

United States Patent

[11] 3,590,131

[72] Inventor **Robert R. Meyers**
709 Magnolia Ave., Absecon, N.J. 08201
[21] Appl. No. **798,347**
[22] Filed **Feb. 11, 1969**
[45] Patented **June 29, 1971**

3,490,327	1/1970	Volpe.....	84/1.01 X
re.26,521	2/1969	Park.....	84/1.03
3,358,068	12/1967	Campbell.....	84/1.01
3,383,452	5/1968	Park et al.....	84/1.03
3,493,667	2/1970	Campbell.....	84/1.03
3,499,091	3/1970	Bunger.....	84/1.03
3,499,092	3/1970	Bunger.....	84/1.03

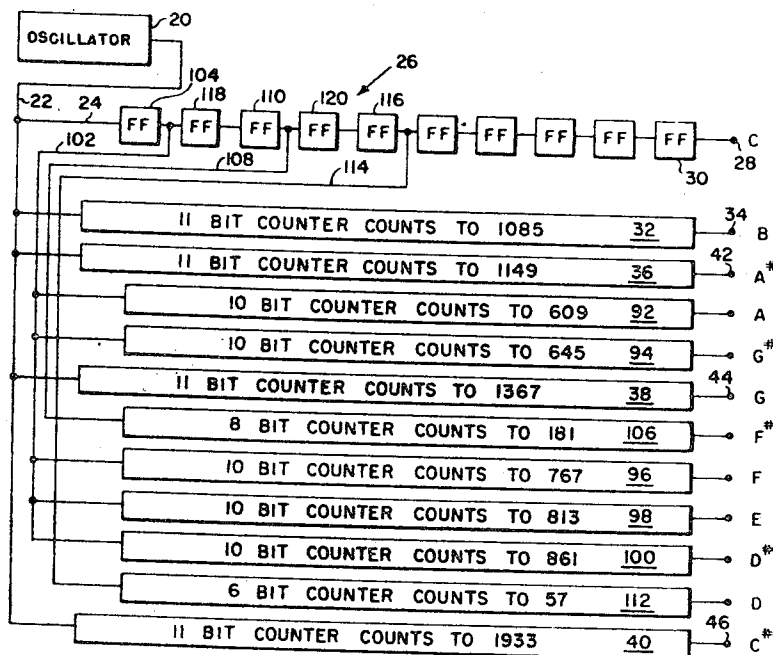
[54] **ELECTRONIC MUSICAL SCALE GENERATOR
EMPLOYING A SINGLE MASTER OSCILLATOR**
11 Claims, 4 Drawing Figs.

Primary Examiner—D. F. Duggan
Assistant Examiner—Stanley J. Witkowski
Attorney—John F. A. Earley

[52] U.S. Cl. **84/1.03**
[51] Int. Cl. **G10h 5/02,**
G10h 5/10
[50] Field of Search. **84/1.01,**
1.03, 1.11, 1.19, 1.21, 1.22

[56] **References Cited**
UNITED STATES PATENTS
2,697,959 12/1954 Kent..... 84/1.22
2,879,387 3/1959 Kahn..... 84/1.22 X
3,006,228 10/1961 White..... 84/1.01
3,476,865 11/1969 Bereskin..... 84/1.11 X

ABSTRACT: For use in electronic organs and the like, an electronic circuit for generating 12 signals, the frequencies of which correspond to the notes of the musical scale, comprises a single, variable frequency oscillator which produces pulses at a high repetition rate. A counting network, driven by the oscillator pulses, produces 12 pulse trains, the frequencies of which are related to each other by $\sqrt[12]{2}$. The 12 pulse trains are filtered directly to produce musical notes, and are further reduced in frequency, and then filtered to produce lower octaves.



