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Morez et al.

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[45] **Sept. 2, 1975**

[54] **ELECTRONIC MUSICAL INSTRUMENT WITH VARIABLE AMPLITUDE TIME ENCODED PULSES**

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[73] Assignee: **Chicago Musical Instrument Co.**, Chicago, Ill.

[22] Filed: **Feb. 20, 1974**

[21] Appl. No.: **444,028**

Related U.S. Application Data

[63] Continuation of Ser. No. 323,247, Jan. 12, 1973, abandoned.

[52] **U.S. Cl.** **84/1.27**; 84/1.01; 84/1.1; 84/1.27

[51] **Int. Cl.** **G10h 1/02**; G10h 5/00

[58] **Field of Search** 84/1.01, 1.03, 1.09–1.12, 84/1.17, 1.19, 1.21, 1.27

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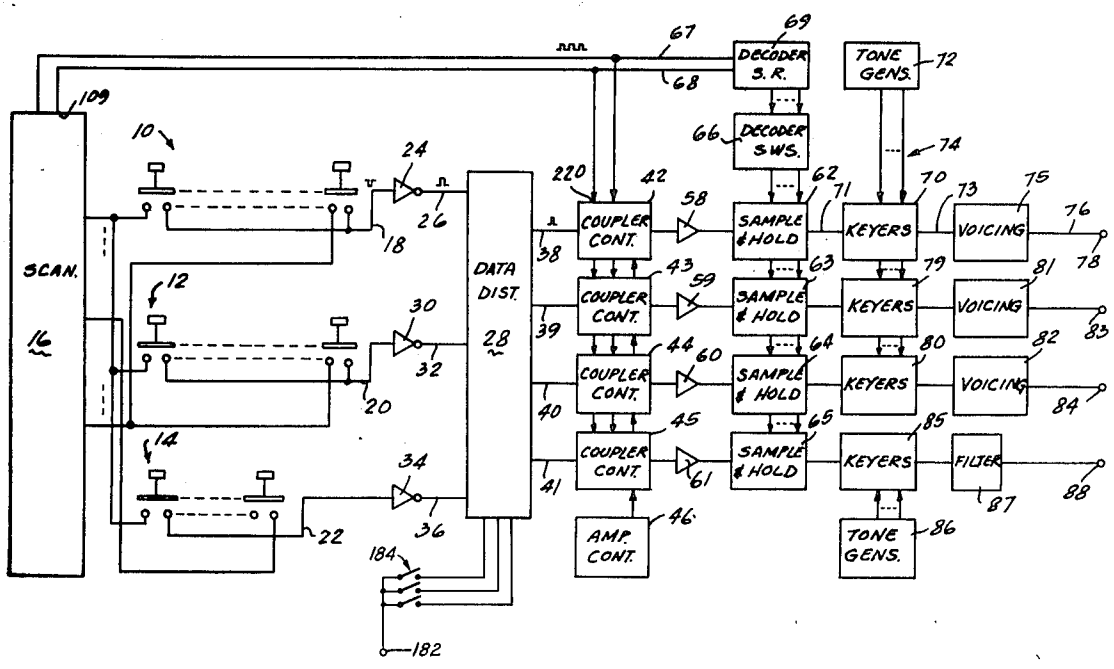
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[57] **ABSTRACT**

An electronic musical instrument has a scanner for scanning a plurality of key-operated switches and/or control switches in order to produce trains of pulses, encoded in time position during successive time intervals, in response to the keys or control switches which are operated, and a decoder for decoding the pulses for producing an output signal having components corresponding to the operated keys. A coupler control unit is provided for selectively shifting the position of the pulses within the train and for individually controlling the amplitude of the pulses of the train. A set of sample and hold units is responsive to the decoder for controlling the amplitude of each component of the output signal in accordance with the amplitude of its respective pulse. The key-operated switches are divided into three groups, associated with an upper manual of the instrument, a lower manual, and a pedal clavier, and a data distribution unit connects a selected group with a selected one of a plurality of coupler control units, each having an independent set of sample and hold units responsive to the decoder for controlling the selection and amplitude of components of an individual output signal.

