

[54] **DIGITAL TONE GENERATOR SYSTEM
FOR ELECTRONIC ORGAN
EMPLOYING A SINGLE MASTER
OSCILLATOR**

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[52] U.S. Cl. **84/1.01, 84/1.04, 84/1.11,
84/1.19, 84/1.22, 84/1.24**
[51] Int. Cl. **G10h 1/00**
[58] Field of Search.....84/1.01, 1.03, 1.11, 1.17,
84/1.25, DIG. 11, 1.19; 307/225, 226;
331/51, 53

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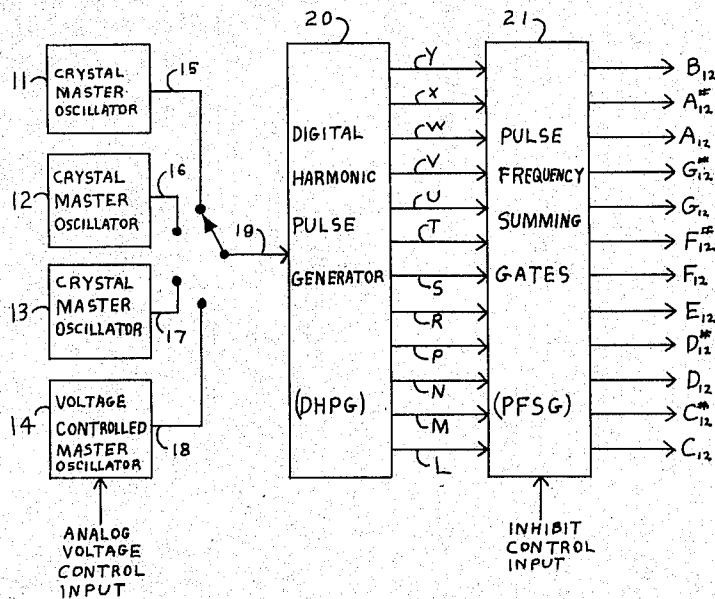
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Assistant Examiner—U. Weldon

[57] **ABSTRACT**
For use in electronic organs and the like, an electronic
circuit for generating a number of signals, the frequen-
cies of which may correspond to the notes of the musi-
cal scale, comprises a single master oscillator produc-
ing an alternating signal coupled to a harmonic pulse
frequency generator producing a number of harmoni-
cally related pulse frequency outputs which are selec-
tively connected to summing means, each summing
means producing a single output frequency which cor-
responds to a note of a musical scale. Twelve summing
means may be connected selectively to produce the
twelve notes of a musical scale.