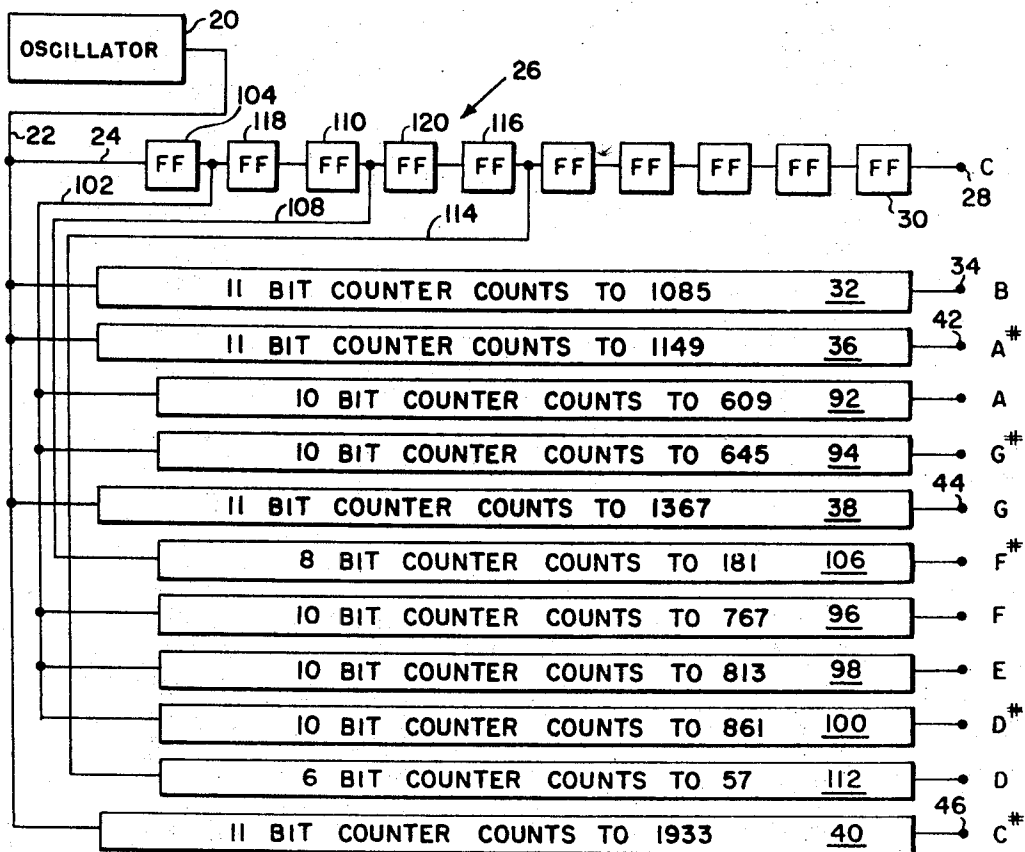


FIG. 1.

