United States Patent [19]

Luce

[11] **4,145,943**

[45] **Mar. 27, 1979**

[54] **ELECTRONIC MUSICAL INSTRUMENT CAPABLE OF GENERATING A STRING CHORUS SOUND**

[75] Inventor: **David A. Luce**, Clarence Center, N.Y.

[73] Assignee: **Norlin Music, Inc.**, Lincolnwood, Ill.

[21] Appl. No.: **696,195**

[22] Filed: **Jun. 15, 1976**

[51] **Int. Cl.**^{2} **G10H 1/02**

[52] **U.S. Cl.** **84/1.01**; 84/1.24; 84/DIG. 4

[58] **Field of Search** .... 84/1.01, 1.11, 1.19, 84/1.21, 1.22, 1.24–1.26, DIG. 4

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,007,361	11/1961	Wayne, Jr.	84/1.01
3,443,463	5/1969	Campbell	84/1.01
3,476,863	11/1969	Campbell	84/1.01
3,535,431	10/1970	Szabo	84/1.22
3,603,809	9/1971	Uchiyama	84/1.22 X
3,790,693	2/1974	Adachi	84/1.01
3,800,060	3/1974	Hallman, Jr.	84/1.24
3,816,637	6/1974	Whitefield	84/1.24
3,821,460	6/1974	Maynard	84/1.17
3,835,236	9/1974	Adachi	84/1.24
3,837,254	9/1974	Southard	84/1.01
3,855,893	12/1974	Chase	84/1.24
3,902,396	9/1975	Hiyoshi	84/1.19
3,956,961	5/1976	Peterson	84/1.24
3,978,755	9/1976	Woron	84/1.24
3,981,218	9/1976	Luce	84/1.24
3,992,970	11/1976	Chibana et al.	84/1.11
3,999,458	12/1976	Suzuki	84/1.01

Primary Examiner—Robert K. Schaefer
Assistant Examiner—Vit W. Miska
Attorney, Agent, or Firm—Allegretti, Newitt, Witcoff & McAndrews

[57] **ABSTRACT**

Improved apparatus for use in an electronic musical instrument having a keyboard including a group of keys corresponding to the notes of a musical scale. Electronic circuitry is used to generate simultaneously with respect to each of the keys first and second electrical tone signals. The circuitry causes the waveshapes of the tone signals to deviate with respect to each other. In addition, the repetition rates of the tone signals are detuned and frequency modulated with respect to each other so that the sound of a string chorus is simulated.

The disclosure also describes circuitry useful in an electronic musical instrument having a keyboard including twelve keys corresponding to the twelve notes of a chromatic musical scale. The circuitry generates simultaneously a first series of twelve tone signals corresponding to a first tempered scale and a second series of twelve tone signals corresponding to a second tempered scale different from the first tempered scale. Each time a key is actuated, a pair of tone signals, one from each of the first and second series, is mixed and converted to an acoustical wave in order to simulate the sound of a string chorus.

The disclosure further describes apparatus useful for maintaining the notes of an electronic musical instrument in pitch by phase locking a high frequency oscillator to a low frequency oscillator.

25 Claims, 8 Drawing Figures

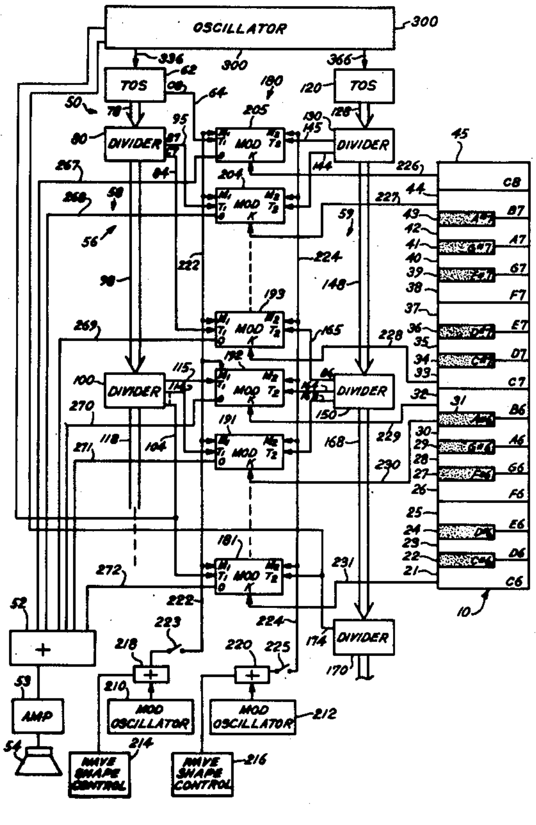


Fig. 1

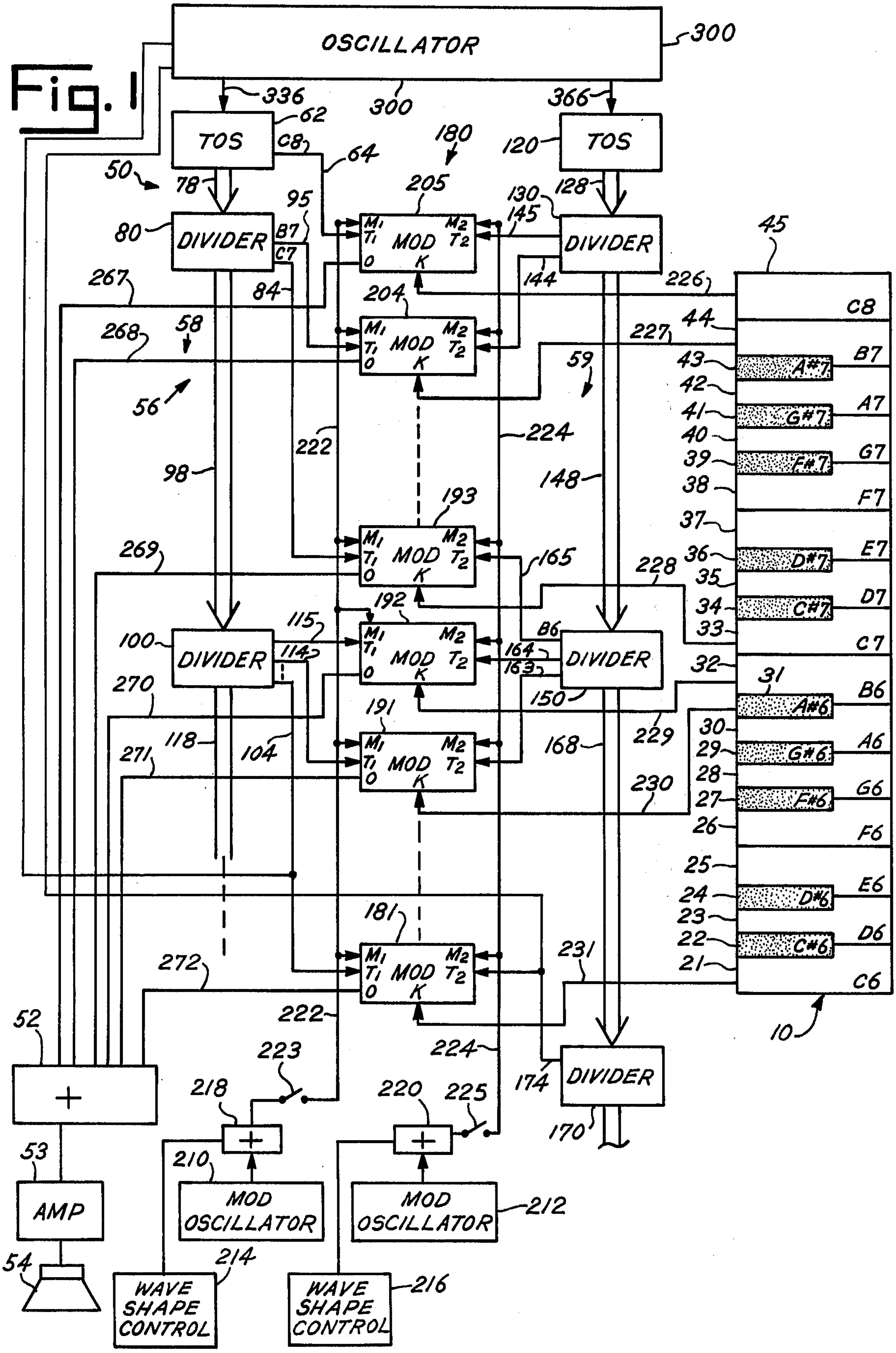

OSCILLATOR
300
336
300
366
TOS
62
C8
64
180
120
TOS
50
78
205
95
130
128
145
80
DIVIDER
B7
C7
MOD
M1
T1
O
M2
T2
K
DIVIDER
45
267
84
204
144
226
C8
44
268
58
227
B7
43
A#7
42
56
59
A7
41
G#7
40
G7
39
F#7
222
224
98
148
38
F7
37
193
E7
269
36
D#7
165
228
35
D7
34
C#7
192
33
115
B6
C7
100
DIVIDER
114
164
163
DIVIDER
32
31
270
150
B6
A#6
191
30
118
104
168
229
A6
29
G#6
271
28
G6
230
27
F#6
F6
26
25
E6
24
D#6
23
181
231
D6
22
C#6
272
21
C6
52
222
10
223
224
218
220
225
174
DIVIDER
+
170
53
210
AMP
MOD OSCILLATOR
MOD OSCILLATOR
212
54
214
216
WAVE SHAPE CONTROL
WAVE SHAPE CONTROL

