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Nelson

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[54] **TONE SYNTHESIZER FOR ELECTRONIC MUSICAL INSTRUMENTS**

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[52] **U.S. Cl.** ..... **328/14;** 84/1.25; 84/DIG. 11; 328/39; 331/77; 331/106; 331/108 D

[51] **Int. Cl.²**.. **G10H 1/04;** G10H 1/06; G10H 5/06; H03B 19/00

[58] **Field of Search**..... 328/14.39; 307/261; 84/1.01, 103, 1.04, 1.11, 1.12, 1.19, 1.22, 1.24, 1.25, DIG. 11; 331/60, 74, 77

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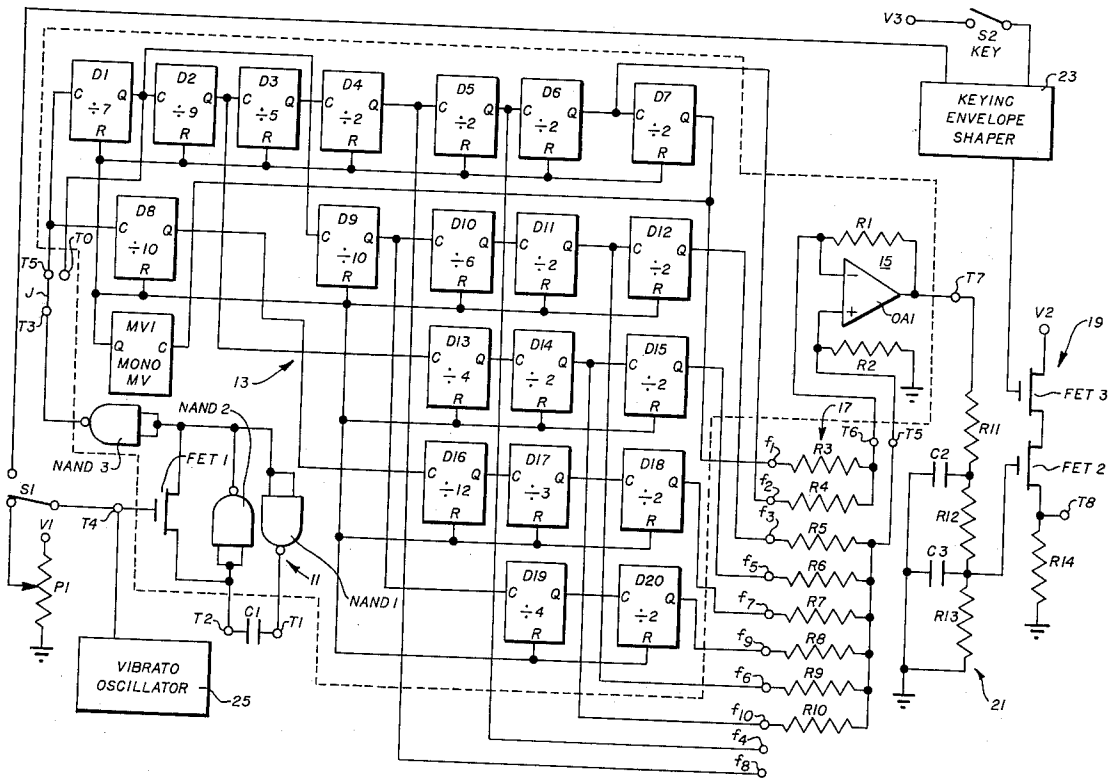
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Attorney, Agent, or Firm—Christensen, O'Connor, Garrison & Havelka

[57] **ABSTRACT**

A driving signal is divided into a plurality of synchronous harmonically related square waves. From the thusly created square waves, the harmonic components of a desired musical voice are selected, attenuated and combined to create the desired musical voice waveform. Any high order components which may result are adjusted or eliminated by filtering. A vibrato oscillator, connected to the driving signal source, controls the output of the driving signal source in a manner such that the electronically synthesized wave form of the desired musical voice is modified in a vibrato manner. In one form, complementary square wave components are created and selectively combined together. Alternatively, components of only one phase state are created and selectively combined together.