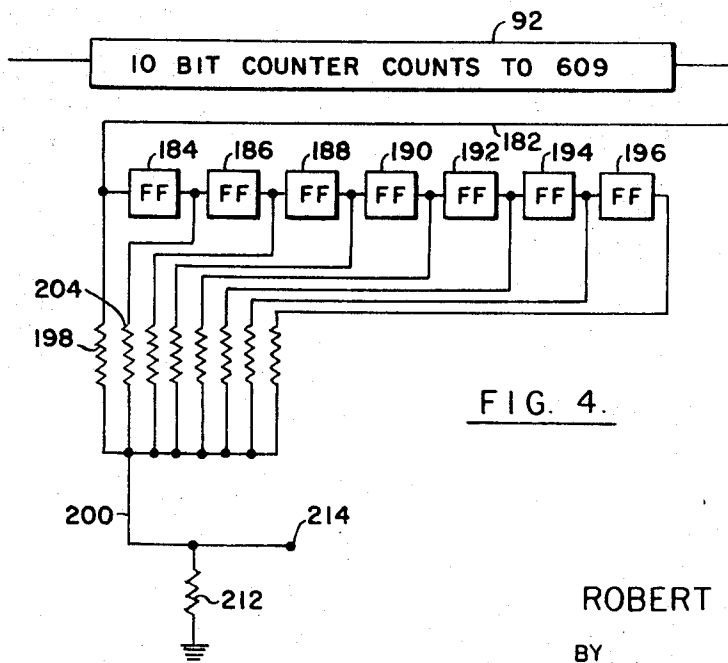
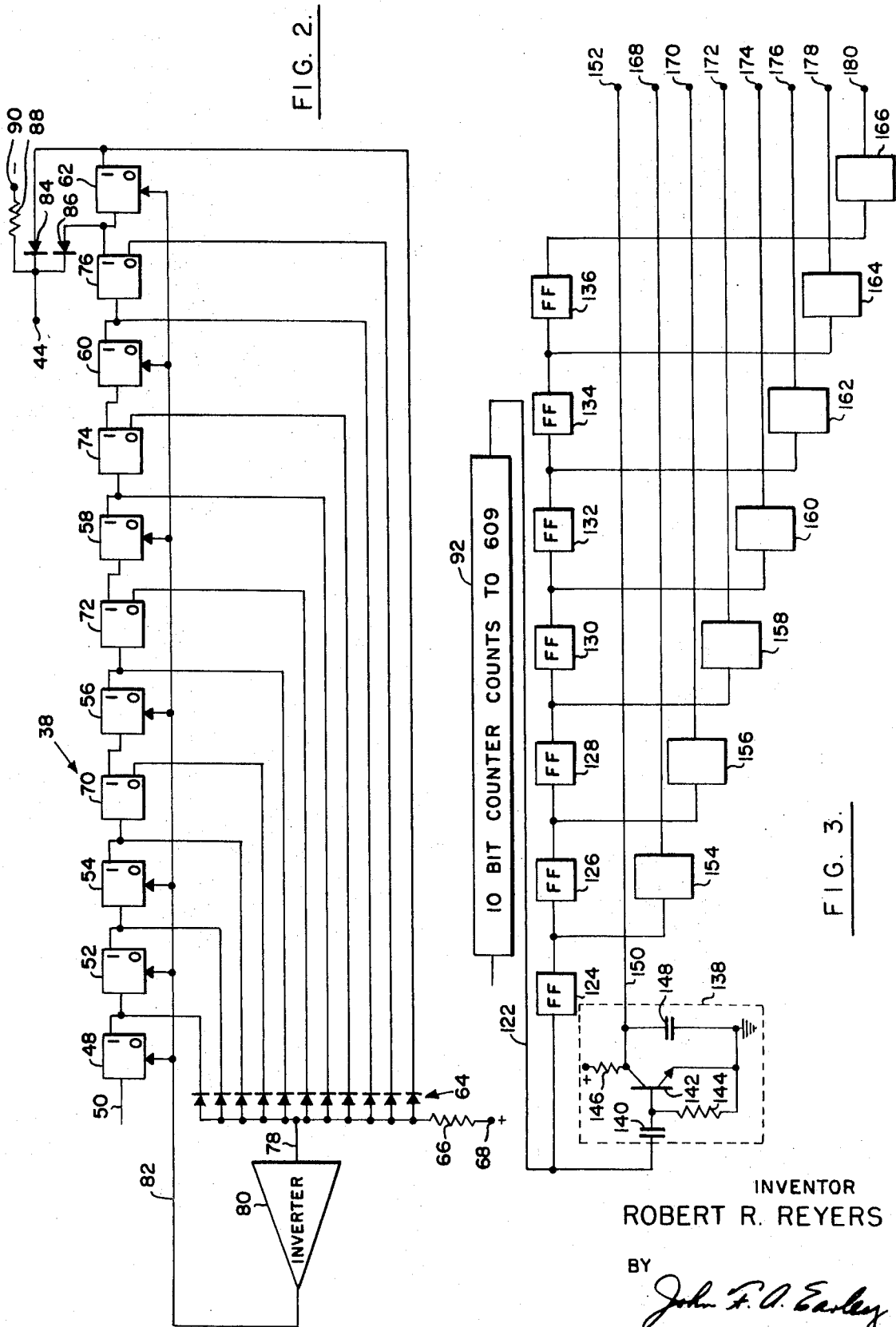


FIG. 4.

INVENTOR
ROBERT R. REYERS

BY
John F. A. Earley
ATTORNEY



INVENTOR
ROBERT R. REYERS

BY *John F. A. Early*
ATTORNEY

ELECTRONIC MUSICAL SCALE GENERATOR EMPLOYING A SINGLE MASTER OSCILLATOR

BACKGROUND OF THE INVENTION

This invention relates to improvements in electronic scale generation for musical instruments, and more particularly to an apparatus for generating a complete scale of musical notes in which the absolute pitch of the notes can be variable, but in which the frequency ratios between the various notes in the scale cannot change.