6 Claims, 7 Drawing Figures



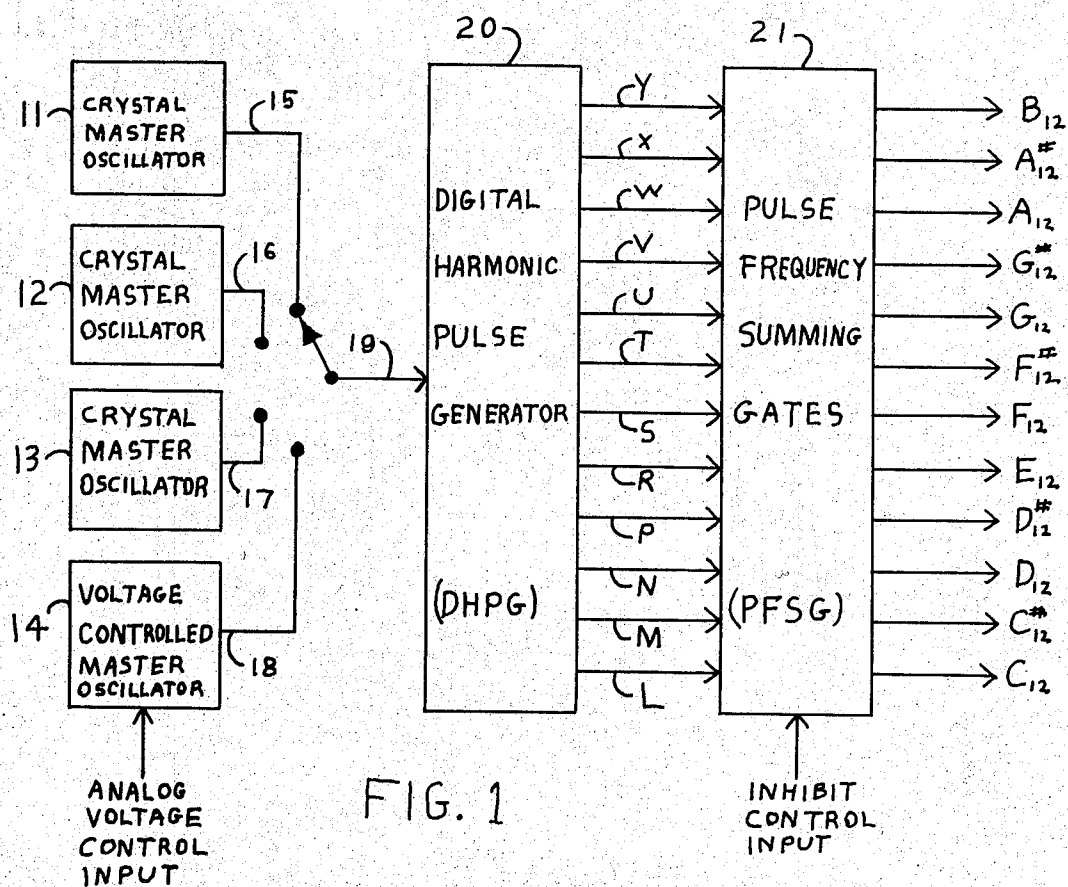


FIG. 1

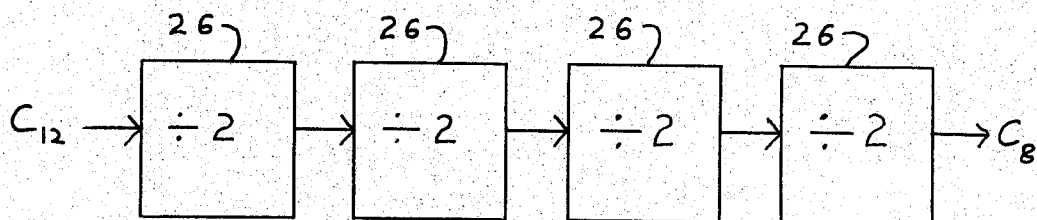


FIG. 7

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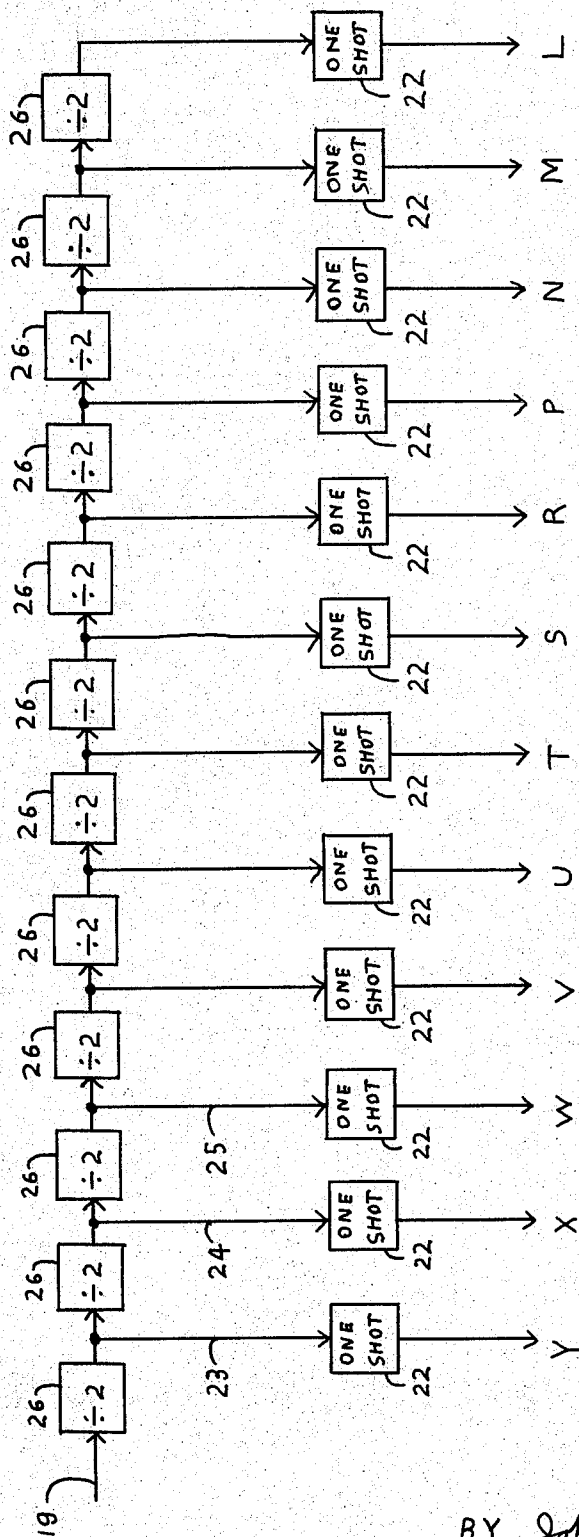