9 Claims, 2 Drawing Figures



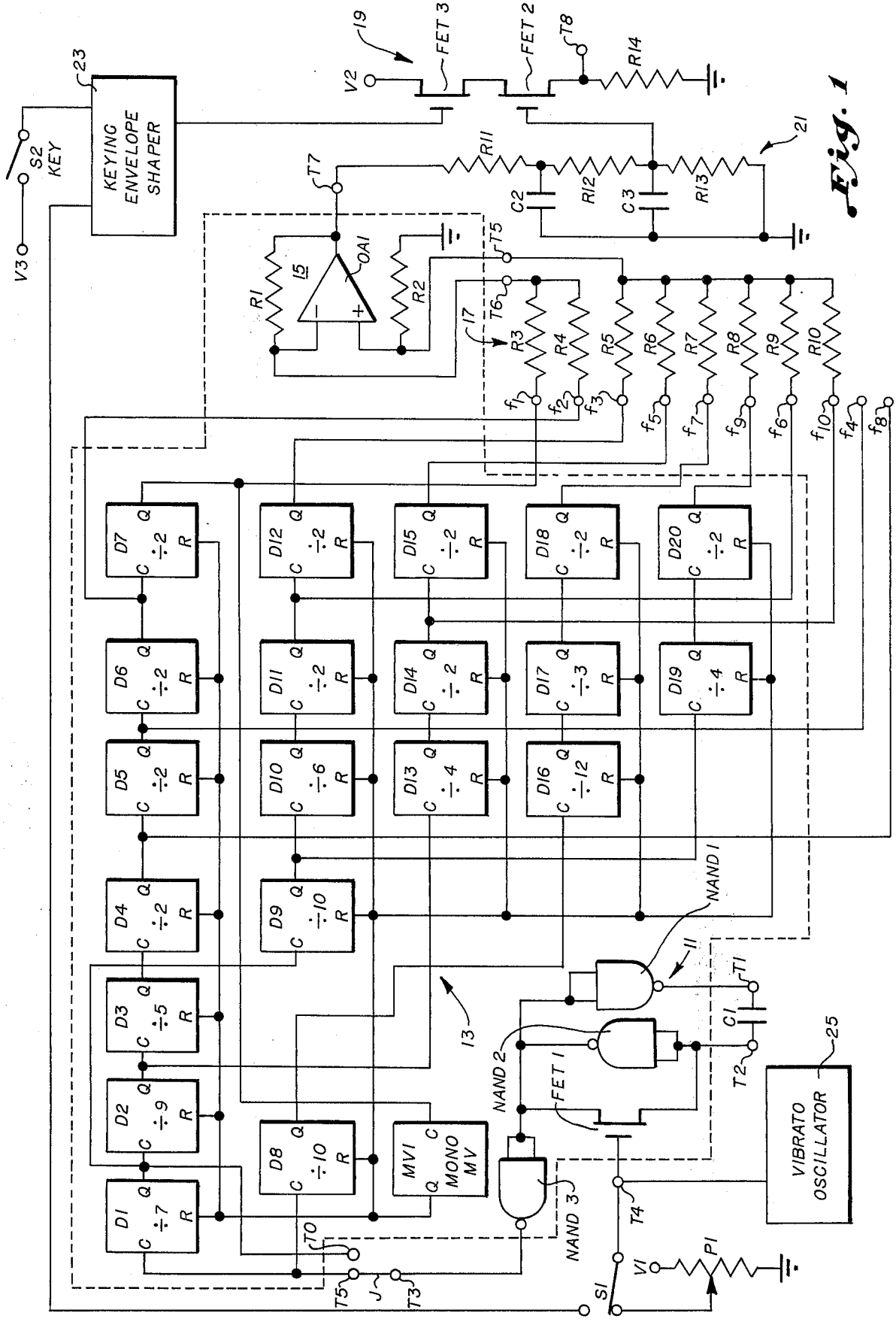

KEYING ENVELOPE SHAPER
S2 KEY
V3
V2
FET 3
FET 2
R14
R11
R12
R13
C2
C3
OA1
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
D7 ÷2
D6 ÷2
D5 ÷2
D4 ÷2
D3 ÷5
D2 ÷9
D1 ÷7
D12 ÷2
D11 ÷2
D10 ÷6
D9 ÷10
D8 ÷10
D15 ÷2
D14 ÷2
D13 ÷4
D18 ÷2
D17 ÷3
D16 ÷12
D20 ÷2
D19 ÷4
MV1 MONO MV
NAND 1
NAND 2
NAND 3
FET 1
VIBRATO OSCILLATOR
P1
V1
S1
J
C1

Fig. 1

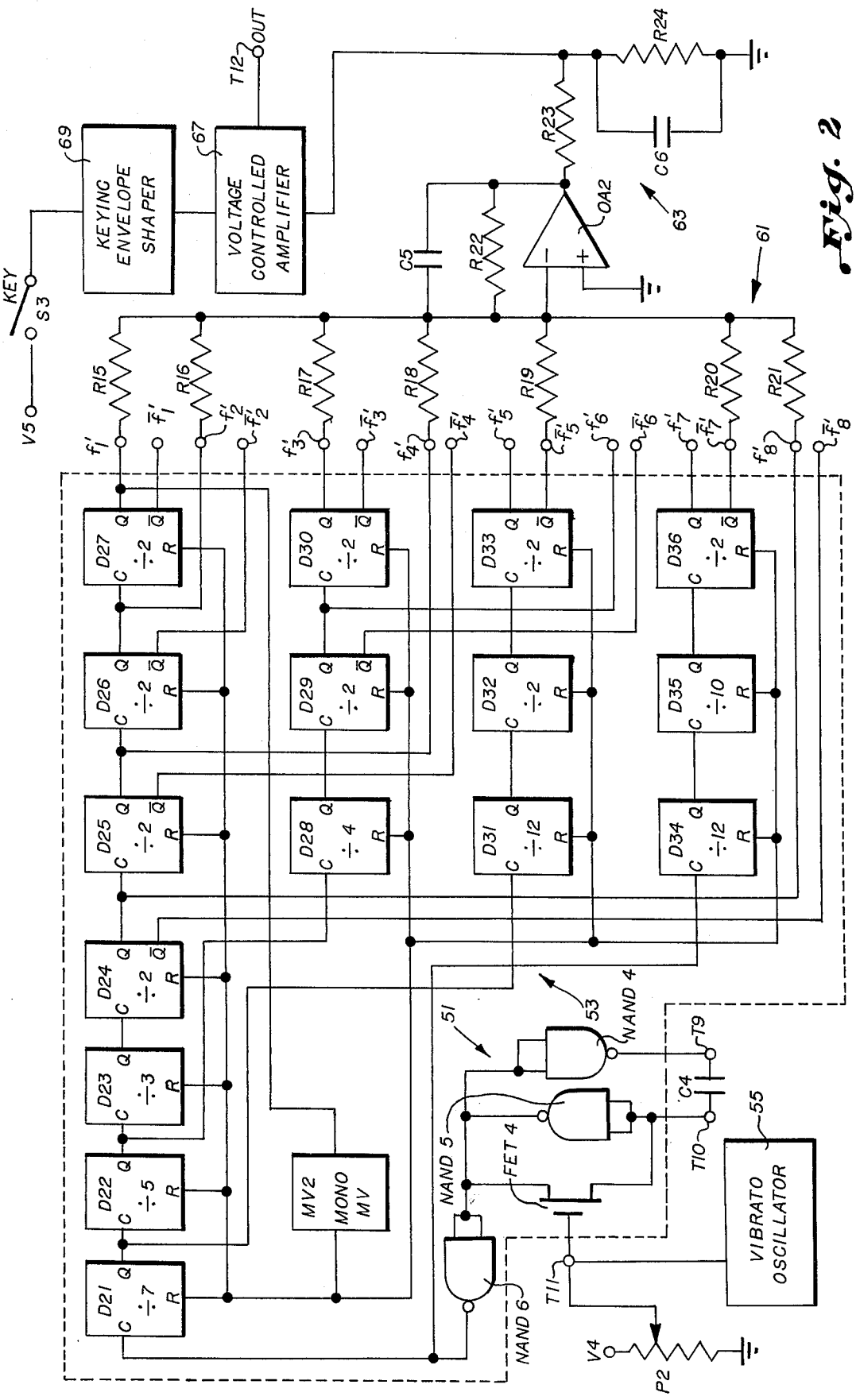

KEY
S3
V5
KEYING ENVELOPE SHAPER
69
VOLTAGE CONTROLLED AMPLIFIER
67
T12
OUT
R24
R23
C6
63
OA2
C5
R22
61
R15
R16
R17
R18
R19
R20
R21
f'1
f̄'1
f'2
f̄'2
f'3
f̄'3
f'4
f̄'4
f'5
f̄'5
f'6
f̄'6
f'7
f̄'7
f'8
f̄'8
D27 ÷2
D26 ÷2
D25 ÷2
D24 ÷2
D23 ÷3
D22 ÷5
D21 ÷7
D30 ÷2
D29 ÷2
D28 ÷4
D33 ÷2
D32 ÷2
D31 ÷12
D36 ÷2
D35 ÷10
D34 ÷12
MV2 MONO MV
51
53
NAND 4
T9
C4
55
NAND 5
FET 4
T10
VIBRATO OSCILLATOR
T11
NAND 6
V4
P2

Fig. 2

TONE SYNTHESIZER FOR ELECTRONIC MUSICAL INSTRUMENTS

BACKGROUND OF THE INVENTION

This invention is directed to tone synthesizers, and more particularly, to tone synthesizers for generating musical instrument voices.