The tempered musical scale consists of 12 fundamental notes (in decreasing frequency from C through C sharp) which do not have a simple arithmetic relationship. Notes in octaves above and below a selected scale, however, are harmonic multiples or submultiples of the corresponding notes in the selected scale. Thus, once the basic scale 12 notes is generated, octaves of this scale can be obtained by frequency division or multiplication.

Previous methods of generating the notes of the scale have involved the use of elaborate electromechanical rotating assemblies, or have involved the use of 12 or more individually tuned oscillator circuits. A major disadvantage of the rotating assembly method is the complexity and bulk of the various multispeed gears, rotating members and pickup coils, and in addition, the difficulty of raising or lowering the absolute pitch of the scale. In the case of individually tuned oscillator circuits, aging temperature changes and other factors cause a gradual change in the individual oscillator frequencies so that they no longer have the proper relationship to each other. This necessitates frequent retuning of the oscillator circuits. Furthermore, if it is desired to raise or lower the absolute pitch of the scale in order to accompany other musical instruments, it is necessary to retune each of the oscillator circuits individually.

In the prior art, while frequency dividers have been used to produce lower octaves, all of the notes in a single octave have never been produced by frequency division of the signal produced by a single oscillator.

SUMMARY OF THE INVENTION

In accordance with this invention all of the notes in a particular octave, preferably the fourth or fifth octave above middle C, are produced by a counter network, which receives as its input the pulses produced by a single high frequency oscillator. A counter comprising a chain of flip-flops is provided for each note in the octave, and each of the counters is preset to provide one output pulse for a particular number of input pulses produced by the oscillator. The counter network is preferably designed so that certain of the chains of flip-flops receive their inputs from flip-flops in other chains. In this way, redundant flip-flops are eliminated.

Each of the signals produced by the counter network corresponds to a note in the highest octave. Corresponding notes in the lower octaves are produced by delivering each of the signals to an additional flip-flop chain. The pulse outputs of the flip-flops chains in the counter network and the pulse outputs of the flip-flops in the additional flip-flop chains are shaped and filtered to produce signals which can then be amplified to produce a musical tone. Alternatively, the output of a flip-flop chain in the counter network and the outputs of the flip-flops in the additional flip-flop chain can be combined by addition to produce a staircase waveform which is then filtered and amplified to produce a musical note.

The principal object of the invention is to provide a musical scale generator which will produce a scale of electronically generated notes which are locked together in frequency and which cannot get out of tune with each other. An additional object is to provide a musical scale generator which will permit raising or lowering of the absolute pitch of the scale by the operation of a single control.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram showing, in block form, a variable frequency oscillator and an associated counter network for producing a fundamental scale;

FIG. 2 is a schematic diagram showing a circuit for presetting a counter in the counter network to a count which is not a power of 2;

FIG. 3 is a schematic diagram of a circuit for producing notes in lower octaves which correspond to the note produced by a flip-flop chain in the counter network; and

FIG. 4 is a schematic diagram of an alternative circuit for producing lower octave notes.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Before describing in detail the specific embodiment of the invention, some theoretical requirements of musical scale generation should be considered.

The tempered musical scale consists of the notes C sharp, D, D sharp, E, F, F sharp, G, G sharp, A, A sharp, B and C. From these notes, lower or higher octaves can be derived by frequency division or multiplication, or additional scale generators can be used. The frequencies of any two adjacent notes are related by a constant multiplier which is the $\sqrt[12]{2}$. Numerically, this is an irrational number having value of approximately 1.05946309. The $\sqrt[12]{2}$ will be referred to hereafter as k . Thus, the frequency of D is k times the frequency of C sharp, etc. It is therefore the ratios of frequencies that establish the condition of notes being "in tune" with each other, and not their absolute frequencies. As mentioned above, one of the purposes of this invention is to keep the ratios of the notes or tones of the scale constant and locked together. Since the ratio of adjacent note frequencies in a scale is an irrational number, the tolerance or accuracy required in the generated tones must be established. It has been shown that the average person can detect tone differences (errors) of about 0.69 percent, while the best performance in a group of excellent musicians was 0.023 percent. (C. E. Seashore, "Psychology of Music," McGraw-Hill, 1938.) The degree of accuracy provided by this invention is proportional to the number of stages in the counters in the counter network. Thus, the accuracy required can be readily met.