Fig. 1a

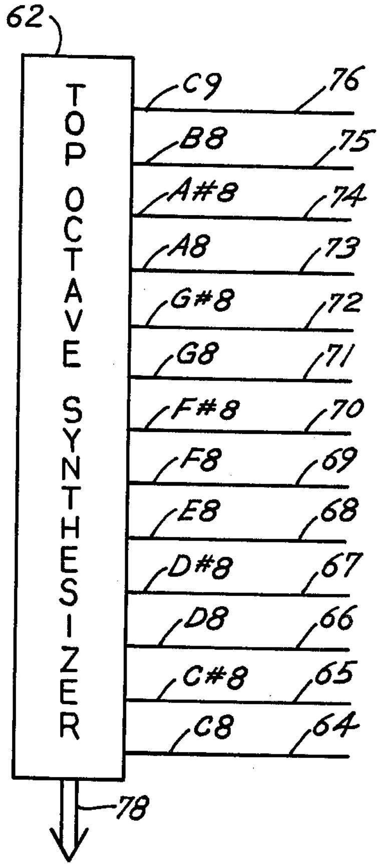


Fig. 7

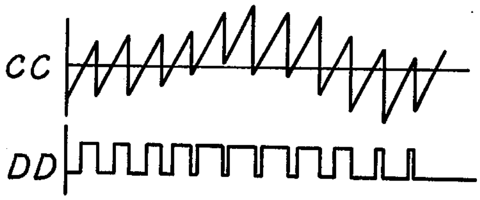


Fig. 6

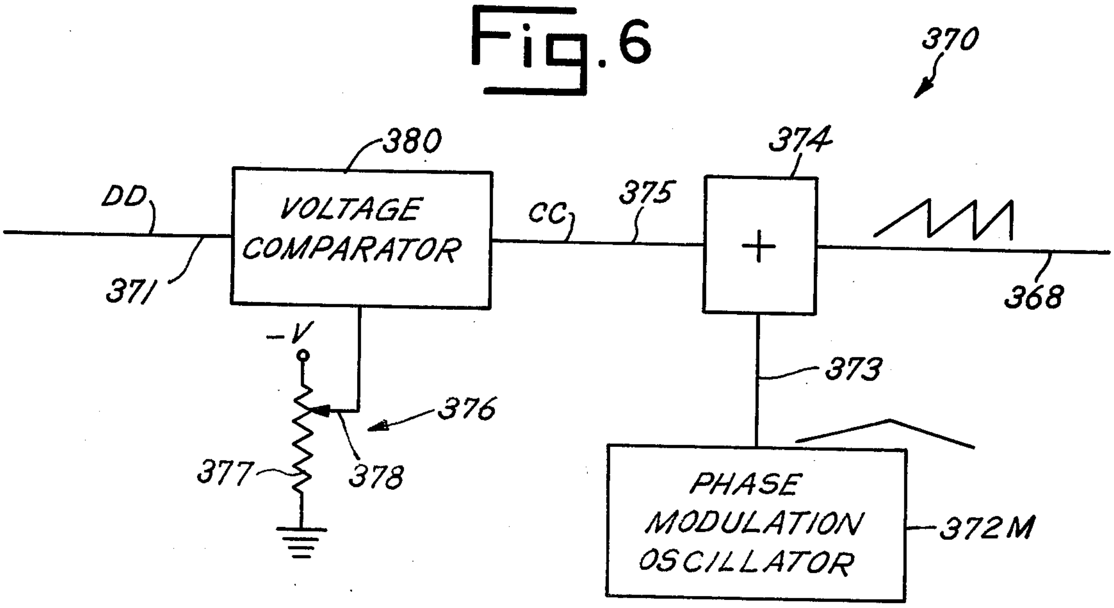
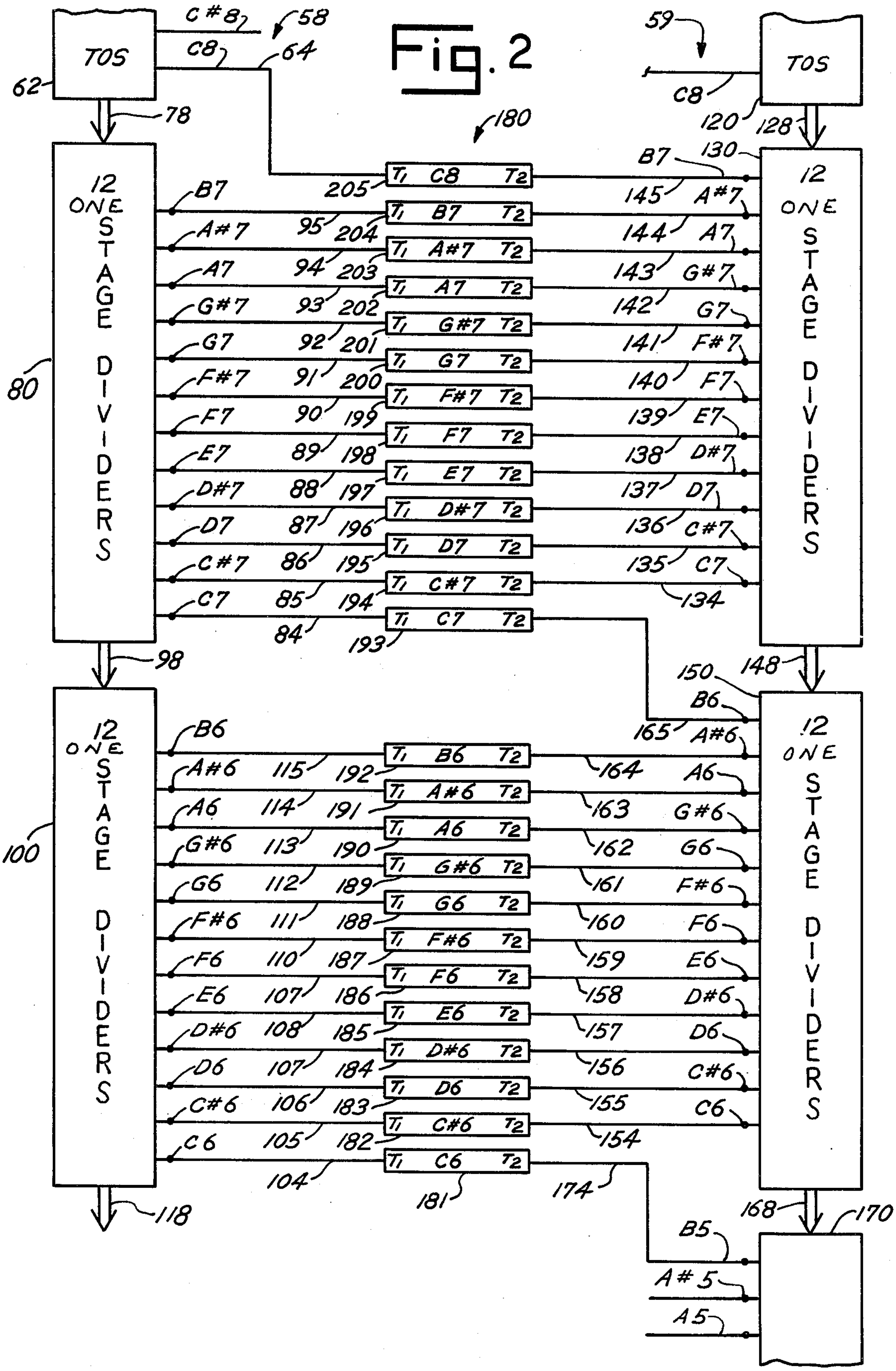