A wide variety of tone synthesizers suitable for electronically generating the harmonic structure of musical instrument voices, have been proposed by the prior art. For many reasons, these proposals have not been entirely satisfactory. In many cases, compromises have been made between cost, space requirements, and the end result whereby the generated musical instrument voices have not perfectly duplicated actual musical instrument voices. More specifically, the ultimate electronic organ (one type of tone synthesizer) is one in which an actual pipe organ is closely simulated by providing electronic tone generators for each of the hundreds of pipes found in the pipe organ. In an attempt to produce the ultimate electronic organ, some electronic organs have been manufactured with individual electronic tone generators, each designed to simulate the tone produced by a pipe of a pipe organ. However, in the past, the cost and space requirements of these complex electronic organs have approached the cost and space requirements of a comparable pipe organ.

Attempts have been made to overcome the foregoing cost and space disadvantages by using integrated circuit and other techniques. The invention described in U.S. Pat. No. 3,755,609, entitled "Integrated Circuit All-Harmonic Wave Organ System Including Provision for Flute Tones and Pedal Tones" issued to David Millett and Ray B. Schrecongost, is an example of such attempts. However, the type of system proposed by this patent remains a compromise between result and cost. For example, because the system described in U.S. Pat. No. 3,755,609 derives tones from a single frequency source, they are locked in phase. Because they are locked in phase, only a suggestion of magnificent chorus or ensemble effect produced by organs with individual tone generators is obtained, rather than a simulation of a magnificent chorus or ensemble effect. In other words, while systems of this nature have eliminated the need for individual tone generators, they have done so at the expense of end result. In addition, since a set of filters is required for each instrumental voice simulated, these systems still require a multitude of components and, even though somewhat integrated, have space requirements still greater than desired.

Therefore, it is an object of this invention to provide a new and improved method of and apparatus for creating tones similar to the tones produced by musical instruments and the like.

It is also an object of this invention to provide a new and improved method of and apparatus for creating desired waveforms.

It is a further object of this invention to provide a new and improved tone synthesizer suitable for use in generating musical instrument voices.

It is a still further object of this invention to provide an uncomplicated and inexpensive tone synthesizer suitable for large scale production using integrated circuit techniques that does not require the resultant tones to be filtered by complex filter arrangements.

It is a still further object of this invention to provide a tone synthesizer suitable for use in an electronic organ to generate desired musical instrument voices electronically that is inexpensive, relatively small in size, and uncomplicated.

It is a still further object of this invention to provide a tone synthesizer suitable for use in an electronic organ which can be assembled in ranks of tone generators which will have much reduced space requirements when compared to the ranks of tone generators in prior art electronic or pipe organs.

SUMMARY OF THE INVENTION

In accordance with principles of this invention, a method of creating the harmonic structure of musical instrument voices is provided. The method generally compriises the steps of: generating a signal at a suitable frequency; dividing the signal into a plurality of synchronized harmonic square waves; selecting certain of said synchronized harmonic square waves; selectively attenuating the selected synchronized harmonic squarer waves; and, combining the selected and attentuated synchronized harmonic square waves to create the desired musical instrument voice waveform.

In accordance with further principles of this invention, the synchronized harmonic square waves include both complementary states.

In accordance with other principles of this invention, the summed, attenuated and selected harmonic square waves are filtered to eliminate higher order sign wave components.

In accordance with still other principles of this invention, apparatus for carrying out the method of the invention is provided. The apparatus comprises an oscillator for generating a driving signal at a predetermined frequency. A divider network receives the output of the oscillator and divides the output into a plurality of synchronized harmonically related square waves. The synchronized harmonically related square waves are selectively connected to suitable attenuators. The attenuators are connected to a summation circuit which sums the attenuated synchronized harmonically related square waves to provide the desired musical instrument voice waveform.

In accordance with still further principles of this invention, the divider network produces both complementary states of the synchronized harmonic square waves. In addition, attenuation is provided by a resistor network, the resistors making up the network having different values.

In accordance with alternate principles of this invention, the divider network only creates signals of only one complementary state, and summation is provided by an operational amplifier having both inverting and non-inverting inputs.

In accordance with still further principles of this invention, the output of the summing means is connected to the input of an uncomplicated low pass filter circuit which adjusts or eliminates high frequency components from the musical instrument voice waveform.

In accordance with still other principles of this invention, the divider network, the oscillator and other desired components are formed as part of a single large scale integrated circuit.

It will be appreciated from the foregoing brief summary that the invention provides new and improved tone synthesizers suitable for synthesizing the harmonic structure of musical instrument voices. The method of the invention comprises a series of uncomplicated steps which result in the synthesis of desired musical instru-

ment voices. The apparatus for carrying out the method of the invention is equally uncomplicated, particularly when compared with prior art apparatus for electronically synthesizing the harmonic structure of musical instrument voices. In this regard, it should be noted that the invention eliminates one of the primary disadvantages of prior art devices designed to perform a similar function. Specifically, the requirement for complex filter arrangements is eliminated. Because the invention is suitable for formation using large scale integrated circuit techniques, it allows a plurality of individual tone generators to be manufactured at low cost. Moreover, these circuits are small enough in size so that each rank of 61 tone generators normally included in an electronic organ can be assembled on one or two plug-in circuitboards. Thus, the overall size is such that all of the ranks of an electronic organ can be housed within the confines of an organ console of relatively small size.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing objects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a partially block and partially schematic diagram illustrating a preferred embodiment of the invention; and,

FIG. 2 is a partially block and partially schematic diagram illustrating an alternate preferred embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Prior to discussing the preferred embodiments of the invention illustrated in the drawings, a brief description of the method of the invention, and its basis, is hereinafter set forth. The invention is based on the fact that a square wave consists of odd sine wave components of decreasing amplitude. The invention utilizes this basic feature of a square wave by combining selected, suitably attenuated, harmonic square waves which are synchronized with one another. The end result of the combination is the generation of a sine wave harmonic structure (waveform) that simulates a chosen one of a large number of waveforms of the type generated by musical instruments. Obviously, the specific waveform generated depends upon the selection, attenuation and combination of the related square waves.