Referring to FIG. 1, oscillator 20 is a fixed or variable frequency oscillator of conventional design which produces pulses continuously at its output. For purposes of this description, the frequency of the output of oscillator 20 will be assumed to be 4.286473 mHz. The frequency of the output of oscillator 20 will be referred to as f , and it will be understood that f can be varied throughout a wide range, and that, in alternative embodiments f can be several times 4.286 mHz. The output pulses of oscillator 20 are delivered through lines 22 and 24 to a counter comprising chain of flip-flops generally indicated as 26. Counter 26 comprises 10 flip-flops connected in cascade so that, at the output terminal 28 of the highest order flip-flop 30 a pulse train is produced having a frequency of $f/2^{10}$. This frequency corresponds to C, the highest note on the scale. If the oscillator frequency is 4.286473 mHz, then C is 4.286473/1024 or 4186.009 Hz.

An 11-bit counter 32 is preset to produce one pulse at its output terminal 34 for every 1085 oscillator pulses in line 22 to which the input of counter 32 is connected. Counters 36, 38 and 40 are similar to counter 32, each comprising a chain of 11 flip-flops connected in cascade. Counter 36 produces a pulse at terminal 42 for every 1149 oscillator pulses; counter 38 produces a pulse at terminal 44 for every 1367 oscillator pulses; and counter 40 produces a pulse at terminal 46 for every 1933 oscillator pulses.

In order to illustrate the manner in which the above-mentioned counters are preset to counts which are not powers of 2, reference is made to FIG. 2, in which the binary flip-flops chain of counter 38 is shown in greater detail. The input to the

first flip-flop in the chain is derived from the oscillator through line 50. The 11 flip-flops are connected in cascade, the 1 output of each of the lower order flip-flops being connected to the input of the next higher order flip-flop. Switching of a flip-flop occurs when the preceding flip-flop switches from 1 to 0. The 1 output of each flip-flops 48, 52, 54, 56, 58, 60 and 62 are each connected to the cascade of a diode of a group of diodes indicated at 64 which act as an AND gate. The 0 outputs of flip-flops 70, 72, 74 and 76 are connected to the cathodes of diodes in group 64. The anodes of the diodes are connected in common and through resistor 66 to a positive supply terminal 68. The common connection of the anodes of the diodes is also connected through line 78 to the input of an inverter 80. The output of inverter 80 is connected through line 82 to resetting terminals of flip-flops 48, 52, 54, 56, 58, 60 and 62. The output to terminal 44 is derived from the 1 terminals of flip-flops 76 and 62 through an OR gate comprising diodes 84 and 86, the cathodes of which are connected in common to terminal 44 and through a resistor 88 to a negative supply terminal 90.

It will be apparent that the circuitry just described establishes a condition such that all of the flip-flops in counter 38 are reset to 0 when positive signals appear at the cathodes of all of the diodes in group 64. This condition occurs when flip-flops 48, 52, 54, 56, 58, 60 and 62 are in the 1 condition and flip-flops 70, 72, 74 and 76 are in the 0 condition. This corresponds to a count of 1367 oscillator pulses. When this count is reached, all of the flip-flops in the counter are reset to the 0 condition. The outputs of flip-flops 76 and 62 are connected through diodes 84 and 86 to terminal 44. Diodes 84 and 86 along with resistor 88 act as an OR gate so that the voltage at terminal 44 becomes more positive if either or both of flip-flops 76 and 62 are in the 1 condition. Although the output of the last flip-flop 62 has a duty cycle of about 25 percent as a result of the presetting, the output signal at terminal 44 has a duty cycle of about 62 percent. The OR gate insures that there is a high amplitude of fundamental frequency content in the output at terminal 44.