Fig. 2


TOS
C#8
C8
58
64
62
78
TOS
59
C8
120
128
130
180
12 ONE STAGE DIVIDERS
80
B7
A#7
A7
G#7
G7
F#7
F7
E7
D#7
D7
C#7
C7
205
95
204
94
203
93
202
92
201
91
200
90
199
89
198
88
197
87
196
86
195
85
194
84
193
T1 C8 T2
T1 B7 T2
T1 A#7 T2
T1 A7 T2
T1 G#7 T2
T1 G7 T2
T1 F#7 T2
T1 F7 T2
T1 E7 T2
T1 D#7 T2
T1 D7 T2
T1 C#7 T2
T1 C7 T2
B7
145
A#7
144
A7
143
G#7
142
G7
141
F#7
140
F7
139
E7
138
D#7
137
D7
136
C#7
135
C7
134
12 ONE STAGE DIVIDERS
98
148
150
B6
165
A#6
12 ONE STAGE DIVIDERS
100
B6
A#6
A6
G#6
G6
F#6
F6
E6
D#6
D6
C#6
C6
115
192
114
191
113
190
112
189
111
188
110
187
107
186
108
185
107
184
106
183
105
182
104
181
T1 B6 T2
T1 A#6 T2
T1 A6 T2
T1 G#6 T2
T1 G6 T2
T1 F#6 T2
T1 F6 T2
T1 E6 T2
T1 D#6 T2
T1 D6 T2
T1 C#6 T2
T1 C6 T2
164
A6
163
G#6
162
G6
161
F#6
160
F6
159
E6
158
D#6
157
D6
156
C#6
155
C6
154
12 ONE STAGE DIVIDERS
174
118
168
170
B5
A#5
A5

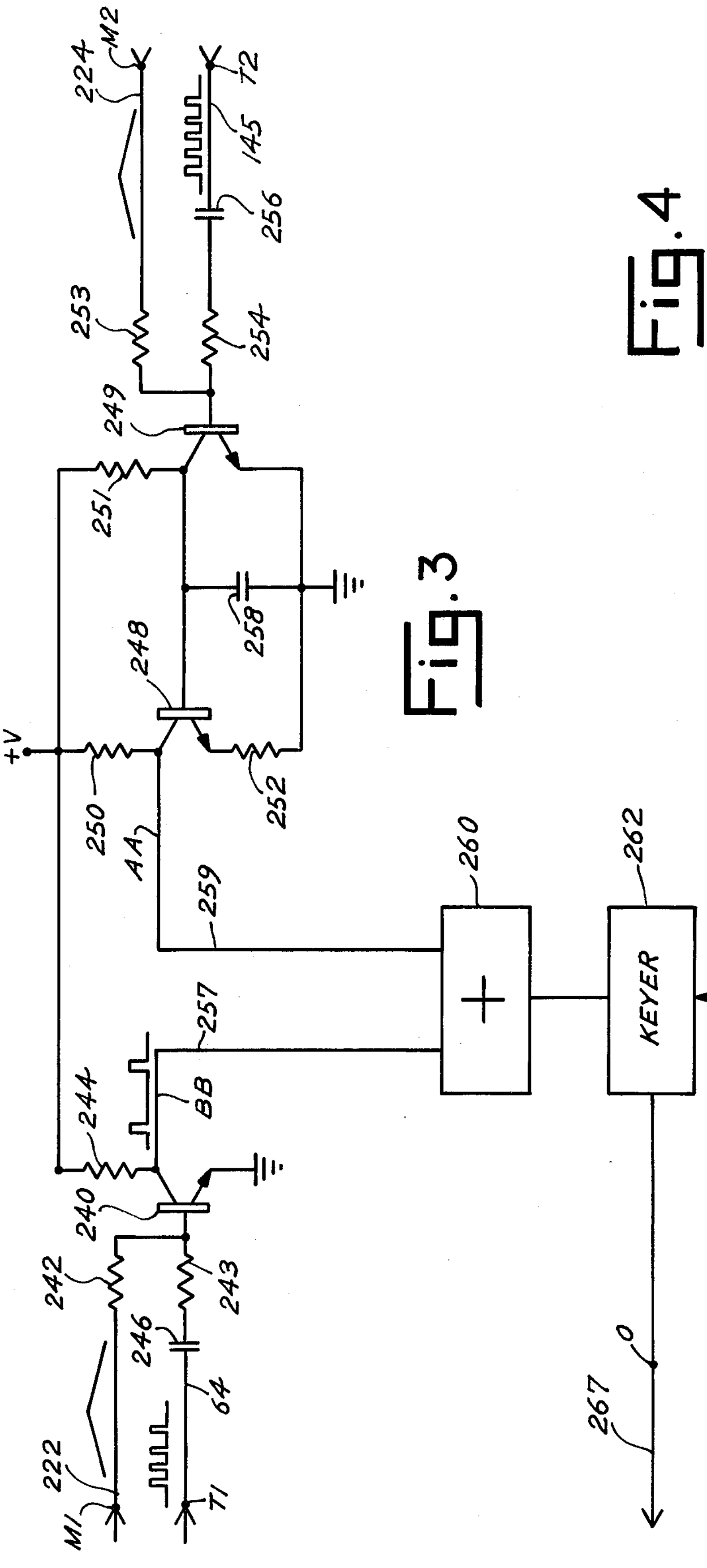


Fig. 3

M2
224
72
145
256
253
254
249
251
+V
248
258
250
252
AA
259
260
+
262
KEYER
K
257
BB
244
240
242
243
246
64
222
M1
T1
0
267
226
265
+V
264
45