FIG. 2

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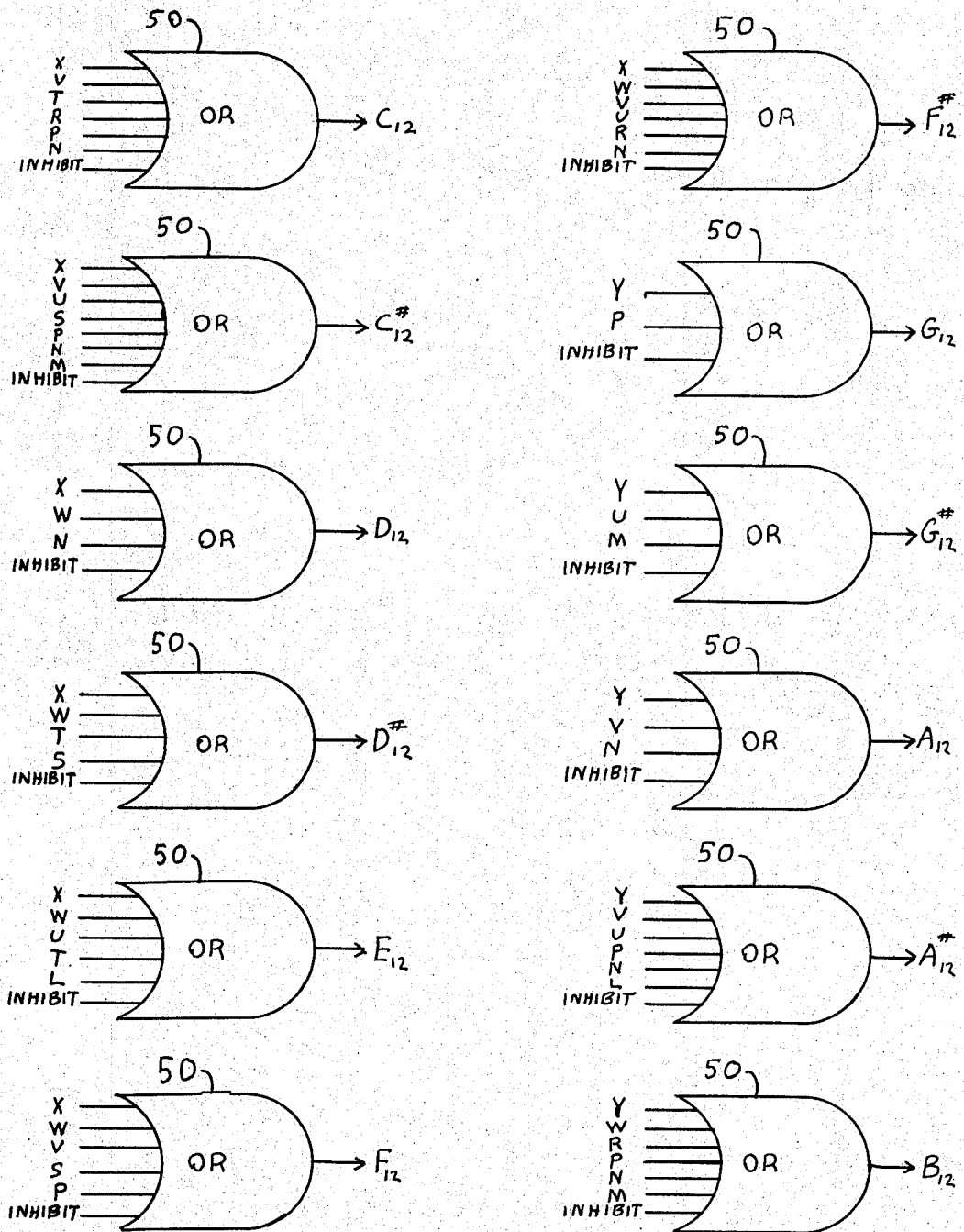