It will be apparent from the above description how the remaining counters in the counter network in FIG. 1 can be preset to any desired count. Alternative methods of presetting flip-flops chains to desired predetermined counts can be used as well. For example, the flip-flops in the chain can be arranged so that some are set to 1 and others are set to 0 on the occurrence on the change of state of the highest order flip-flop. In such an arrangement, the preset count would be the difference between the initial count immediately following the change of state of the highest order flip-flop and 2^N power where N is the number of flip-flops. Other methods of presetting the binary counter chains involving high order bit translation and selective gating are well known and can be used as well.

Returning to FIG. 1, 10-bit counters, 92, 94, 96, 98 and 100 are preset so that they count to the various counts indicated in the drawing. Their inputs are derived through line 102 from the output of the lowest order flip-flop in counter 26. An 8-bit counter, which is preset to count to 181, is indicated at 106. Its input is derived through line 108 from flip-flop 110, which is the third lowest order flip-flop in counter 26. A 6-bit counter, which is preset to count to 57, derives its input through line 114 from flip-flop 116, which is the fifth lowest order flip-flop in counter 26.

	True frequency	Calculated count	Rounded count	Counted frequency	Percent frequency error
Note:					
C.....	4,186,009	1,024	1,024	4,186,009	+0.000
B.....	3,951,690	1,064,690	1,065	3,950,666	+0.010
A.....	3,729,310	1,149,491	1,149	3,730,612	+0.035
A.....	3,520,000	1,217,748	1,218	3,519,272	+0.021
G.....	3,322,436	1,290,159	1,290	3,322,847	+0.012
G.....	3,135,964	1,368,878	1,367	3,135,670	+0.009
F.....	2,959,955	1,448,155	1,448	2,960,271	+0.011
F.....	2,789,826	1,534,267	1,534	2,794,911	+0.017
E.....	2,637,031	1,628,490	1,628	2,636,207	+0.031
D.....	2,499,016	1,722,150	1,722	2,499,241	+0.009
D.....	2,349,816	1,824,801	1,824	2,350,040	+0.031
C.....	2,217,491	1,938,055	1,938	2,217,524	+0.003

In FIG. 1, the notes produced by the various counters are indicated at the right of the output terminals.

In order to illustrate the operation of the apparatus shown in FIG. 1, reference is made to the following table, in which the true frequencies of the notes of the scale (based on a frequency for A of 3520.000 Hz.) are compared with the frequencies at the outputs of the various counters.

It will be noted that the maximum error is well below that which can be detected by the average person, and is nearly as low as the smallest error detectable by the best musician in a group of excellent musicians.

As will be apparent from the table, the counters and their preset counts were determined by the first choosing an oscillator frequency which will produce the true frequency of the note C when divided by 2^{10} or 1024. The chosen oscillator frequency was 4.286473 MHz. From this chosen oscillator frequency, the divisors necessary to produce the true frequencies of the other notes were calculated. These divisors are shown in the calculated count column of the table. The divisors were rounded to the integers shown in the rounded count column of the table, and the counted frequency was calculated.

Certain of the rounded counts are divisible by powers of two. For example, the rounded counts for A, G sharp, F, E, and D sharp are divisible by two. Because of this, in counters 92, 94, 96, 98 and 100, an 11th flip-flop is unnecessary. Flip-flop 104 in flip-flop chain 26 takes the place of the unnecessary 11th flip-flop in each of these counters.

The preset count of 1448 for the note F sharp is divisible by 2^5 . Accordingly, counter 106 requires only eight flip-flops, the division by 2 being accomplished by flip-flops 104, 118 and 110 in flip-flop chain 26.

The rounded count for the note D is 1824. This is divisible by 2^5 , and accordingly counter 112 requires only six flip-flops. A division of 2^5 is accomplished by flip-flops 104, 118, 110, 120 and 116 of flip-flop chain 26.

Thus, the arrangement shown in FIG. 1 results in the saving of 13 flip-flops in the counter network while the maximum frequency error is only 0.035 percent. If greater errors were tolerated, still more flip-flops could be eliminated. If closer tolerances were desired, a higher oscillator frequency could be used which would be divided by counters having greater numbers of flip-flops.

By reducing the number of flip-flops in a flip-flop chain, the resetting circuitry is simplified. In fact, the flip-flop chains in the 10, and 8 6-bit counters can be preset by well-known techniques much simpler than that illustrated in FIG. 2 since the input frequencies are lower, permitting slower resetting.