More specifically, in relation to a fundamental square wave, which contains first, third, fifth, seventh, etc. sine wave components, the second harmonic square wave contains second, sixth, 10th, etc. sine wave components, the third harmonic square wave contains third, ninth, 15th, etc. sine wave components. The fourth, fifth and higher harmonic square waves have similarly related patterns, i.e., patterns that are related to the fundamental square wave. In accordance with the invention, synchronized, harmonically related square waves of the foregoing nature are generated, i.e., square waves having interrelated components are generated. From the plurality of square waves generated, predetermined square waves having components related to the harmonic structure of the musical instrument voice desired, are selected. The selective components are attenuated and the results of the attenuation are added or subtracted together. The addition or subtraction adds to or cancels other sine wave components. The end result, when suitable attenuation is provided, is the creation of a complex waveform which relates to the harmonic structure of the musical instrument voice desired.

While any number of harmonically related square waves can be generated, eight or 10 have been found adequate to closely synthesize most musical instrument voices. By complying with this limitation, actual embodiments of the invention are kept within easily produced bounds.

It will be appreciated for those skilled in the art, that the decreasing amplitude of the inherent higher sine wave components of the selected square waves tend to correspond to the decreasing amplitude of the higher harmonics contained in actual musical instrument voices. If desired, the amplitude of these higher sine wave components, those beyond the eighth or 10th harmonic (depending upon the maximum harmonic chosen for inclusion), can ae easily controlled by passing the resultant waveform through an uncomplicated resistor-capacitor low pass filter network.

As a general example of the invention, a pure sine wave, which is characteristic of the flute tones, is produced by outphasing (subtracting) the third, fifth, seventh, etc., (up to some predetermined maximum level) sine wave components contained in the square wave of the fundamental frequency from that square wave. Any components above the predetemined level are removed by passing the resultant signal through an uncomplicated low pass filter. In other words, all of the components of the fundamental frequency square wave beyond the first component are removed, either by subtraction or by an uncomplicted low pass filter. The end result is, essentially, a pure sine wave which, as stated above, is characteristic of a flute tone.

Table I below sets forth the components necessary to create a flute tone in somewhat more detail. Specifically, as discussed above, the complex wave voltage level only requires that the first harmonic component be produced. However, the fundamental square wave includes the first, third, fifth, etc. components, at decreasing relative voltage levels i.e., 1, ⅓, 1/5, etc. Thus, it is necessary to remove the undesired components. This result is achieved in accordance with the invention by "choosing" the square wave harmonics having the desired components (third, fifth, etc.), attenuating these components to the desired voltage level (⅓, 1/5, etc.) and subtracting them from the fundamental square wave. The remaining higher order sine wave components (i.e., those above a predetermined harmonic—ninth in the illustrated example) are removed by an uncomplicated low pass filter.

TABLE I

FLUTE TONE (SINE WAVE)										
Harmonic Components	1	2	3	4	5	6	7	8	9	10
Complex Wave Voltage Level	1	0	0	0	0	0	0	0	0	0
	1	0	1/3	0	1/5	0	1/7	0	1/9	0

TABLE I-continued

FLUTE TONE (SINE WAVE)										
	2	0	0	0	0	0	0	0	0	0
Square Wave	3		−1/3	0	0	0	0	0	−1/9	0
Harmonic Voltage	4			0	0	0	0	0	0	0
Level	5				−1/5	0	0	0	0	0
	6					0	0	0	0	0
	7						−1/7	0	0	0
	8							0	0	0
	9								0	0
	10									0
TOTAL	1	0	0	0	0	0	0	0	0	0

Table II below provides the same information as Table I for a more complicated waveform—specifically, an alto saxophone waveform. In this case the higher order sine wave components are adjusted for best effect by the use of an uncomplicated low pass filter, rather than entirely eliminated.

TABLE II

ALTO SAXOPHONE (196~)										
Harmonic Components		1	2	3	4	5	6	7	8	9	10
Complex Wave Voltage Level		.8	.8	1	.5	.56	.22	.22	.25	.28	.35
	1	.8	0	.27	0	.16	0	.11	0	.09	0
	2		.8	0	0	0	.27	0	0	0	.16
Square Wave	3			.73	0	0	0	0	0	.24	0
Harmonic Voltage	4				.5	0	0	0	0	0	0
Level	5					.40	0	0	0	0	0
	6						−.05	0	0	0	0
	7							.11	0	0	0
	8								.25	0	0
	9									−.05	0
	10										.19
TOTAL		.8	.8	1	.5	.56	.22	.22	.25	.28	.35

It should be noted at this point that the harmonic structure of musical instrument voices varies over the tonal (frequency) range of the instrument. The trumpet, as an example, has both odd and even harmonics with the second harmonic predominating at the low range and the fundamental and third harmonic predominating at the higher range. The invention has the capability of producing the harmonic structure over the entire tonal range, if desired.

It will be appreciated from the foregoing description, that the method of the invention comprises the steps of: generating a signal at a predetermined frequency; dividing the signal into a plurality of synchronized, harmonically related square wave signals; selecting and attenuating a predetermined number of the synchronized, harmonically related square wave signals; and, combining the selected and attenuated synchronized, harmonically related square wave components to produce the harmonic structure (waveform) of a desired musical instrument voice. If desired, the synchronized, harmonically related square waves can include both complementary states, any of which can be chosen to create the desired harmonic structure of a musical instrument voice. Alternatively, the synchronized and harmonically related square waves may consist of components of only one complementary state and the summation step accomplished in a positive and negative manner. In either case, harmonics above a predetermined level may be controlled by the use of uncomplicated low pass filtering.

Turning now to the drawings wherein preferred embodiments of the apparatus of the invention are illustrated, FIG. **1** illustrates a tone synthesizer formed in accordance with the invention that generates components of only one complimentary phase state. The tone synthesizer illustrated in FIG. **1**, generally comprises: an oscillator **11**; a divider network **13**; a summation circuit **15**; and an attenuation network **17**. In addition to the actual tone synthesizer other subsystems described hereinafter are also illustrated in FIG. **1**.