FIG. 3

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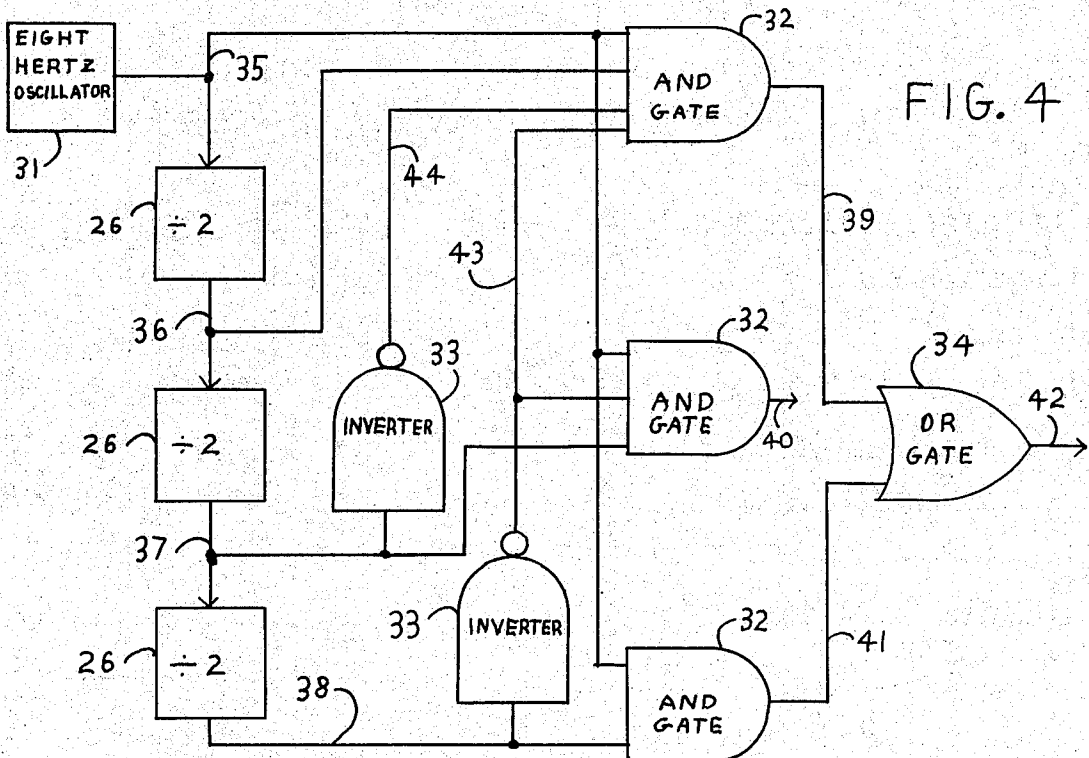
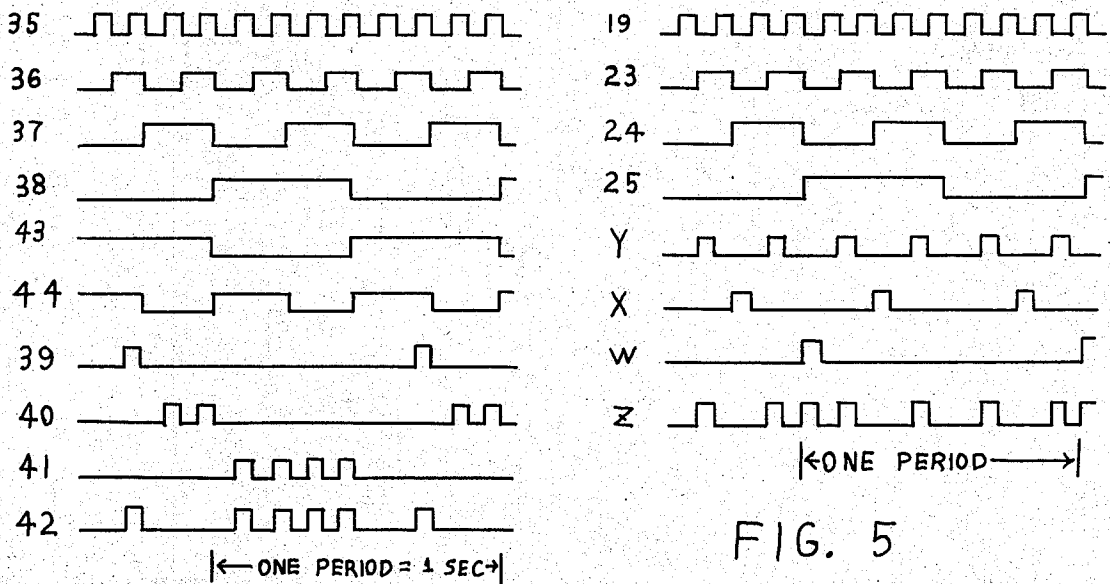


FIG. 6

FIG. 5

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DIGITAL TONE GENERATOR SYSTEM FOR ELECTRONIC ORGAN EMPLOYING A SINGLE MASTER OSCILLATOR

The present invention relates generally to electronic organs and more particularly to the production of the supersonic or high frequency signals corresponding to the twelve notes of the musical scale used in some electronic organ systems.

In the usual tone generator of an electronic organ, an array of 12 master oscillators is provided which operate at high audio or supersonic frequencies. These oscillators each drive a chain of octave dividers producing the octaves of the notes. In accordance with the present invention on the other hand, only one master oscillator is required. This oscillator is coupled to a digital harmonic pulse generator (DHPG) that produces a multiplicity of harmonics of the master oscillator. The harmonics produced are fixed by the organ designer and may be chosen for convenience of design as well as economy. The various harmonics produced in a DHPG are selectively summed in a digital or gate pulse summing scheme to produce the 12 frequencies of the notes of a musical scale, the octave of which is chosen by the designer but is usually a high octave in the upper range of human hearing ability. It may actually be higher than the range of human hearing and usually is. Each of these note frequencies is connected to a conventional octave divider chain producing the lower octaves of each note. Thus, the whole gamut of note frequencies may be produced.