A further reduction of the number of flip-flops in the counter network can be obtained by a more extensive use of flip-flops which are common to several counters. For example, counters 92, 94, 98 and 100 provide counts which are divisible by 3. A common 2-bit counter, preset to divide by 3 could be arranged to receive the output of flip-flop 104, and the number of flip-flops in each of counters 92, 94, 98 and 100 could be reduced by two for a net reduction of six flip-flops.

In another technique for reducing the number of flip-flops in the counter network, a single flip-flop chain could be used to produce two or more notes by obtaining signals at appropriate counts through the use of conventional decoding networks. For example, an 11-bit counter connected to receive the output of flip-flop 104 could be preset to count to 1626. A first decoder could be connected to respond at counts of 813 and 1626 to produce the note E. A second decoder could be connected to respond at counts of 542, 1084 and 1626 to produce the note B. The note B would then have a slightly larger error than that produced by counter 32, since the number of counts would be 1084 rather than 1085.

The notes produced by the counter network shown in FIG. 1, of course, are in the fourth octave above middle C. This range of notes is used as the highest octave in some currently manufactured musical instruments. Better instruments would use a range one octave higher, and this higher range can be accomplished easily by doubling the output frequency of oscillator 20.

The outputs provided by the counter network in FIG. 1 are in the highest octave and are in the form of rectangular pulses having various duty cycles. When the frequencies are divided down to produce the lower octave notes, square waves are produced having no even harmonics. The ideal waveform for electronic musical note production is the sawtooth. It contains both even and odd harmonics, and the magnitudes of the harmonics are inversely proportional to the harmonic number. FIGS. 3 and 4 illustrate alternative circuits for producing sawtooth waveforms in the lower octaves.

Referring particularly to FIG. 3, a circuit is shown for converting the output of counter 92 to produce sawtooth waveforms in the highest octave and in seven lower octaves. Line 122 delivers the output of counter 92 to a chain of cascaded flip-flops including flip-flops 124, 126, 128, 130, 132, 134 and 136. The rectangular waveform produced by counter 92 is delivered through line 122 also to the input of a shaping circuit indicated generally at 138. A capacitor 140 is connected between line 122 and the base of a transistor 142. A resistor 144 is connected between the base of the transistor and ground. The emitter is connected to ground, and the collector is connected through resistor 146 to a positive supply. A capacitor 148 shunts the collector and emitter, and an output is delivered from the junction between the collector and capacitor 148 through line 150 to output terminal 152. Similar shaping circuits 154, 156, 158, 160, 162, 164 and 166 receive the outputs of the respective flip-flops 124 through 136 and deliver their outputs to terminals 168 through 180 respectively.

Capacitor 140 differentiates the rectangular waveform in line 122. Capacitor 148 charges through resistor 146. When the differentiated signal at the base of transistor 142 is positive, capacitor 148 is discharged through the transistor. As a result, a sawtooth waveform is produced at terminal 152. Sawtooth waveforms are also produced at terminals 168 through 180, the waveforms corresponding to the note A in successively lower octaves.

Circuits similar to that shown in FIG. 3 may be provided for each of the counters shown in FIG. 1.

Referring to FIG. 4, an alternative method of producing a sawtooth waveform is illustrated. The output of counter 92 is delivered through line 182 to a chain of flip-flops comprising flip-flops 184 through 196. The signal in line 182 is delivered through a resistor 198 to a line 200. The output of flip-flop 184 is delivered through a second resistor 204 to line 200, and the outputs of the remaining flip-flops are delivered respectively through other resistors to line 200. Line 200 is connected to an output terminal 214 and through resistor 212 to ground.

Resistor 198 has approximately twice the resistance of resistor 204, and resistor 204 has approximately twice the resistance of the next resistor, and so on.

In its essence, the circuit is an adder which combines the added signals in inverse proportion to their frequencies. A repeating staircase waveform is produced at terminal 214, and it resembles a sawtooth in its harmonic content.