While they may be separately formed preferably, the oscillator **11**, the divider network **13** and the operational amplifier **15** are all formed as part of a single large scale integrated (LSI) circuit. On the other hand, the attentuation network **17** is, preferably, an external circuit adapted to selectively attenuate predetermined portions of the harmonic components generated. Because the attenuation circuit **17** is external, a single large scale integrated circuit can be utilized to provide the basis for producing a plurality of different musical instrument tones. In other words a single LSI circuit can be used to produce all of the necessary synchronized, harmonically related components and a chosen attenuation network can be used to select and attenuate the components to create a desired musical instrument waveform for each note of the musical scale.

The oscillator **11** is a square wave oscillator and comprises three NAND gates designated NAND**1**, NAND**2** and NAND**3**; an external capacitor designated C**1**; and a field effect transistor designated FET**1**. The output of NAND**2** is connected to both inputs of NAND **1**. The output of NAND**1** is connected to an external capacitor terminal designated T**1**. The inputs of NAND**2** are connected to a second external capacitor terminal designated T**2**. C**1** is connected across T**1** and T**2**. In addition, the output of NAND**2** is connected to the two inputs of NAND**3**. The output of NAND**3** is connected to a first external jumper terminal designated T**3**. In addition, the drain-source terminals of FET**1** are connected across the inputs and output of NAND**2**. The gate of FET**1** is connected to a fourth external terminal designated T**4**. T**4** is connected to the common terminal of a single pole double throw switch designated S**1**. One of the remote terminals of S**1** is connected to the move-

able element of a poteniometer designated P1. P1 is connected between a suitable voltage source designated V1 and ground.

Since the operation of the driving oscillator 11 is well understood by those skilled in the art, it will not be fully and completely described herein. In general, however, the three NAND gates, FET1 and C1 make the oscillator act as a voltage controlled oscillator. The frequency of oscillation is determined by the value of C1 and the voltage level applied to the gate of FET 1 through S1. The voltage level is adjusted by adjusting the position of the moveable element of P1.

For the divider network illustrated and hereinafter described, the frequency of oscillation is 5040 times the fundamental frequency (f_1) i.e., the frequency of the lowest order square wave created. However, this frequency should not be construed as limiting since it may be changed to any other frequency as determined by the specific nature of the divider network.

A jumper wire designated J connects T3 to a second jumper terminal designated T5, or to a terminal designated T0. T5 and T0 are connected to the divider network 13 in the manner hereinafter described. T3, T5, T0 and J are provided so that the divider network can be driven by an external source rather than the oscillator 11, if and when desired.

The divider network 13 comprises a monostable multivibrator designated MV1 and 20 divider circuits designated D1–D20. D1 is a divide-by-7 divider; D2 is a divide-by-9 divider; D3 is a divide-by-5 divider; D4, D5, D6, D7, D11, D12, D14, D15, D18 and D20 are divide-by-2 dividers; D8 and D9 are divide-by-10 dividers; D10 is a divide-by-6 divider; D13 and D19 are divide-by-4 dividers; D16 is a divide-by-12 divider; D17 is a divide-by-3 divider.

T0 is connected to the count (c) input of D2 and T5 is connected to the count (C) input of D1 and D8. D1 through D7 are connected in series, Q output to C input i.e., the positive or Q output of each divider circuit is connected to the count or C input of the next divider in the series chain. Similarly, D9 through D12; D13 through D15; D8 and D16 through D18; and, D19 and D20 are each connected output (Q) to input (C) in a series chain. Further, the Q output of D1 is connected to the C input of D9; the Q output of D2 is connected to the C input of D13; and, the Q output of D9 is connected to the C input of D19.

The input of MV1 is connected to the Q output of D7. The output of MV1 is connected to the reset (R) inputs of all of the dividers, D1–D20.

The Q output of D7 is connected to an output terminal designated f_1 and the Q output of D6 is connected to an output terminal designated f_2. The Q output of D12 is connected to an output terminal designated f_3 and Q output of D5 is connected to an output terminal designated f_4. The Q output of D15 is connected to an output terminal designated f_5, the Q output of D11 is connected to an output terminal designated f_6; and, the Q output of D18 is connected to an output terminal designated f_7. The Q output of D4 is connected to an output terminal designated f_8 and the Q output of D20 is connected to an output terminal designated f_9. Finally, the Q output of D14 is connected to an output terminal designated f_{10}.

It will be appreciated from viewing FIG. 1 and the previous description that all of the divider network outputs, f_1–f_{10} are interrelated to f_1 in the manner designated by their subscripts. That is, f_2 is twice f_1; f_3 is three times f_1, etc. Thus, the output signals, f_1–f_{10}, are all square waves which are harmonically interrelated.

MV1 is triggered at the fundamental square wave frequency f_1, and thus, clears all of the dividers to effect synchronization of the square wave outputs. Thus, synchronization as well as a harmonic interrelationship is provided. The various divide-by-2 dividers are required in order to obtain symmetrical square waves from the outputs of the other dividers which produce unsymmetrical square waves.

The summation circuit 15 comprises: an operational amplifier designated OA1; a feedback resistor designated R1 and a grounding resistor designated R2. OA1 has inverting and non-inverting inputs and its output is connected through R1 to its inverting input. The non-inverting input is connected through R2 to ground. In addition, the non-inverting input is connected to an input terminal designated T5 and the inverting input is connected to an input terminal designated T6. The input terminals, T5 and T6, as hereinafter described, are connected through the attenuating network 17 to selected terminals of the output terminals, f_1–f_{10}, connected to various divider outputs of the divider network 13. The output of OA1 is connected to a signal output terminal designated T7.

The attenuation network 17 is illustrated as comprising eight attenuation resistors designated R3–R10, each of which has a value which depends upon the amount of attenuation needed to attenuate the related square wave. Thus, each value may be different. R3 is connected between f_1 and T6; and R4 is connected between f_2 and T6. R5, R6, R7, R8, R9, and R10 are connected between f_3, f_5, f_6, f_7, f_9, and f_{10}, respectively, and T5.

It will be understood by those skilled in the art and others from the foregoing description and viewing FIG. 1 that the summation of the synchronized, harmonically related square waves is accomplished by connecting the selected divider network outputs to the inverting or non-inverting inputs of an operational amplifier. In accordance therewith, the operational amplifier sums the signals it receives in an additive and subtractive manner. The voltage levels of the selected square waves are controlled by the values assigned to the resistors forming the attenuation network 17. Unselected square waves, such as f_4 and f_8 in the illustrated embodiment, are merely left unconnected.

T7 is connected to a voltage controlled source follower amplifier 19 through a low pass filter circuit 21. The low pass filter circuit 21 comprises three resistors designated R11, R12, and R13; and two capacitors designated C2 and C3. The voltage controlled source follower amplifier comprises two field effect transisitors designated FET2 and FET3; and, a resistor designated R14.