The whole system is digital in nature and hence, is well defined. As the science of large scale integration in packaging circuits advances, it will soon be possible to package the entire integrated circuit into a single chip with a multiplicity of leads connecting to the mechanical parts of the organ. So the entire digital electronic circuit may be packaged into an integrated circuit allowing great economy in building electronic music instruments. This invention of the present application also improves the tuning stability of the organ since only one oscillator is required with all other frequencies being digitally related to the one master oscillator.

In accordance with the invention, a master oscillator is provided with a frequency (F_0) several times higher than the highest note played on the organ. F_0 depends on several factors, namely; F_0 is chosen to minimize the required structure of the pulse summing gates, F_0 must be in the range of the oscillator capability, F_0 must be chosen high enough above the highest note on the organ so that the unwanted harmonic content (phase jitter) of this note is minimized to an acceptable level, and other factors, all of which become more apparent after consideration of the detailed description of one embodiment of this invention.

In further accordance with the invention, a digital harmonic pulse generator (DHPG) is provided to produce the pulse frequencies. In the present invention, the DHPG produces 12 frequencies. This is pure coincidence with the fact that there are 12 notes in the musical scale, but any other quantity of pulse frequencies could be chosen. There is an optimum quantity that is a trade off between economy and precision of frequency of the musical notes that are produced in this organ tone generator system. The more pulse frequencies produced by the DHPG, the more precise will be the musical notes and also the more expensive will be

the organ as will become apparent after the invention is completely described. Also, the pulse widths produced by the DHPG are very narrow. The pulse width is chosen to be equal to about one-half the period of the frequency that results from the arithmetic sum of the values of all the frequency outputs of the DHPG. The description of the pulse frequency summing gates should make this clear.

In further accordance with the invention, the pulse frequency summing gates (PFSG) are provided to selectively sum the outputs of the DHPG. The PFSG performs an arithmetic addition of the DHPG outputs similar to the following simplified example. If we have a DHPG to which has been connected an oscillator at a frequency of 8 hertz and further, the DHPG is binary so that it produces the harmonic pulse frequencies of 4 hertz, 2 hertz, and 1 hertz; then we may obtain the frequency of 5 hertz by using a digital "or" gate to add the two DHPG outputs of 1 and 4 hertz. In fact, we may obtain any of the frequencies 1, 2, 3, 4, 5, 6, or 7 hertz in this way. Note that 7 hertz is 1 hertz less than the oscillator frequency of 8 hertz. One hertz is equal to the least significant bit of the DHPG where each of the output frequencies of the DHPG are referred to as bits. It can be seen that the choice of the DHPG output pulse width of one-fourteenth second is optimum because this provides an approximately 50 percent duty factor at the PFSG output for 7 hertz which further assures that no DHPG output pulses occur at the same instant of time which would cancel pulses, thereby causing frequency errors. For the case where the tone generator system operates from the output of a voltage controlled oscillator the pulse width mentioned above should be selected after considering the highest frequency output of the voltage controlled oscillator. In order that this invention produce the 12 frequencies of the notes of the scale, it is necessary that the DHPG have more than three bits. The actual quantity is dependent on the frequency of the master oscillator, the type of coding or harmonic relationship of the outputs of the DHPG, and the precision of the musical note frequencies produced. This is again a cost vs precision trade off. The type of coding mentioned above is concerned with the digital coding schemes used in any conventional digital systems design. Any type coding may be employed but after design considerations it will be found that certain coding schemes are better than others affording more precision at less cost. Some examples of coding that may be used are 8421 binary, coded decimal, 5411, 5211, 1111, etc. In the embodiment of the invention presented here the coding used is 8421 binary which is easily generated from a digital binary counter. The invention in final form will contain a minimum of 12 pulse frequency summing gates if it is desired to have the capability of producing all the notes of the musical scale. However, it may be desirable to include more or less for special effects. The output pulse frequency from a summing gate is not very musical in quality since it contains many undesirable harmonics. These harmonics may be reduced by dividing the frequency through octave dividers of digital flip flops. The larger division ratio produces a greater reduction of the undesirable harmonics, since these harmonics are in the form of phase jitter and very narrow pulses in the conventional sense. These effects are divided at the

same ratio as frequency is divided in flip flops and octave divider systems. In view of this effect it may be desirable to increase the frequency of the master oscillator to compensate for a number of stages of division if employed before making available the highest octave outputs from the conventional octave dividers. The lower octaves are further divided in frequency and hence will contain an even smaller percentage of unwanted harmonics. This organ system employs 12 chains of octave dividers in one application, one for each note of musical scale. Essentially the invention is intended to replace the 12 master oscillators usually connected to the octave dividers found in conventional organ designs. The number of stages in the octave divider chain depends on the overall range that the organ is to have. The gamut of notes of the organ are found at the outputs of these octave dividers in the conventional way. These outputs may be connected to conventional or unconventional waveshaping and harmonic operational circuits to produce the various stops of a conventional organ.

