mixing circuit; and means to superpose a DC voltage at a portion of the circuit so as to lower ends of said divided frequency output signal to an extent sufficient to compensate the voltage drop between the transistor base and emitter causing said buffer transistor to perform as a perfect class "A" amplifier.

2. The circuit as claimed in claim 1 which includes an emitter resistor connected at one end thereof to the emitter of said buffer transistor the other end being earthed, and a DC voltage superposing resistor connected between the base and collector of the buffer transistor.

3. The circuit as claimed in claim 1 in which said means to superpose a DC voltage is adapted to superpose the voltage in the same direction as the starting operational voltage of said buffer transistor.

4. The circuit as claimed in claim 1 in which said means to superpose a DC voltage includes connections to superpose the DC voltage to said input sawtooth wave, and means to set the emitter source voltage of said buffer transistor to a value at least equal to the DC voltage and to so set the direction of said emitter source voltage that the buffer transistor is conductive.

5. The circuit as claimed in claim 1 in which said means to superpose a DC voltage is adapted to superpose the DC voltage to the frequency-divided output of the square-wave dividing circuit, and the circuit includes means to set the DC voltage to be larger than twice the voltage V_{BE} between the base and the emitter of said buffer transistor, whereby the voltage V_{BE} causes the buffer transistor to operate and the buffer transistor is made conductive.

6. The circuit as in claim 2 which comprises a plurality of said stages and means connecting them in cascade.

7. The circuit as in claim 3 which comprises a plurality of said stages and means connecting them in cascade.

8. The circuit as in claim 4 which comprises a plurality of said stages and means connecting them in cascade.

9. The circuit as in claim 5 which comprises a plurality of said stages and means connecting them in cascade.

10. A circuit for producing signals of sawtooth wave, having one or more stages "*n*," each comprising: a buffer transistor; at least two mixing resistors of equal value feeding at the base of the transistor an input sawtooth wave and a square wave of equal peak amplitude; a frequency mixing circuit including said buffer transistor and said resistors to mix the input sawtooth wave and square wave to produce a required sawtooth signal; a square-wave frequency-dividing circuit having an output thereof connected to one of said mixing resistors to feed said square wave into the frequency-mixing circuit; and means including a DC voltage source to make an emitter source voltage of said buffer transistor equal to or larger than

$$2\left(1-\frac{1}{2}n\right)$$

times the voltage V_{BE} between the base and emitter of the buffer transistor, said voltage

$$2\left(1-\frac{1}{2}n\right)V_{BE}$$

serving to start said transistor and, with the direction of said emitter source voltage set suitably, maintain the transistor conductive.

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