T7 is connected through R11, R12, and R13 connected in series to ground. The C2 is connected between the junction between R11 and R12, and ground. C3 is connected between the junction between R12 and R13, and ground. The junction between R12 and R13 is also connected to the gate of FET2. The source/drain terminals of FET2 and FET3, and R14 are connected in series between a voltage source designated V2 and ground. The junction between the drain terminal of FET 2 and R14 is also connected to an output terminal designated T8. The gate of FET 3 is connected to the output of a keying envelope shaper circuit 23. Since keying envelope shaper circuits are well

known in the art, and do not form part of this invention, the keying envelope shaper illustrated in FIG. 1 is not described herein in detail. However, as will be understood by those skilled in the art, keying envelope shaper circuits are used to control the attack and decay characteristics of musical tones.

The low pass filter network and the voltage control source follower amplifier control the level of the output of the operational amplifier, OA1, and the level of any higher order sine wave components included in the resultant complex wave (musical instrument tone). The control voltage applied by the keying envelope shaper circuit 23 to FET3 controls the voltage level at the output terminal, T8. Specifically, the signal applied to FET3 by the keying envelope shaper circuit 23 is a control voltage which acts to control the level of the output voltage at T8. This output voltage is, of course, related in shape to the output of OA1 as modified by the low pass filter 21.

It will be appreciated by those skilled in the art and others that other forms of filter networks and voltage controlled amplifiers can be used by the invention. All that is required is the provision of a suitable filter network to adjust the level of or eliminate high frequency components, in combination with a suitable amplifying circuit. It should also be noted that the attenuator network 17 can also take on a variety of other forms. In some cases, for example, it may be desirable to include the attenuation network within the large scale integrated circuit whereby a predetermined tone synthesizer is provided, as opposed to a generalized circuit modifiable by an attenuator network to provide a desired tone. If such is the case, as will be understood by those skilled in the art and others, it is more desirable to use internal field effect transistors, rather than internal resistors, to provide attenuation, because in this manner the beneficial effects transistor attenuation circuits will be realized.

The control voltage applied to the gate of FET3 by the keying envelope shaper circuit 23 is derived from a suitable voltage source designated V3. V3 is connected through a key switch designated S2 (single pole-single throw) to the input of the keying envelope shaper circuit 23. When the key switch is closed, the keying envelope shaper circuit receives a suitable voltage. This voltage is utilized to control the operation of FET3. In addition, in some situations, it may be desirable to turn the driving oscillator 11 on and off, in order to create special effects. For example, it may be desirable to vary the frequency of the oscillator in accordance with a predetermined pattern. This effect is provided by connecting the keying envelope terminal to the other remote terminal of S1 and switching the gate of FET1 from the moveable terminal of P1 to this output of the keying envelope shaper circuit. The varying voltage from the keying envelope shaper circuit 23 then controls the operation of FET1.

In addition to the foregoing aspects, a vibrato oscillator can be combined with the invention to provide a vibrato capability. Since vibrato oscillators are well known in the art, and since the particular form thereof does not form a part of this invention, a specific vibrato oscillator is not described herein. The vibrato oscillator 25 is connected to the gate of FET1. As will be understood by those skilled in the art and others, the vibrato oscillator 25 provdes a slowly varying voltage. This voltage modifies the operation of FET1 and thus oscillator 11 to affect the output waveform in a vibrato manner.

It will be appreciated from the foregoing description that the apparatus of the invention comprises a square wave oscillator which drives a divider network which, incidently, may be composed of a plurality of flip-flops. The divider network is organized and arrayed in a manner such that square waves which are synchronized with, and harmonically related to, a fundamental frequency are generated. Selected ones of the thusly generated square waves are selectively attenuated. The square waves resulting from the selection and attenuation are combined together in a positive or negative manner to generate a resultant waveform. The resultant waveform relates to the waveform of a desired musical instrument voice. If desired, high frequency components can be reduced in voltage leveel or entirely eliminated by passing the resultant waveform through an uncomplicated low pass filter.

It will be appreciated by those skilled in the art and others that the third C above middle C of the musical scale is the top key of an organ. For the configuration illustrated in FIG. 1 the signal necessary to create that tone of the scale requires that the oscillator frequency be in the order of 10 megahertz. Such a signal is well within the state of the digital oscillator art. On the other hand, in organ design, certain ranks of tone generators are required to respond at a fundamental frequency one, two or three octaves higher than the normal pitch associated with the playing key. Thus tone generators which have fundamental pitches higher than normally associated with the third C above middle C would require higher driving frequencies. However, in this range, musical voices have fewer distinguishing features and the higher harmonic sine wave components become progressively more inaudible to the human ear so fewer square wave harmonics are required to synthesize higher pitch voices. Terminal T0, which is connected to the count (C) input of divider D2, provides the necessary means to reduce the oscillator driving frequency by a factor of 7. Thus if it becomes desirable to limit the frequency of the driving oscillator, for the voices of higher pitch, terminal T3 can be connected to terminal T0 instead of terminal T5. This change has the effect of eliminating only the f_7 output and reducing the oscillator frequency by a factor of 7. Since f_7 is substantially above the normal audible frequency range for the conditions described, its elimination has little or no effect on the resultant sound. Hence, no problem exists with respect to the production of square waves at the desired frequency.

It should be noted that the invention overcomes many of the difficulties of prior art systems noted above. For example, heretofor, in instruments with individual tone generators for each note of the musical scale, the size of the components which determined the frequency of the tone generators have occupied considerable volume. Such is not the case with the instant invention, particularly in view of the fact that it can be produced using state of the art large scale integrated circuit techniques. Moreover, the invention, per se, reduces complexity because of its design. For example, the frequency of the oscillator controlling the musical tone of the instant invention, illustrated in FIG. 1, is in the range of 80,000 hertz for the lowest tone on the musical scale; thus, the size of the frequency determining elements occupy an insignificant volume.

It should also be noted that the embodiment of the invention illustrated in FIG. 1 actually only produces the first through the fifth harmonic square waves. The sixth through the tenth harmonic square waves are obtained from the divider chains creating the first through the fifth harmonics i.e. they are not separately generated. Thus, the overall complexity of the system is substantially less than it would be if it were necessary to separately generate all of the harmonic square waves desired.

FIG. 2 illustrates an alternate embodiment of the invention wherein only the first through the eighth harmonic square waves are created, as opposed to the first through the tenth (FIG. 1). However, rather than single phase state square waves being created, both complementary phase states of the square waves are created.