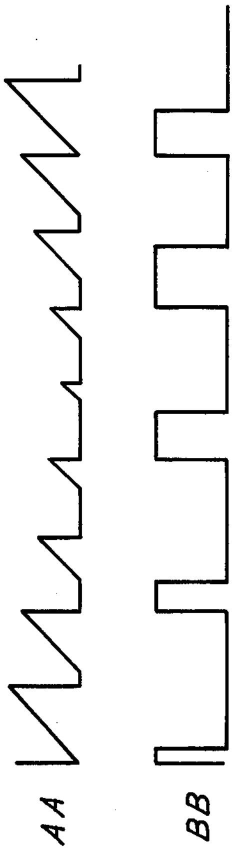


Fig. 4

AA
BB

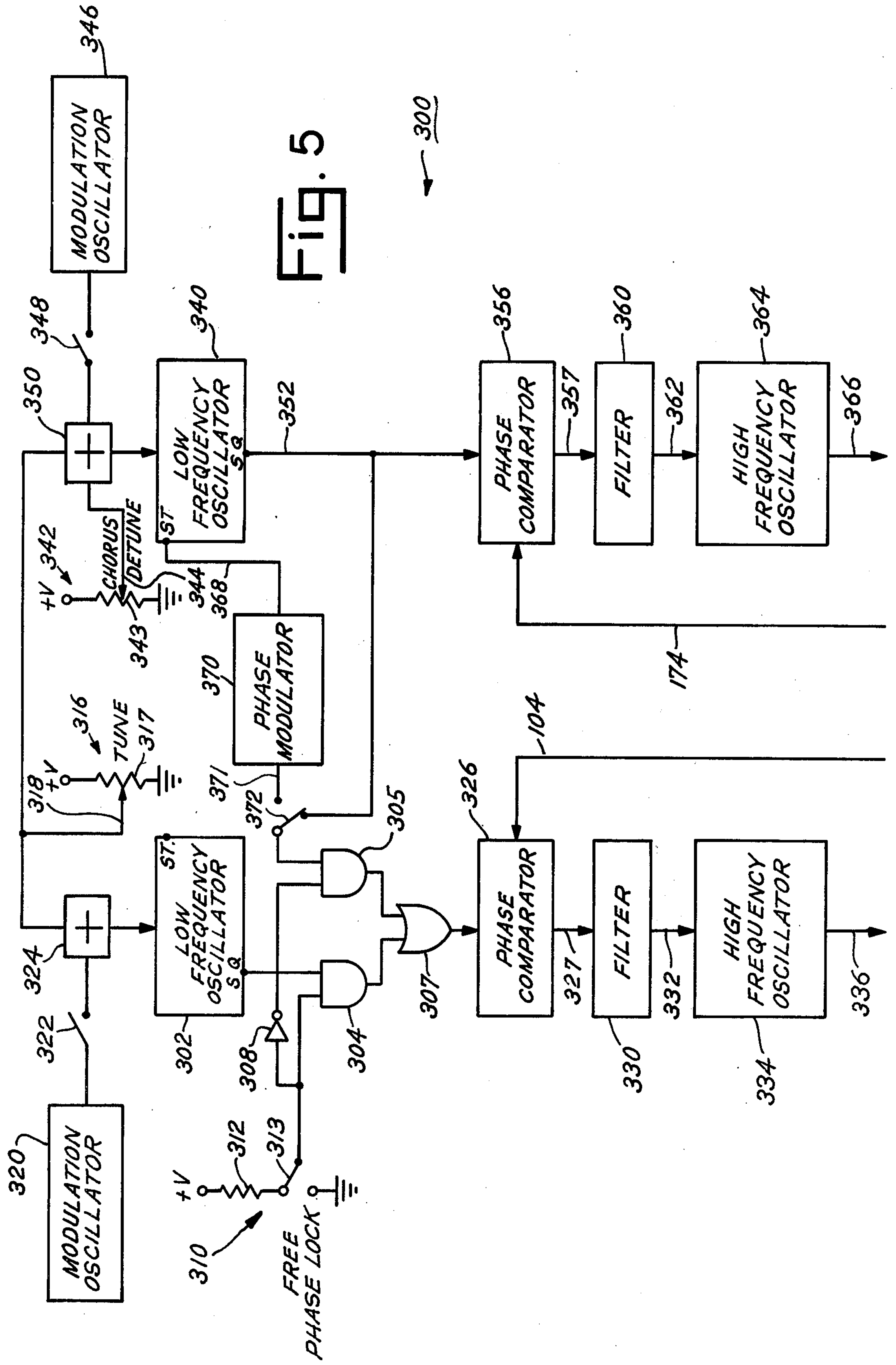

300
346
MODULATION OSCILLATOR
348
350
340
LOW FREQUENCY OSCILLATOR
SQ
ST.
352
CHORUS
DETUNE
+V
342
343
344
368
PHASE MODULATOR
370
371
372
316
TUNE
317
318
+V
356
PHASE COMPARATOR
357
360
FILTER
362
364
HIGH FREQUENCY OSCILLATOR
366
174
104
326
PHASE COMPARATOR
327
FILTER
330
332
HIGH FREQUENCY OSCILLATOR
334
336
305
307
304
302
LOW FREQUENCY OSCILLATOR
SQ
ST.
324
322
320
MODULATION OSCILLATOR
308
+V
312
313
310
FREE
PHASE LOCK

Fig. 5

ELECTRONIC MUSICAL INSTRUMENT CAPABLE OF GENERATING A STRING CHORUS SOUND

BACKGROUND AND SUMMARY OF THE INVENTION

This invention relates to electronic musical instruments, and more particularly relates to such instruments employing a keyboard in order to simulate the sounds of non-keyboard instruments.

String instruments which are bowed, such as violins and cellos, have long been known for their singular qualities of expressiveness and tone color which have made them the premier instruments in western orchestras for hundreds of years. These instruments create many harmonics of each fundamental note played on them, and this characteristic, in large part, is responsible for their rich tone color or timbre. Excitement is added by the fact that the tone color or timbre of these instruments changes as they are played. Even minute changes in the bowing pressure, rate, and attack angle, as well as the pressure and position of the fingers on the finger board of the instruments, create differences in the intensity and identity of the harmonics. As a result, the harmonics of a single bowed instrument change in a complex way, and the harmonics of multiple bowed instruments played simultaneously involve random and complicated changes which defy mathematical analysis.

Multiple bowed instruments often are played simultaneously in order to form a string chorus. The blending of the sounds of the multiple instruments in the chorus creates an audible sensation which is qualitatively different from the sound of a solo instrument. The variations in sound created by the eccentricities of the individual players of the chorus combine to form a rich sonority which is pleasing to the ear.

Since the sound of a string chorus requires a performance by many skilled and dedicated musicians, it is an expensive art form which is generally reserved for a concert stage. Because of the expense and difficulty of obtaining a string chorus sound with natural acoustical instruments and musicians, it is highly desirable to design an electronic musical instrument which can simulate this sound.

Accordingly, it is a primary object of the present invention to provide an electronic musical instrument which simulates the sound of a string chorus.

Another object of the present invention is to provide an electronic musical instrument playable by a keyboard which simulates the sound of a string chorus.

Still another object of the present invention is to provide an electronic musical instrument of the foregoing type in which the fundamental pitch of the tone being produced can be accurately maintained over a long period of time.

It has been surprisingly discovered that the foregoing objects can be achieved by simultaneously generating in connection with each of the keys of the instrument first and second electrical tone signals which have a particular relationship to each other. The first tone signal is generated at a first repetition rate which is frequency modulated. That is, the first repetition rate has a value which oscillates at a modulation frequency around a center rate. The second electrical tone signal has a waveshape which deviates from the waveshape of the first electrical tone signal either statically or dynamically. In addition, the second electrical tone signal has a repetition rate which is different from the center rate of the first electrical tone signal. In response to the actuation of the keys, the first and second electrical tone signals are mixed and converted to corresponding acoustical waves in order to produce the sound of a string chorus. Since pairs of first and second electrical tone signals are produced for each of the keys, several of the keys can be actuated at once to play chords which further enhance the string chorus effect.

Another feature of the present invention can be used in connection with electronic musical instruments having a keyboard including twelve keys corresponding to the twelve notes of a chromatic musical scale. Circuitry simultaneously generates a first series of twelve tone signals corresponding to a first tempered scale and a second series of twelve tone signals corresponding to a different second tempered scale. A pair of tone signals, one from each of the first and second series, corresponds to each of the keys. When a key is actuated, the tone signals from the first and second series tuned according to the different tempered scales are mixed and converted to an acoustical wave which simulates the sound of a string chorus.

The first and second features of the invention also can be combined in order to enhance the string chorus effect.

According to a third aspect of the invention, the notes of an electronic musical instrument having a keyboard by which the notes are played can be kept in tune by providing a high frequency oscillator which generates clock pulses that are divided in time in order to form tone pulse waveforms corresponding in pitch to the various keys. A low frequency oscillator generates timing pulses corresponding to the pitch of one of the tone pulse waveforms. A comparator compares the phase of the timing pulses with the predetermined one of the tone pulse waveforms and generates a correction signal which varies the repetition rate of the high frequency oscillator so that the notes remain in tune.

By using the foregoing techniques, it has been discovered that the sound of a string chorus can be simulated with a degree of ease and accuracy heretofore unattainable, and that the instrument can be kept in accurate tone over long periods of time.

DESCRIPTION OF THE DRAWINGS

These and other objects, advantages and features of the present invention will hereafter appear in connection with the accompanying drawings wherein like numbers refer to like parts throughout, and wherein:

FIG. 1 is a schematic block diagram of a preferred form of musical instrument made in accordance with the present invention;

FIG. 1A is a schematic block diagram of a preferred form of top octave synthesizer as shown in FIG. 1;

FIG. 2 is a schematic block diagram describing in detail the divider and modifier system used in connection with FIG. 1;

FIG. 3 is an electrical schematic drawing of a preferred form of modifier circuit shown in FIG. 1;

FIG. 4 is a waveform diagram illustrating the voltage waveforms occurring at points AA and BB of FIG. 3;

FIG. 5 is a detailed schematic diagram of the oscillator shown in FIG. 1;

FIG. 6 is a detailed block diagram illustrating the phase modulator shown in FIG. 5; and

FIG. 7 is a waveform diagram showing the voltage waveforms generated at points CC and DD of FIG. 6.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. **1**, a preferred form of a musical instrument made in accordance with the present invention basically comprises a keyboard **10**, a generator **50** which generates tone signals, a mixer **52** which electrically mixes or sums the tone signals, and an amplifier **53** and loud speaker **54** which convert the mixed tone signals into a corresponding acoustical wave. Mixer **52**, amplifier **53** and loud speaker **54** are well-known components in the art, and need not be described in detail.

Keyboard **10** can take the form of any conventional musical keyboard, such as found in a piano or organ. Although two octaves of keys are illustrated in FIG. **1**, additional octaves could be added depending on the scope of the instrument desired. As shown in FIG. **1**, keyboard **1** includes keys **21–45**. Keys **21–32** are used for playing the second octave of the instrument, and keys **33–45** are used to play the top octave of the instrument (i.e., the octave highest in pitch).