It is accordingly a broad object of the invention to provide novel tone generators of electronic organs that are polyphonic in operation.

It is another object of the invention to provide a complete organ tone generation system that has as its reference requirement, although not limited to, one master oscillator and that is capable of generating the 12 supersonic note frequencies that are usually produced by a set of 12 master oscillators in most conventional systems.

It is another object of the invention to provide a vibrato effect with heretofore unattainable wide frequency modulation range of many octaves by voltage control of the master oscillator when a voltage controlled oscillator is employed instead of a crystal controlled oscillator.

It is a further object of the invention to provide switch selectable instrument key selection. Organs and pianos usually are tuned in the key of C. But with this invention by providing more crystal oscillators selected by switch or some other variable oscillator reference, the organ may be tuned to any other musical key quite easily without the necessary tuning job that would otherwise be required.

It is a further object of the invention to provide an electronic organ that may be easily tuned to any other musical instrument instead of requiring that all instruments be tuned to the organ. This may easily be done by just turning a knob that controls the potential applied to the control terminal of a voltage controlled master oscillator.

It is a further object of the invention to provide for easily and selecting tuning the organ to other temperaments such as the just, mean, or pythagorean scales. This embodiment of the invention is mainly shown in this patent application adjusted for the equal temperament scale, however.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a block diagram of a system for generating the 12 high audio or supersonic frequencies corresponding to the notes of the musical scale.

FIG. 2 is a digital harmonic pulse generator (DHPG) providing 12 harmonically related pulse frequencies, in the system of FIG. 1.

FIG. 3 is a group of 12 pulse frequency summing gates for producing the 12 high audio or supersonic musical note frequencies when connected to the outputs of the DHPG of FIG. 2, in the system of FIG. 1.

FIG. 4 is a simplified alternate construction of a digital harmonic pulse generator (DHPG) coupled to a pulse frequency summing gate (PFSG) that were shown in FIGS. 2 and 3.

FIG. 5 is a timing diagram showing the timing sequences of some of the signals in the circuit of FIG. 2.

FIG. 6 is a timing diagram showing the timing sequences of signals present in the simplified example of FIG. 4.

FIG. 7 is an optional 4 octave divider that may be employed to improve the purity of the supersonic note frequency outputs of the pulse frequency summing gates (PFSG).

Referring now to the accompanying drawings, in FIG. 1, the blocks 11, 12, 13, and 14 are all oscillators producing squarewave outputs 15, 16, 17, and 18 compatible with the driving requirements of the type of digital logic circuits employed in this embodiment of the present invention. In all examples of the present invention the logic used is transistor-transistor logic (TTL) integrated circuits. This is not a limitation since any form of logic circuits may be employed in the design of the invention. In conventional TTL circuits the following definitions prevail. A logic 1 is true and a voltage level of approximately plus 5 volts, whereas a logic 0 is false and is a voltage level of approximately ground potential. A plus edge is a logic transition from 0 volts to plus 5 volts, whereas a minus edge is a logic transition from plus 5 to 0 volts. A plus pulse is comprised of a plus edge followed after a time interval (pulse width) by a minus edge back to ground potential, whereas a negative pulse is comprised of a minus edge followed after a time interval by a plus edge back to plus 5 volts level.

The four oscillators are shown switch selectable to allow the organ to be tuned to a different musical key simply by changing a selector switch. In actual application there may be as many oscillators as the builder desires but there must be at least one oscillator since this is the reference to which all musical notes produced by the invention are referenced. So, with the proper oscillator frequencies chosen, three different musical keys would be allowed by the oscillators 11, 12, and 13. For the purpose of all examples of the invention herein, the oscillator frequency of 199884.8 hertz will cause the organ to be tuned to the key of C. If this oscillator frequency is multiplied by the twelfth root of two and this new frequency is assigned to the second oscillator, then by changing the selector switch to connect oscillator 12 will cause the instrument to be tuned to the key of C-sharp. The oscillator 14 is a voltage controlled oscillator allowing special frequency modulation effects of the organ such as vibrato, allowing a vibrato range of many octaves heretofore not possible with other organ tone generator systems. In

fact by playing a chord on the organ and then varying the potential on the control input of the voltage controlled oscillator 14 in a selective way music comprising chord progressions may be produced. Also, manual control of the instrument key is allowed by turning a potentiometer that adjusts the voltage input to the oscillator 14. Also, a lever or pedal may be attached to cause the variable tuning. And also, the voltage controlled oscillator 14 input allows the key of the organ to be externally programmed by a computer or function generator that produces sinewaves, squarewaves, ramp or triangular waves, and any combination of these to produce any type of complex waveform that is desired by the builder. An exceedingly large number of special effects is possible with this feature.