The fundamental frequency of the note A at terminal 214 is the seventh subharmonic of the frequency at the output of counter 92. The higher octave notes of A are, of course, produced by additional adding networks having their resistors connected to the outputs of appropriate flip-flops of the group 184-196. For example, the fourth subharmonic would be produced by a circuit having resistors combining the outputs of flip-flops 184, 186, 188 and 190 and the output of counter 92.

In summary, the invention produces signals corresponding to notes in a scale, which are locked together so that they cannot get out of tune with each other. Additional octaves of the basic scale can be obtained by frequency division or by providing additional tone generators using additional oscillators operating at frequencies octavely related to the frequency of the output of oscillator 20. The absolute pitch of the scale can be raised or lowered by adjustment of the frequency of the

oscillator, and, even though this adjustment is made, the various notes in the scale will remain in the proper relationship to each other. Accordingly, tuning of the individual notes of an instrument having a scale generator in accordance with the invention is unnecessary. Although numerous flip-flops are used in the basic scale generator, a significant number of flip-flops are eliminated by deriving the inputs to individual counters from higher order flip-flops of another counter.

I claim:

1. Apparatus for generating alternating audiofrequency electrical signals corresponding to the notes of a musical scale comprising

a master oscillator for producing a master alternating electrical signal at a frequency above the audio range,

a network comprising at least 12 counters, each comprising a plurality of cascaded stages of frequency-dividing means,

each of said counters having an output line connected to the output of its last stage, and an input line connected to the input of its first stage,

said network including means connected to receive the master alternating electrical signal and delivering to each said input line an alternating electrical signal to which the frequency of said master signal has an integral multiple relationship,

at least all but one of said counters having means for sensing a first predetermined condition of their stages and resetting said stages to a second predetermined condition when said first predetermined condition is reached to establish a scale of each counter such that the signals on the output lines are related to each other by integral powers of the $12\sqrt[2]{2}$.

2. Apparatus according to claim 1 in which said master oscillator includes means for varying the frequency of said master alternating electrical signal.

3. Apparatus according to claim 1 in which each of said counters comprises a plurality of flip-flops connected in cascade for successive divisions by two of the frequency at the input to each flip-flop.

4. Apparatus according to claim 1 including a plurality of frequency dividing means each having an input terminal connected to receive the alternating output signal at one of the output lines in said network, each said frequency dividing means having at least one output terminal and providing an output signal at its output terminal having a frequency which is a subharmonic of the frequency of the signal at the input terminal of said dividing means related to the frequency of said signal at the input terminal by an integral power of two.

5. Apparatus according to claim 1 in which the input line of at least one of said counters is connected to the output of a stage of another counter in said network.

6. Apparatus for generating alternating audiofrequency electrical signals corresponding to the notes of a musical scale comprising

a master oscillator for producing a master alternating electrical signal at a frequency above the audio range,

a network comprising at least 12 counters, each comprising a plurality of cascaded stages of frequency-dividing means,

each of said counters having an output line connected to the output of its last stage, and an input line connected to the input of its first stage,

said network including means connected to receive the master alternating electrical signal and delivering to each said input line an alternating electrical signal to which the frequency of said master signal has an integral multiple relationship, and

said network also including means for establishing a scale of each counter such that the signals on the output lines are related to each other by integral powers of $12\sqrt[2]{2}$.

7. Apparatus according to claim 6 in which said master oscillator includes means for varying the frequency of said

master alternating electrical signal.

8. Apparatus according to claim 6 in which each of said counters comprises a plurality of flip-flops connected in cascade for successive divisions by two of the frequency at the input to each flip-flop.

9. Apparatus according to claim 6 including a plurality of frequency dividing means each having an input terminal connected to receive the alternating output signal at one of the output lines in said network, each said frequency dividing means having at least one output terminal and providing an

output signal at its output terminal having a frequency which is a subharmonic of the frequency of the signal at the input terminal of said dividing means related to the frequency of said signal at the input terminal by an integral power of two.

10. Apparatus according to claim 6 in which the input line of at least one of said counters is connected to the output of a stage of another counter in said network.

11. Apparatus according to claim 6 in which said means establishing a scale of each counter effects production of a musical octave in 12 of said output lines.

15

20

25

30

35

40

45

50

55

60

65

70

75