As shown on FIG. **1**, the keys are labeled with the pitch of the note played by each key. For example, if the lowest C note on a piano keyboard is designated C1, key **21** is used to produce a pitch corresponding to the sixth C on the piano keyboard (C6). C6, of course, is two octaves below the highest C on the piano keyboard (C8). Likewise, the black notes on the piano keyboard are designated by a sharp (#). For example, key **43** is used to play the note A#7, the highest pitched black note on a conventional piano keyboard. The same notation is used in connection with FIGS. **1A** and **2**.

Tone signal generator **50** basically comprises a divider system **56**, a modifier and control system **180**, and an oscillator system **300**.

Referring to FIG. **1**, a divider system **56** can be divided into a first channel of components **58** and a second channel of components **59**. Referring to channel **58**, a top octave synthesizer **62** receives clock pulses at a rate of about 1.5–2.0 MHz (Megahertz) from oscillator **300**. In a well-known manner, the synthesizer generates chromatic frequencies corresponding to the semitones or notes within an octave which is one octave higher in pitch than the highest octave on the keyboard. The manner in which these tones are generated is illustrated in FIG. **1A**.

As shown in FIG. **1A**, top octave synthesizer **62** may comprise a conventional device such as generator MM5832, MM5833, manufactured by National Semiconductor Corporation. Synthesizer **62** takes the clock pulses generated by oscillator **300**, divides them an appropriate number of times, and produces corresponding tone pulse waveforms on output taps **64–76** which correspond to pitches or notes C8, C#8, D8, D#8, E8, F8, F#8, G8, G#8, A8, A#8, B8 and C9, respectively.

The repetition rates of the tone pulse waveforms on output taps **64–76** correspond to a particular tempered scale. Musicians, and those skilled in the design of musical instruments, recognize that tempering is a system of tuning in which the intervals within an octave (notes having frequencies divisible by 2) deviate from the pure intervals of the Pythagorean system. The deviations are necessary because the Pythagorean system, although perfect within a small range of tones in one key, becomes inadequate if the musician attempts to play in other keys. Most modern keyboard instruments are tuned with a tempering system known as the equally tempered scale. According to the system of equal temperment, an octave is divided into twelve equal semitones. Since the frequency ratio of the octave is two, the frequency ratio S of a semitone is given by the equation $S = \sqrt[12]{2} = 1.05946$. Sometimes a logarithmic measurement is also used in connection with equal temperment in which the whole octave equals twelve hundred cents and the interval of pitch between each semitone equals one hundred cents. Thus, a change in frequency of 0.05946% is a change in frequency of 1 cent.

Commercially available top octave synthesizers closely approximate the equally tempered scale, but deviate from it to a slight extent. For example, in the case of the National Semiconductor synthesizer described above, assuming as input repetition rate of 2.00024 MHz, the resulting error in cents from the true equally tempered scale is illustrated in Table A:

TABLE A

NOTE	OUTPUT FREQUENCY	EQUALLY TEMPERED SCALE FREQUENCY	CENT ERROR
C9	8369.21	8372.02	– 0.565
B8	7906.09	7902.13	0.842
A#8	7463.58	7458.62	1.119
A8	7043.10	7040.00	0.740
G#8	6645.32	6644.88	0.112
G8	6270.34	6271.93	– 0.424
F#8	5917.87	5919.91	– 0.580
F8	5587.26	5587.65	– 0.117
E8	5277.68	5274.04	1.160
D#8	4975.72	4978.03	– 0.780
D8	4695.40	4698.64	– 1.159
C#8	4184.61	4186.01	– 0.565

Thus, top octave synthesizer **62** produces tone pulse waveforms corresponding to a predetermined tempered scale which is slightly different from the equally tempered scale. Referring to FIG. **2**, each of taps **64–75** of synthesizer **62** are conducted through a cable **78** to twelve separate inputs of twelve single stage dividers **80**. Each of the separate stages of divider **80** includes a flipflop circuit which divides the repitition rate of its input signal in half. Thus, the tone pulse waveform appearing on conductor **75** (corresponding to pitch B8) is divided in half by the first stage of divider **80** to form note B7, one octave below note B8, on output conductor **95**. (Each of the other tone pulse waveforms produced by synthesizer **62** are treated in a like manner, so that the divider **80** produces on output conductors **84–95** (taps C7-B7) and tone pulse waveforms corresponding to notes C7-B7, respectively.

Each of the output taps of divider **80** are connected through a cable **98** to twelve individual stages of a divider **100** which is identical to divider **80**. As a result, on output conductors **104–115** (taps C6-B6), divider **100** produces tone pulse waveforms corresponding to notes C6–B6, respectively. The output taps of divider **100** are each conducted through a cable **118** to as many additional divider stages as desired in the instrument. The tone pulse waveforms produced by synthesizer **62**, divider **80** and divider **100** differ in octaves, but all correspond to the same system of tempering.

Referring to FIG. **1**, channel **59** includes divider components identical to those in channel **58**. More specifically, channel **59** includes a top octave synthesizer **120** identical to synthesizer **62**, cables **128**, **148** and **168** identical to cables **78**, **98** and **118**, respectively; and dividers **130** and **150** identical to dividers **80** and **100**, respectively. An additional divider **170** is identical to divider **150**.

As shown in FIG. **2**, the output taps on dividers **130** and **150** produce tone pulse waveforms which are separated by semitones or pitch intervals identical to those provided by dividers **80** and **100**, respectively. That is, assuming synthesizers **62** and **120** receive clock pulses at the same rate from oscillator **300**, the repetition rates of the tone pulse waveforms produced on output conductors **84–95** are identical to the repetition rates of the tone pulse waveforms produced on output conductors **134–145**, respectively. Likewise, the repetition rates for the tone pulse waveforms produced on conductors **104–115** are identical to the repetition rates of the tone pulse waveforms produced on output conductors **154–165**, respectively.

As shown in FIG. **2**, the output taps of dividers **80**, **100**, **130**, **150** and **170** are connected to individual modifier circuits **181–205** of modifier and control system **180**. A separate modifier circuit is provided for each key of the keyboard and is labeled with the note produced by its corresponding key. One important feature of the preferred embodiment results from the fact that each modifier circuit is connected to non-corresponding taps of a pair of dividers. Basically, the dividers in channel **59** are shifted one semitone lower than the dividers of channel **58** with respect to the modifier circuits. For example, the C8 output of synthesizer **62** is connected to modifier **205**, whereas the B7 tap of divider **130** is connected to modifier **205**. Likewise, the B7 tap of divider **80** is connected to modifier **204**, whereas the A#7 tap of divider **130** is connected to modifier **204**. This pairing arrangement continues for all of the modifiers. As a result of this arrangement, the tone pulse waveforms generated in channel **58** by synthesizer **62**, divider **80** and divider **100** are arranged according to a different tempered scale from the tone pulse waveforms generated in channel **59** by dividers **130**, **150** and **170**.

As described in more detail later, oscillator **300** tunes the C outputs of channel **58** (i.e., the C outputs of synthesizer **62**, divider **80** and divider **100**) to the same frequency as the B outputs of channel **59** (i.e., the B outputs of synthesizer **120** and dividers **130**, **150** and **170**). For example, the C8 output of synthesizer **62** has the same repetition rate as the B7 output of divider **130**, and the C7 output of divider **80** has the same repetition rate as the B6 output of divider **150**. However, since the ratios of frequencies between adjacent taps on the dividers are not equal, the remaining pairs of tone pulse waveforms from channel **58** and **59** supplied to the same modifier circuit are slightly different in frequency. Moreover, within each octave, the tone pulse waveforms supplied by channel **58** are tuned according to a tempered scale which is different from the tempered scale corresponding to the tone pulse waveforms supplied by channel **59**. The result of transmitting to each modifier circuit pairs of tone pulse waveforms tuned according to different tempered scales is graphically illustrated in Table B:

TABLE B

(1) NOTE	(2) MODIFIER CIRCUIT RECEIVING PULSES FROM DIVIDERS	(3) CENTS ERROR OF WAVEFORM RECEIVED FROM SYNTHESIZER 62 or DIVIDER 80	(4) CENTS ERROR OF WAVEFORM RECEIVED FROM DIVIDER 130 OR 150	(5) CENTS OF DIFFERENCE IN FREQUENCY BETWEEN WAVEFORMS RECEIVED FROM DIFFERENT DIVIDERS
C8	205	− .565	− .565	0
B7	204	+ .842	− .288	1.13
A#7	203	+ 1.119	− .667	1.786
A7	202	+ .740	− 1.295	2.035
G#7	201	+ .112	− 1.831	1.943
G7	200	− .424	− 1.987	1.519
F#7	199	− .580	− 1.524	.944
F7	198	− .117	− .247	.13
E7	197	+ 1.160	− 2.187	3.347
D#7	196	− .780	− 2.566	1.786
D7	195	− 1.159	− 1.331	.172
C#7	194	+ .076	− 1.972	2.048
C7	193	− .565	− .565	0

Column 1 describes the notes in the octave C7 and C8. These notes are generated by modifier circuits **193–205** which receive input signals from the like-lettered keys. Column 2 in Table B describes the modifier circuit receiving pulses from channels **58** and **59** in order to generate tone signals resulting in the notes shown in column 1. Column 3 of Table B describes in cents the error by which the frequency of the waveform received from channel **58** deviates from the equally tempered scale. Column 4 of Table B describes in cents the error by which the frequency of the waveform received from channel **59** deviates from the equally tempered scale. Column 5 of Table B shows the cents of difference in frequency between the waveforms received from channels **58** and **59**. As noted in column **5**, with the exception of the C7 and C8 notes, each of the modifier circuits receives tone pulse waveforms which deviate in frequency from each other by 0.13 to 3.347 cents. It has been surprisingly discovered that by mixing these tone pulse waveforms together, the sound of a string chorus can be simulated.