The digital harmonic pulse generator 20 has 19 as the input from a reference oscillator. The outputs L,M,N,P,R,S,T,U,V,W,X,Y are harmonically related to the reference oscillator. For this example of the invention the outputs are plus pulses that follow the binary progression whereby Y is one-half the oscillator frequency and X is one-fourth the oscillator frequency and so on until L is 1/4096 of the reference oscillator frequency. The digital harmonic pulse generator circuit may be any one of several types of devices without departing from the true spirit of the invention.

These pulse frequencies are then selectively summed by the pulse frequency summing gates 21, to produce the supersonic pulse train frequencies of the musical notes of the scale. These pulse train frequency outputs are inharmonic since they contain much phase jitter as well as being very narrow pulses. These outputs may be made more pure by dividing with digital flip flop circuits before allowing any outputs to reach the listener. The circuit of FIG. 7 may be used for this purpose and is optional as how many stages of division to employ. More stages of division will produce more purity of the outputs.

In FIG. 7 the input is C12, for example connected from C12 of FIG. 1. The divide by two circuits 26, are flip flops, four stages of which will produce C8 at the output. It may be desirable to increase the master oscillator frequency by a factor of 16 thereby raising the input to C16 following the nomenclature. The output of the circuit of FIG. 17 will then be C12, allowing the full musical range of the organ. These outputs may then be connected to conventional octave divider and harmonic processing tone circuits to provide the gamut of notes usually produced by electronic organs. The invention is polyphonic in operation so that any or all notes may be played at one time.

Referring now to FIG. 2, which is a detailed example of a digital harmonic pulse generator 20 in FIG. 1, we have an input 19 connected from a master oscillator. The 12 divide-by-twos 26 form a 12 bit binary counter. The flip flops 26 are minus edge triggered so that their outputs toggle with negative transitions of the inputs. The flip flop outputs drive monostable one shots that trigger on different edges from the flip flops namely the plus edges so that on plus transitions of the outputs of the flip flops there are pulses present at L,M,N,P,R,S,T,U,V,W,X, and Y. These are the pulse frequency outputs of the digital harmonic pulse generator.

A timing diagram showing the timing sequence of some of the signals present in the digital harmonic pulse generator of FIG. 2 is shown in FIG. 5. Notice that the transitions of 23, 24, and 25 occur during negative transitions of the clock input 19. Also note further that pulse trains W, X, and Y occur at plus edges of 25, 24, and 23, respectively. This must be arranged this way to assure that no two one shots are triggered at the same instant which would cause their outputs to occur in coincidence, thereby causing cancellation of some pulses being summed by the summing gates rendering frequency summing errors. The important thing is that no two pulses be allowed to occur at the same instant of time.

If a digital or gate has inputs connected to W and Y then with a master oscillator frequency of 8 hertz, a frequency of 5 hertz is present at the output of the or gate since the frequency of Y under these conditions is 4 hertz and W is 1 hertz. The pulse frequencies of W and Y are summed by the or gate. Z in FIG. 5 shows what the or gate output looks like in time sequence. Note that the pulses are not evenly spaced but exhibit a "phase jitter." Because of this effect musical notes produced directly from a system such as this are inharmonic, since many harmonics not correctly related to the fundamental are produced. However, this phase jitter may easily be reduced by dividing through flip flops and increasing the master oscillator frequency to compensate for the division ratio of several flip flops.

FIG. 3 shows a group of 12 pulse frequency summing gates 50 that may be employed in item 21, FIG. 1 to process the outputs of the DHPG to produce the high audio or supersonic frequencies corresponding to 12 notes within a single octave range for the organ. The operation of these or gates is identical to that of the or gate in the preceding paragraph except that more inputs are present. L,M,N,P,R,S,T,U,V,W,X, and Y are inputs to the gates from the DHPG of FIG. 2, the pulse frequencies of which are tabulated in table 1.

TABLE 1

F₀=780.8 frequencies in hertz

Y=390.4

X=195.2

W=97.6

V=48.8

U=24.4

T=12.2

S=6.1

R=3.05

P=1.525

N=.7625

M=.38125

L=.190625

The frequencies shown result if the master oscillator frequency E₀ is set equal to 780.8 hertz. These frequencies may be selectively summed in certain ways to produce the proper frequencies of the 12 notes of the equal tempered musical scale, approximated to an average accuracy of 0.0953125 hertz. Table 2 is a tabulation of the exact frequencies of the notes of the musical scale of equal temperament. The summing combinations are shown on the right side of the table. To obtain the note G for example we add Y and P as indicated by a 1 in the respective columns. The note will be approximated to an accuracy of plus 0.190625 hertz

or minus 0.0 hertz. The error will not be noticed by the listener. Accuracy and system cost may be reduced by reducing the number of frequencies generated by the DHPG. More accuracy may be obtained by increasing same.