The embodiment of the invention illustrated in FIG. 2 comprises an oscillator **51** and a divider network **53** both formed as part of a large scale integrated circuit. The oscillator **51** is identical to the oscillator **11** illustrated in FIG. 1 in that it comprises three NAND gates designated NAND4, NAND5, and NAND6; a field effect transistor designated FET4; and, an external frequency determining capacitor designated C4. The output of NAND5 is connected to both inputs of NAND6. C4 is connected between a pair of external terminals designated T9 and T10, T9 being connected to the output of NAND4 and T10 being connected to the inputs of NAND5. The source/drain terminals of FET4 are connected across the inputs and the output of NAND5. The output of NAND5 is also connected to the inputs of NAND6. The gate FET4 is connected to the moveable element of a potentiometer designated P2 via an external terminal designated T11. P2 is connected between a suitable voltage source designated V4 and ground. The output of a vibrato oscillator **55**, similar to the vibrato oscillator **25** illustrated in FIG. 1, and described with respect thereto, is also connected to the gate of FET4 via T11.

The divider network **53** comprises 16 divider circuits designated D21–D36; and, a monostable multivibrator designated MV2. D21 is a divide-by-7 divider; D22 is a divide-by-5 divider; and, D23 is a divide-by-3 divider. D24, D25, D26, D27, D29, D30, D32, D33, and D36 are divide-by-2 dividers. D28 is a divide-by-4 divider; and D31 and D34 are divide-by-12 dividers. D35 is a divide-by-10 divider.

The output of NAND6 is connected to the count (C) inputs of D21 and D34. D21 through D27 are connected in a series chain Q output to C input, in their indicated numerical order. Similarily, D28–D30; D31–D33; and, D34–D36 are connected in individual serial divider chains Q output to C input. Further, the Q output of D21 is connected to the C input of D31 and the Q output of D22 is connected to the C input of D28. The Q output of D27 is connected to the trigger input of the MV2; and, the Q output of MV2 is connected to the reset (R) inputs of all 16 of the divider circuits D21–D36.

The Q output of D27 is connected to an output terminal designated f_1' and, the $\overline{Q}$ output of D27 is connected to an output terminal designated $\overline{f_1'}$. The Q output of D26 is connected to an output terminal designated f_2'; and, the $\overline{Q}$ output of D26 is connected to an output terminal designated $\overline{f_2'}$. The Q and $\overline{Q}$ outputs of D30 are connected to output terminals designated f_3' and $\overline{f_3'}$, respectively. The Q and $\overline{Q}$ outputs of D25 are connected to output terminals designated f_4' and $\overline{f_4'}$, respectively.

The Q output of D33 is connected to an output terminal designated f_5'; and, the $\overline{Q}$ output of D33 is connected to an output terminal designated $\overline{f_5'}$. The Q and $\overline{Q}$ outputs of D29 are connected to output terminals designated f_6' and $\overline{f_6'}$, respectively. The Q and $\overline{Q}$ outputs of D36 are connected to output terminals designated f_7' and $\overline{f_7'}$, respectively. The Q output of D24 is connected to an output terminal designated f_8'; and, the $\overline{Q}$ output of D24 is connected to an output terminal designated $\overline{f_8'}$.

It will be appreciated from the foregoing description of the nature of the oscillator **51** and the divider network **53** that the signals at the output terminals f_1'–f_8' and $\overline{f_1'}$–$\overline{f_8'}$ are opposite phase state square waves that are synchronized and harmonically related. These square wave signals are attenuated and combined by an attenuation and combining circuit **61**.

The attenuation and combining circuit **61** comprises seven resistors designated R15–R21. One end of R15 is connected to f_1'; one end of R16 is connected to f_2'; one end of R17 is connected to f_3'; one end of R18 is connected to f_4'; one end of R19 is connected to $\overline{f_5'}$; one end of R20 is connected to $\overline{f_7'}$; and, one end of R21 is connected to f_8'. The other ends of R15–R21 are all connected to the inverting input of an operational amplifier, designated OA2 and forming part of an amplification and filter circuit **63**.

The amplification and filter circuit **63** also comprises: three resistors designated R22, R23 and R24; and two capacitors designated C5 and C6. The non-inverting input of OA2 is connected to ground. R22 and C5 are connected in parallel, with one another, between the output and the inverting input of OA2. The output of OA2 is also connected through R23 in series with C6 to ground. R24 is connected in parallel with C6. The junction between R23 and R24 is also connected to the input of a voltage controlled amplifier **67**.

The output of the voltage controlled amplifier **67** is connected to an output terminal designated T12. The voltage controlled amplifier **67** is under the control of a keying envelope shaper circuit **69**. More specifically, the keying envelope shaper circuit **69** is connected through a switch designated **53** (single pole-single throw) to a voltage source designated V5. When S3 is closed, the keying envelope shaper circuit **69** creates a control voltage which controls the operation of the voltage controlled amplifier **67**.

Turning now to a description of the operation of the embodiment of the invention illustrated in FIG. 2; in general, the FIG. 2 embodiment of the invention is a system wherein a plurality of divider circuits generate synchronized, harmonically related square waves to the eighth harmonic. Components of both phase states of the square waves are produced. Selected ones of the produced components are attenuated and combined, and high frequency components (above f_8) are adjusted or eliminated by an uncomplicated low pass filter. More specifically, FIG. 2 illustrates a multiplicity of flip-flop dividers in integrated circuit form connected together to create harmonically related square waves. Once each fundamental frequency cycle MV2 is triggered and clears all of the dividers, D21–D36, to provide synchronization. Thus, the generated signals are synchronized, harmonically related square waves. Selected ones of these signals are attenuated and combined by the attenuation and combining circuit **61**. In

the illustrated case f_1', f_2', f_3', f_4', $\overline{f_5'}$, $\overline{f_7'}$, and f_8', are chosen. These signals are attenuated by **R15–R21,** respectively. The resistance values of **R15–R21** are chosen such that the summation of the square waves produces the desired waveform. In this regard attention is directed to Table I and II, and their related description set forth above.