As shown in FIG. **1**, each of the modifier circuits includes input terminals M1, M2, T1, T2 and K, as well as an output terminal **0**. Basically, each modifier circuit receives a tone pulse waveform from channel **58** through an input T1 and receives a corresponding tone pulse waveform from channel **59** through an input T2. Control signals for modifying the tone pulse waveforms from channels **58** and **59** are received through inputs M1 and M2. If the player wants to sound the note corresponding to a modifier circuit, he depresses a corresponding key which generates a control signal received through input K. In response to the control signal, the tone pulse waveforms from channels **58** and **59** are mixed and transmitted through output terminal **0** where they can be amplified and converted to an acoustic wave.

In addition to modifier circuits **181–205**, modifier and control system **180** includes shape modulation oscillators **210**, **212**. Each of these oscillators generates a triangular waveshape. Oscillator **210** generates a triangular waveshape of predetermined appropriate amplitude at a shape modulation rate of, for example, 6.3 cycles per second, and oscillator **212** generates a triangular waveshape of predetermined, appropriate amplitude at a shape modulation rate of, for example, 6.0 cycles per second. Waveshape control circuits **214**, **216** establish an adjustable DC signal level for oscillators **210** and **212**, respectively. The adjustable DC and triangular waveshape signals are mixed in summing circuits **218**, **220** and are thereafter transmitted to control buses **222**, **224** through manually actuated switches **223**, **225**, respectively.

The depression of a key by the player results in a control signal on a corresponding conductor connected to a modifier circuit. Referring to FIG. **1**, exemplary control conductors **226–231** are illustrated in connection with modifier circuits **205**, **204**, **193**, **192**, **191** and **181**.

Each of the modifier circuits **181–205** is identical and may be understood with reference to the following discussion of exemplary modifier circuit **205** shown in FIG. **3**. Modifier circuit **205** includes a transistor **240** and associated resistors **242–244** connected as shown. The tone pulse waveform received on input conductor **64** through terminal **T1** is differentiated by differentiating capacitor **246**. Circuit **205** also includes transistors **248**, **249** and associated resistors **250–254** connected as shown. The tone pulse waveform received on conductor **145** through terminal **T2** is differentiated by differentiating capacitor **256**. If transistor **249** is switched to its non-conductive state, current is conducted to a charge storage capacitor **258** through a resistor **251** which is connected to a source of positive voltage V. If transistor **249** is switched to its conductive state, capacitor **258** is rapidly discharged.

The manner in which transistor **240** shape modulates the tone pulse waveform received on conductor **64** is illustrated in FIG. **4** in connection with waveform BB. Assuming switch **223** (FIG. **1**) is closed so that a shape modulating signal is received on conductor **222**, the pulses received on conductor **64** are width modulated in the manner shown by waveform BB at the shape modulation rate of the signal received on conductor **222**. The form of pulse width modulation performed by transistor **240** is trailing edge modulation. That is, the trailing edge of the pulses varies in time with respect to the leading edge, but the position of the leading edge with respect to time is not altered.

The manner in which transistors **249** and **248** shape modulate the tone pulse waveform received on conductor **145** is illustrated in connection with waveform AA of FIG. **4**. Assuming switch **225** is closed (FIG. **1**), the collector of transistor **248** produces a sawtooth waveform which is shape modulated in the manner shown by waveform AA at the shape modulation rate of the signal received on conductor **224**.

If either switch **223** or **225** is closed, the shape of the tone pulse waveform received on either conductor **64** or **145** is altered with respect to time so that the resulting tone pulse signals generated on conductors **257** and **259** deviate dynamically from each other. If both of the switches **223** and **225** are open, no shape modulating signal is received on either conductor **222** or **224**. In this mode of operation, a pulse waveform having a constant width and fixed shape is generated on conductor **257** and a sawtooth waveform having a fixed shape is generated on conductor **259** so that the shapes of the resulting tone signals on conductors **257** and **259** deviate statically.

The tone signals generated on conductors **257** and **259** are mixed in a summing circuit **260** and are conducted to output terminal 0 by a conventional keyer **262** in response to a 0 volt signal on control conductor **226**. As shown in FIG. **3**, the depression of key **45** closes switch **264** which places a 0 volt signal on conductor **226**. If key **45** is not depressed, conductor **226** is biased at a positive voltage from a source of DC potential +V through a resistor **265**.

Each of the other modifier circuits contains an output conductor similar to conductor **267** shown in FIG. **3**. In order to clarify the explanation, only output conductors **268–272** have been shown in FIG. **1**.

Referring to FIG. **5**, oscillator system **300** comprises a group of components which supply clock pulses to channel **58** and an analogous group of components which supply clock pulses to channel **59**. Channel **58** includes a low frequency voltage-controlled oscillator **302** of a well-known design. Oscillator **302** produces squarewave timing pulses at an output SQ and sawtooth timing pulses at output ST. In the present embodiment, the oscillator is adjusted to produce the timing pulses at a nominal center repetition rate of **1046** cycles per second, although this rate can be frequency modulated above and below the center rate.

The SQ output of oscillator **302** is conducted through a logic circuit comprising logical AND gates **304**, **305**, a logical OR gate **307**, and an inverter **308**. The logical circuit is controlled by a selection circuit **310** comprising a resistor **312**, which is connected to the positive source of voltage +V and a switch **313**. When switch **313** is in the free position shown in FIG. **5**, the timing pulses produced by oscillator **302** are conducted through the logic circuit.

The frequency of oscillator **302** is controlled by a tune potentiometer **316** comprising a resistor **317** and a slider **318**, as well as by a frequency modulation oscillator **320**. Oscillator **320** produces a triangular waveform of predetermined, appropriate amplitude at a modulation frequency of, for example, 4.7 cycles per second. If a switch **322** is closed, the DC tune signal from potentiometer **316** and the waveform from oscillator **320** are mixed in a summing circuit **324** and are transmitted to the input of oscillator **302**. In this mode of operation, the frequency of the timing pulses produced by oscillator **302** are frequency modulated at the rate of, for example, 4.7 cycles per second.

Assuming switch **313** is in the free position shown in FIG. **5**, the output of oscillator **302** is conducted to the input of a phase comparator **326** which may be implemented by model CD4046 manufactured by Radio Corporation of America. Comparator **326** compares the phase of the timing pulses from oscillator **302** with the phase of the tone pulse waveform received from conductor **104** (tap C6 of divider **100**). Comparator **326** generates a correction signal having a magnitude proportional to the difference between the phase of the timing pulses and the tone pulse waveform. The correction signal is transmitted to output conductor **327**, is converted to a corresponding DC level by filter **330** and is conducted to a voltage-controlled, high-frequency oscillator **334** through an output conductor **332**. The correction signal alters the repetition rate of the clock pulses produced by oscillator **334** so that the frequency and phase of the timing pulses from oscillator **302** are identical to the frequency and phase of the tone pulse waveform on conductor **104**.

Channel **59** components within oscillator **300** comprise a low-frequency, voltage-controlled oscillator **340**, identical to oscillator **302**, which also produces timing pulses at a nominal repetition rate of **1046** cycles per second. The repetition rate of the timing pulses from oscillator **340** is controlled by tune potentiometer **316**, a chorus detune potentiometer **342** comprising a resistor **343** and a slider **344**, and a frequency modulation oscillator **346**. Oscillator **346** produces a triangular waveform at a modulation frequency of 5.5 cycles per second. If a switch **348** is closed, a DC voltage from slider **344** is added to the waveform from oscillator **346** in a summing circuit **350**, and the summed signals control the repetition rate of oscillator **340**.