TABLE 2

For $F_o = 780.8$ hertz, and all frequencies specified in hertz.

Note	Frequency	Combinationz
		YXWVUTSRPNML
C	261.63364	010101011100
C-sharp	277.19024	010110101110
D	293.67182	011000000100
D-sharp	311.13339	011001100000
E	329.63321	011011000001
F	349.23302	011100101000
F-sharp	369.99823	011110010100
G	391.99813	100000001000
G-sharp	415.30612	100010000010
A	440.00000	100100000100
A-sharp	466.16216	100110001101
B	493.87991	101000011110

These values of frequencies and combinations shown in Tables 1 and 2 were obtained from a computer program that minimized pulse frequency summing gate structure vs. F_o within a small range of F_o . It is obvious that a better computer program will generate more combinations for summing pulse frequencies at different F_o frequencies and that this does not depart from the scope and spirit of the present invention.

The inhibits inputs to the gates of FIG. 3 allow them to be inhibited by logic control signal while another gate or set of gates are enabled. In this case all gates producing C12 for example are coupled to the octave dividers and likewise the other eleven may be coupled to the outputs in the same manner. The feature allows special effects and changable temperaments at will. The inhibit input in FIG. 1 serves the same purpose and in fact, is the same where the inhibit inputs of each gate in a set of 12 are grouped to this input. A logical high level to this input will inhibit the operation of the PFSG in FIGS. 1 and 3. It is obvious that by computer program or other means a set of pulse frequency summing gates may be designed to produce the just, mean, or pathagorean temperament scales.

A simplified alternate system for producing one frequency of 5 hertz is shown in FIG. 4. In this example a gating scheme is employed instead of the analog monostable one shots to produce the pulses. The operation is similar to the previous example and is included for clarity as well as to demonstrate that there are a multiplicity of ways of building the present invention. The oscillator 31 output is an 8 hertz squarewave connected to a chain of three flip flop divide by two's 26. The inverters 33 invert the sense of the logic signals connected to them. The and gates 32 produce 1, 2, and 4 hertz from top to bottom respectively. the outputs 39 and 41 are summed in or gate 34 to produce the 5 hertz output 42. The and gate output 40 is not needed and hence, is not used to produce 5 hertz. A timing diagram for the signals present in FIG. 4 is shown in FIG. 6. Note that none of the pulses of 39, 40, and 41 occur at the same instant of time.

While I have described and illustrated one or two specific embodiments of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

An exact circuit diagram of a model of the invention along with a description is on file at the United States Patent Office and is disclosure document number 5076 filed May 14, 1971.

What I claim is:

1. A tone generating system for an electronic organ comprising a master oscillator means producing a squarewave output connected to a single digital harmonic pulse generating means producing a number of pulse frequencies connected to a plurality of pulse frequency summing means, each pulse frequency summing means connected to selected pulse frequency outputs of said digital harmonic pulse generating means whereby each pulse frequency summing means produces a single high pulse frequency at its output that is equal to the sum of the selectively connected outputs of said digital harmonic pulse generating means; said master oscillator means comprises a plurality of master oscillators set at different frequencies thereby allowing the organ to be tuned by selector switch instantly to different musical keys by selecting corresponding master oscillators.

2. The combination according to claim 1 wherein said master oscillator means comprises a voltage controlled oscillator allowing the musical key to which the organ is tuned to be altered by varying the potential applied to the voltage control input of the master oscillator, thus allowing the organ to produce a multiplicity of special effects.

3. The combination according to claim 1 wherein said digital harmonic pulse generating means comprises a chain of cascaded digital flip flop circuits, the outputs of which are coupled to monostable one shots producing the pulse frequencies.

4. The combination according to claim 1 wherein said digital harmonic pulse generating means comprises a chain of cascaded digital flip flops, the outputs of which are coupled to gating means producing the pulse frequencies.

5. The combination according to claim 1 wherein a number of chains of flip flops of N stages each are connected to each pulse frequency summing means output (and the conventional octave divider chains) and further increasing the master oscillator frequency by a factor of 2^N to compensate for the flip flop division ratios thus reducing the undesirable harmonic content of the musical note frequencies appearing at the outputs of said flip flop divider chains.

6. The combination according to claim 1 wherein said master oscillator means comprising a crystal oscillator, said high pulse frequency, each connected to flip flop divider chains producing audio frequencies to which other types of musical instruments may be tuned thus allowing a reference for the tuning purposes of other music instruments.