The sum signal is applied to the inverting (negative) input of the operational amplifier which operates in an add mode, as determined by the value of **R22.** Undesired components are unselected and, thus not applied in any manner to the operational amplifier. **C5** controls the voltage level of any higher order sine wave components contained in the resulting complex wave. Thus, **C5** tends to control or eliminate undesired harmonic components. The filter network formed by **R23, R24,** and **C6** controls the overall level of the output of the operational amplifier. In addition, this filter network provides additional control of the higher order components contained in the complex wave applied to the voltage controlled amplifier **67.**

V5 when connected to the keying envelope shaper circuit **69** via the key switch **S3** provides control of the attack and decay characteristics of the musical instrument voice generated at the output terminal **T12.** Vibrato, if desired, is provided by the vibrato oscillator **55.**

It will be appreciated from the foregoing description that the invention provides an uncomplicated method of and apparatus for producing musical tones of the type produced by musical instruments. The method of the invention merely comprises the steps of: generating a driving signal at a predetermined frequency dividing the signal into a plurality of interrelated harmonic components; and, attenuating and combining the components in a predetermined manner such that the waveform of the desired musical tone is created. The apparatus of the invention is equally uncomplicated. Specifically, the apparatus of the invention basically comprises: an oscillator; a divider circuit; and an attenuator and combiner circuit. The oscillator drives the divider, and the divider creates a plurality of harmonically related square waves. The square waves may include components of only one phase state or components of both phase states. In any event, chosen ones of the square waves are attenuated and combined in a predetermined manner to create a complex waveform signal. The complex waveform signal is applied to a voltage controlled amplifier whose output is controlled by a keying envelope shaper circuit. Higher harmonic components are controlled by an uncomplicated low pass filter network. If desired, vibrato can be provided by a vibrato oscillator.

Because the apparatus of the invention directly generates desired musical tones, the need for complicated filter circuits is eliminated. In addition, because the invention can be produced in integrated circuit form, it is relatively small in size and inexpensive to manufacture. Thus, it is readily suitable for mounting in an organ console or the like without taking up an undesired amount of room. Moreover, because it can be produced inexpensively in large quantities, it overcomes the cost disadvantages of prior art devices designed to produce similar results.

While preferred embodiments of the invention have been illustrated and described, it will be appreciated by those skilled in the art and others that various changes can be made therein without departing from the spirit and scope of the invention. Specifically, only two of many possible embodiments of the invention have been illustrated and described. Thus, the illustrated embodiments should not be construed as limiting the invention. Other forms and combinations of oscillators, divider networks, and attenuation and combining circuits, depending upon the resultant application, can be assembled in accordance with the principles of this invention. Moreover, the total amount of circuitry included in the integrated circuit, should one be used, may vary. For example, as briefly alluded to above, if desired, the attenuation and summation network can be included in the integrated circuit. The large number of voices of a pipe organ, as well as the voices of other types of musical instruments, can be produced by the invention. While the invention is particularly concerned with the harmonic structure of such voices, it includes circuitry for controlling the attack and decay characteristics of the voices as well. Hence, the invention can be practiced otherwise than as specifically described herein.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. Apparatus for electronically synthesizing waveforms of the type produced by musical instruments comprising:

a square wave oscillator for generating a signal at a frequency integrally related to a fundamental frequency f_1;

vibrato control means connected to said oscillator for controlling the output thereof such that said output is slowly varied;

resettable divider means connected to the output of said square wave oscillator for dividing the output of said square wave oscillator into a plurality of synchronized, harmonically related square waves, said synchronized, harmonically related square waves including said fundamental frequency f_1 and all integrally related frequencies up to a maximum integrally related frequency, said maximum integrally related frequency being at least eight times said fundamental frequency f_1, said resettable divider means being resettable to a predetermined initial state upon the receipt of a reset pulse;

synchronizing means connected to said dividing means for receiving said square wave at said fundamental frequency f_1 and for generating a reset pulse each time said fundamental frequency square wave is received, and applying said reset pulse to said resettable divider means in a manner such that said resettable divider means is reset;

attenuation means connected to said resettable divider means for receiving selected ones of said plurality of synchronized, harmonically related square waves and attenuating said selected ones of said plurality of synchronized, harmonically related square waves in a predetermined manner; and,

summation means connected to said attenuation means for summing said attenuated, synchronized, harmonically related square waves and producing, in accordance therewith, an electrical signal having a waveform of the type produced by a musical instrument.

2. Apparatus for electronically synthesizing waveforms of the type produced by musical instruments as claimed in claim **1** wherein said resettable divider means comprises a plurality of digital divider circuits

connected in predetermined chains, said chains being formed such that the digital divider circuits of said chains, whose outputs create said plurality of said synchronized, harmonically related square waves, are divide-by-2 digital divider circuits.

3. Apparatus for electronically synthesizing waveforms of the type produced by musical instruments as claimed in claim **2** wherein said attenuation means comprises a plurality of resistors having values related to the desired amount of attenuation to be given to the signal passing through a predetermined resistor of said plurality of resistors forming said attenuation network, one end of said resistors being connected to selected outputs of said digital divider circuits and the other end being connected to selected inputs of said summation means.

4. Apparatus for electronically synthesizing waveforms of the type produced by musical instruments as claimed in claim **3** wherein said summation means comprises an operational amplifier.

5. Apparatus for electronically synthesizing waveforms of the type produced by musical instruments as claimed in claim **4** including a low-pass filter connected to the output of said operational amplifier to remove or reduce the voltage level of sine wave frequency components having frequencies above said maximum integrally related frequency of said plurality of synchronized, harmonically related square waves.

6. Apparatus for electronically synthesizing waveforms of the type produced by musical instruments as claimed in claim **2** wherein said resettable divider means divides the output of said square wave oscillator into the complements of said plurality of synchronized, harmonically related square waves as well as said plurality of synchronized, harmonically related square waves.

7. Apparatus for electronically synthesizing waveforms of the type produced by musical instruments as claimed in claim **1** wherein said vibrato control means comprises a vibrato oscillator and a field effect transistor, the output of said vibrato oscillator being connected to the gate of said field effect transistor, the source and drain terminals of said field effect transistor being connected to said square wave oscillator so as to control the output thereof.

8. Apparatus for electronically synthesizing waveforms of the type produced by musical instruments as claimed in claim **7** wherein said square wave oscillator comprises first and second digital logic gates and a capacitor, the output of said first digital logic gate being connected to all the inputs of said second digital logic gate, the output of said second digital logic gate being connected through said capacitor to all of the inputs of said first digital logic gate, the source and drain terminals of said field effect transistor of said vibrato control circuit being connected between the output and all of the inputs of one of said digital logic gates.

9. Apparatus for electronically synthesizing waveforms of the type produced by musical instruments as claimed in claim **1** wherein said resettable divider means divides the output of said square wave oscillator into the complements of said plurality of synchronized, harmonically related square waves as well as said plurality of synchronized, harmonically related square waves.

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