The amplitudes of the triangular waveforms generated by oscillators **320** and **346** are adjusted so that the repetition rates of oscillators **302** and **340**, respectively, are frequency modulated by approximately one percent.

The square wave (SQ) output of oscillator **340** is transmitted over a conductor **352** to a phase comparator **356** identical to phase comparator **326**. Phase comparator **356** compares the phase of the timing pulses from oscillator **340** with the phase of the tone pulse waveform produced on conductor **174** (tap B5 of divider **170**). Comparator **356** generates a correction signal having a value proportional to the difference between the phase of the timing pulses and the tone pulse waveform on conductor **174**. The correction signal is transmitted over a conductor **357** into a filter **360** which generates a corresponding DC level on an output conductor **362**. The DC level controls the frequency of oscillator **364** so that the repetition rate of the tone pulse waveform on conductor **174** is maintained at the same frequency and phase as the timing pulses produced by oscillator **340**. The clock pulses produced by oscillator **364** are conducted to synthesizer **120** over an output conductor **366**.

The sawtooth timing pulses produced by oscillator **340** at output ST are transmitted over a conductor **368** to a phase modulator **370**. Modulator **370** produces phase modulated pulses on output conductor **371** which can be transmitted through a switch **372** to the input of AND gate **305**. When AND gate **305** is enabled by the movement of switch **313** into the grounded, phase lock position shown in FIG. **5**, the output from modulator **370** can be transmitted to the input of phase comparator **326**.

Referring to FIG. **6**, phase modulator **370** comprises a phase modulation oscillator **372M** which produces a triangular waveform at a rate of about 5 cycles per second. The triangular waveform is transmitted over a conductor **373** to a summing circuit **374** which receives the sawtooth timing pulses over conductor **368**. The summing circuit mixes the sawtooth and triangular waveforms to produce on conductor **375** an output waveform CC shown in FIG. 7. Waveform CC is transmitted to the input of a voltage comparator **380** which also receives a negative reference voltage from a reference potentiometer **376** comprising a resistor **377** and a slider **378**. Resistor **377** is connected between ground potential and a source of negative voltage −V. Responsive to its input signals, voltage comparator **380** produces a series of width modulated pulses DD shown in FIG. 7. The particular form of width modulation employed is leading edge modulation. That is, the trailing edges of the pulses shown in waveform DD remain in the same relative position with respect to time, but the leading edges are advanced or retarded at the rate of phase modulation oscillator **372M** (e.g., 5 cycles per second).

The switches and controls of the above-described circuitry may be used in a number of ways to simulate the sound of a string chorus. For example, if all the switches are maintained in the positions shown in FIGS. **1** and **5**, the circuitry is in the free mode. In this mode, oscillator **302** is adjusted in frequency by moving slider **318** until the tone pulse waveform on conductor **104** achieves an appropriate repetition rate (e.g., **1046** cycles per second). The frequency of oscillator **340** then is adjusted by manipulating slider **344** until the repetition rate of the tone pulse waveform on conductor **174** is the same as the tone pulse waveform on conductor **104** (i.e., the **C6** tap of divider **100** is tuned to the same frequency as the **B5** tap of divider **170**).

In this free mode of operation, as previously explained, the repetition rates of the waveforms produced by dividers **80** and **100** are tuned according to one tempered scale, whereas the repetition rates of the waveforms produced by dividers **130**, **150**, **170** are tuned according to a different tempered scale (FIG. **2**). That is, the repetition rates of the waveforms produced on conductors **84–95** and **64** correspond to one tempered scale, whereas the repetition rates of the waveforms produced on conductors **165** and **134–145** correspond to a different tempered scale. In response to the depression of any of the keys **34–44** (C#7-B7), modifier circuits **194–204** combine a pair of tone pulse waveforms each of which is produced according to a different tempered scale and each of which differs from the other in frequency. These tone pulse waveforms are mixed and converted to an acoustical wave to simulate a string chorus sound.

When switch **313** is in the free mode, in order to provide additional difference in frequency between the tone pulse waveform transmitted to each modifier circuit, chorus detune slider **344** can be varied in order to detune all of the tone pulse waveforms produced in channel **59** compared to the tone pulse waveforms produced in channel **58**.

Additional effects useful in simulating the sound of a string chorus can be achieved by closing switch **322** (FIG. **5**) in order to frequency modulate the timing pulses generated by oscillator **302**. The frequency modulation of oscillator **302** results in the modulation of the repetition rate of the clock pulses produced by oscillator **334**. As a result of this operation, each of the tone pulse waveforms generated by the taps of dividers **80** and **100** in channel **58** is defined by a repetition rate having a value which oscillates at the modulation frequency of oscillator **320** around a center rate. A similar effect can be achieved in channel **59** by closing switch **348**. As a result of this operation, each of the tone pulse waveforms generated in channel **59** by the taps of dividers **130**, **150** and **170** are defined by a repetition rate having a value which oscillates at the frequency of oscillator **346** around a center rate.

Additional effects useful in simulating the sound of a string chorus can be generated by closing switch **223** (FIG. **1**) which causes the pulse width modulation of the tone pulse waveforms received at input **T1** of the modifier circuits. Likewise, switch **225** can be closed in order to dynamically alter, with respect to time, the shape of the tone pulse waveforms received at inputs **T2** of the modifier circuits. The shape modulation of each of the resulting tone signals has previously been described in connection with FIGS. **3** and **4**.

Tone pulse waveforms tuned according to differently tempered scales can be automatically transmitted to each modifier circuit by adjusting low frequency oscillator **340** to a repetition rate of 1046 cycles per second and by moving switch **313** (FIG. **5**) to the grounded or phase lock position. In this mode of operation, timing pulses are provided to both channels **58** and **59** by oscillator **340**, and the repetition rates and phases of the tone pulse waveforms on conductors **104** and **174** are identical to the repetition rates and phases of the timing pulses produced by oscillator **340**.

As long as switch **372** is in the position shown in FIG. **5**, the repetition rates of the tone pulse waveforms on the C taps of the channel **58** dividers are identical to the repetition rates of the tone pulse waveforms on the corresponding B taps of the channel **59** dividers. For example, the C7 tap of the divider **80** is tuned to the same frequency as the B6 tap of divider **150**. In order to vary the repetition rates on these taps so that the chorus effect is increased, switch **372** is moved in contact with output conductor **371** so that phase modulator **370** is operated. Phase modulator **370** varies the phase or pulse width of the timing pulses transmitted to phase comparator **326** so that the frequency of the C taps in channel **58** dynamically varies with respect to the corresponding taps in channel **59**. For example, the frequency of the tone pulse waveform on conductor **64** (tap C8 of synthesizer **62**) will oscillate with respect to the frequency of the tone pulse waveform on conductor **145** (tap B7 of divider **130**).

Due to the operation of phase modulator **370**, the repetition rate of each of the tone pulse waveforms produced on the taps of dividers **80** and **100** will oscillate slightly above and below its normal frequency, and, therefore, will vary dynamically with respect to the corresponding repetition rate of each of the tone pulse waveforms produced by dividers **130** and **150** in channel **59**. This slight variation of frequency adds an additional characteristic useful for simulating the sound of a string chorus.

In the phase lock mode of operation, switch **348** can be closed in order to frequency modulate, as well as phase modulate, the timing pulses produced by oscillator **340**. In addition, shape modulation can be obtained in the manner previously described by closing either or both of switches **223** and **225** (FIG. **1**).

In addition to the advantages described above, the phase lock mode of operation also has the additional advantage of maintaining the repetition rates of the tone pulse waveforms at an exact, predetermined value over a long period of time. Voltage-controlled, high-frequency oscillators are notoriously unstable, and the industry has long sought a method of insuring that electronic musical instruments do not go out of tune due to changes in parameter values or temperature conditions. It has been discovered that the desired degree of stability can be permanently maintained if the operation of the high frequency oscillator is locked to a stable low frequency oscillator by use of a phase comparator in the manner described in connection with FIG. **5**.

Those skilled in the art will recognize that only one preferred embodiment of the invention has been disclosed. This embodiment may be altered and modified without departing from the true spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. Apparatus for use in an electronic musical instrument having a keyboard including a group of keys corresponding to the notes of a musical scale, comprising:

means for generating simultaneously in connection with each of the keys a first electrical tone signal defined by a first waveshape and a first repetition rate having a value which oscillates substantially continuously during the depression of one of the keys at a first modulation frequency around a center rate, and for generating a second electrical tone signal defined by a second waveshape which deviates from the first waveshape and by a second repetition rate having an average value different from the center rate;

means for mixing the first and second electrical tone signals to produce a mixed electrical signal; and

means for converting the mixed electrical signal to a corresponding acoustical wave, whereby the sound of a chorus can be simulated.

2. Apparatus, as claimed in claim **1**, wherein the means for generating comprises means for modulating the second repetition rate with respect to time at a second modulation frequency different from the first modulation frequency, said modulating occurring substantially continuously during the depression of said one key.

3. Apparatus, as claimed in claim **1**, wherein said group of keys comprises at least one octave of twelve keys corresponding to the twelve notes of a chromatic scale and wherein the means for generating comprises means for tuning the twelve first electrical tone signals corresponding to the octave of twelve keys according to a predetermined first tempered scale and for tuning the twelve second electrical tone signals corresponding to the octave of twelve keys according to a predetermined second tempered scale different from the first tempered scale.

4. Apparatus, as claimed in claim **1**, wherein the means for generating comprises modifier means for maintaining the first tone signal at a first fixed shape and for maintaining the second tone signal at a second first shape different from the first fixed shape, whereby the first and second waveshapes deviate statically.

5. Apparatus, as claimed in claim **4**, wherein the means for generating further comprises first shape modulator means for modulating the first waveshape at a first shape modulation rate, substantially continuously during the depression of one of the keys so that the first and second waveshapes deviate dynamically.

6. Apparatus, as claimed in claim **5** wherein the first tone signal is a rectangular wave and wherein the second tone signal is a sawtooth wave.

7. Apparatus, as claimed in claim **6**, wherein the first shape modulator means comprises means for pulse width modulating the rectangular wave.

8. Apparatus, as claimed in claim **7**, and further comprising second shape modulator means for modulating the shape of the sawtooth wave at a second shape modulation rate.

9. Apparatus, as claimed in claim **8**, wherein the first and second shape modulation rates are different.

10. Apparatus, as claimed in claim **1**, wherein the means for generating comprises:

oscillator means for producing the first and second tone signals with the same waveshape; and

first shape modulator means for modulating the first waveshape at a first shape modulation rate, so that the first and second waveshapes deviate dynamically with respect to each other.

11. Apparatus, as claimed in claim **10**, wherein the means for generating further comprises second shape modulator means for modulating the second waveshape at a second shape modulation rate.

12. Apparatus, as claimed in claim **11**, wherein the first and second shape modulation rates are different.

13. Apparatus, as claimed in claim **1**, wherein the means for generating comprises:

first high-frequency oscillator means for generating a first series of clock pulses at a first clock rate;

means for frequency modulating the first series of clock pulses at the first modulation frequency;

first divider means for generating a first series of tone pulse waveforms in response to the first series of clock pulses, a separate tone pulse waveform being generated for each key;

second high-frequency oscillator means for generating a second series of clock pulses at a second clock rate different from the first clock rate;

second divider means for generating a second series of tone pulse waveforms in response to the second series of clock pulses, a separate tone pulse waveform being generated for each key;

separate modifier means associated with each key, each modifier means comprising:

means for receiving a first tone pulse waveform from the first series and a second tone pulse waveform from the second series; and

means for altering the shape of the first and second tone pulse waveforms with respect to each other to form the first and second electrical tone signals.

14. Apparatus, as claimed in claim **13** and further comprising means for frequency modulating the second series of clock pulses at a second modulation frequency different from the first modulation frequency.

15. Apparatus for use in an electronic musical instrument having a keyboard including at least twelve keys corresponding to the twelve notes of a chromatic musical scale comprising:

means for generating simultaneously a first series of twelve tone signals having a first waveshape and corresponding to a predetermined first tempered scale, each of the tone signals in the first series having a different repetition rate and corresponding to a different one of the keys, and for generating simultaneously a second series of twelve tone signals having a second waveshape which deviates from the first waveshape and corresponding to a predetermined second tempered scale different from the first tempered scale, each of the tone signals in the second series having a different repetition rate and corresponding to a different one of the keys;

means for mixing with respect to each key a tone signal from the first series with a corresponding tone signal from the second series to produce a mixed electrical signal; and

means for converting the mixed electrical signals to a corresponding acoustical wave, whereby the sound of a chorus can be simulated.

16. Apparatus, as claimed in claim **15**, wherein the means for generating further comprises means for modulating the repetition rates of the first series of tone signals at a first modulation frequency.

17. Apparatus, as claimed in claim **16**, wherein the means for generating further comprises means for modulating the repetition rates of the second series of tone signals at a second modulation frequency different from the first modulation frequency.

18. Apparatus, as claimed in claim **16**, wherein the means for generating comprises means for maintaining each tone signal in the first series at a first fixed shape and for maintaining each tone signal in the second series at a second fixed shape which is different from the first shape, whereby the first and second waveshapes deviate statically.

19. Apparatus, as claimed in claim **16**, wherein the means for generating comprises means for modulating one of the first and second waveshapes so that the first and second waveshapes deviate dynamically with respect to each other.

20. Apparatus, as claimed in claim **19**, wherein the means for generating further comprises means for modulating the other of the first and second waveshapes.

21. Apparatus for use in an electronic musical instrument having a keyboard including at least twelve keys corresponding to the twelve notes of a chromatic musical scale comprising:

first high-frequency oscillator means for generating a first series of clock pulses at a first clock rate and for changing the first clock rate in proportion to the value of a first correction signal;

first divider means for generating a first series of twelve tone pulse waveforms corresponding to a predetermined first tempered scale of a predetermined key in response to the first series of clock pulses, a separate tone pulse waveform having a pitch repetition rate corresponding to a musical pitch being generated for each key;

low-frequency oscillator means for generating timing pulses at a timing repetition rate having a predetermined relationship to the pitch repetition rate of a predetermined one of the tone pulse waveforms in the first series corresponding to a predetermined one of the twelve keys;

first comparator means for comparing the relative phase of the timing pulses and the predetermined one of the tone pulse waveforms, and for generating and transmitting the first correction signal to the first high-frequency oscillator means such that the timing pulses and predetermined one of the tone pulse waveforms in the first series are locked in a predetermined phase relationship;

second high-frequency oscillator means for generating a second series of clock pulses at a second clock rate and for changing the second clock rate in proportion to the value of a second correction signal;

second divider means for generating a second series of twelve tone pulse waveforms corresponding to a predetermined second tempered scale of said predetermined key different from the first tempered scale in response to the second series of clock pulses, a separate tone pulse waveform having a pitch repetition rate corresponding to a musical pitch being generated for each key;

second comparator means for comparing the relative phase of the timing pulses and a predetermined one of the tone pulse waveforms in the second series corresponding to said predetermined one key, and for generating and transmitting the second correction signal to the second high-frequency oscillator means such that the timing pulses and the predetermined one of the tone pulse waveforms in the second series are locked in a predetermined phase relationship;

output means for converting the tone pulse waveforms in the first and second series to a corresponding acoustical wave; and

keyer means for transmitting the tone pulse waveforms to the output means in response to the actuation of the keys, whereby the musical notes corresponding to the keys remain in tune and whereby tone pulse waveforms generated according to the different first and second tempered scales can be mixed to simulate the sound of a chorus.

22. Apparatus, as claimed in claim **21**, and further comprising means for phase modulating the timing pulses transmitted to the second comparator means, whereby the pitch repetition rrates of the tone pulse waveforms in the first and second series vary dynamically with respect to each other.

23. Apparatus, as claimed in claim **21**, and further comprising modifier means for modifying the first series of tone pulse waveforms with respect to the second series of tone pulse waveforms so that the shape of each tone pulse waveform in the first series deviates from the shape of each tone pulse waveform in the second series.

24. Apparatus, as claimed in claim **23**, wherein the modifier means comprises means for maintaining each tone pulse waveform in the first series at a first fixed shape and for maintaining each tone pulse waveform in the second series at a second fixed shape different from the first fixed shape, whereby the shapes of the first and second tone pulse waveforms deviate statically.

25. Apparatus, as claimed in claim **23**, and further comprising first shape modulator means for modulating the shape of each tone pulse waveform in the first series at a first and second tone pulse waveforms deviate dynamically.

* * * * *