17 Claims, 12 Drawing Figures



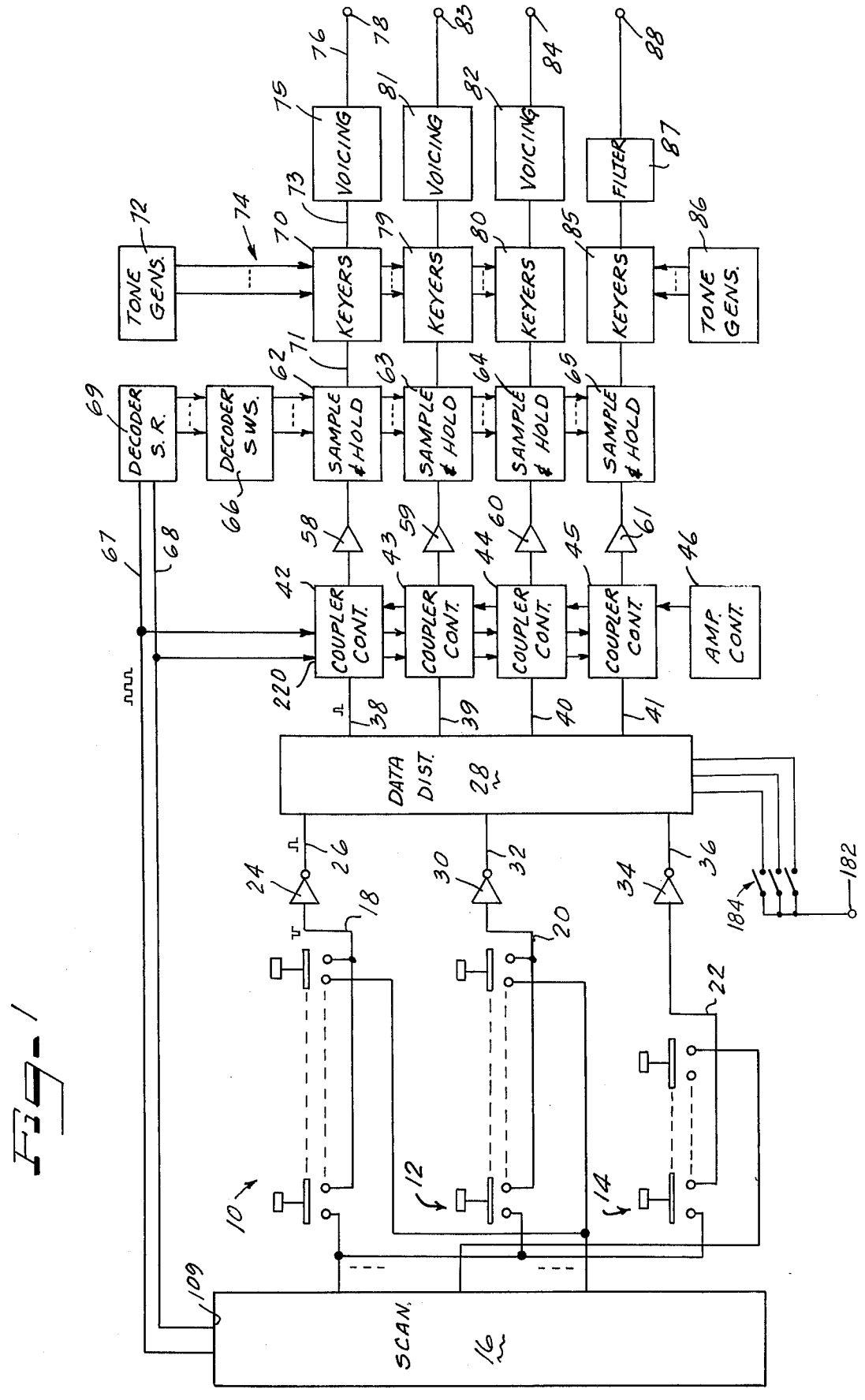

TONE GENS.
KEYERS
VOICING
FILTER
DECODER S.R.
DECODER SWS.
SAMPLE & HOLD
COUPLER CONT.
AMP. CONT.
DATA DIST.
SCAN.
10
12
14
16
18
20
22
24
26
28
30
32
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71
72
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87
88
109
182
184
220

Fig. 1

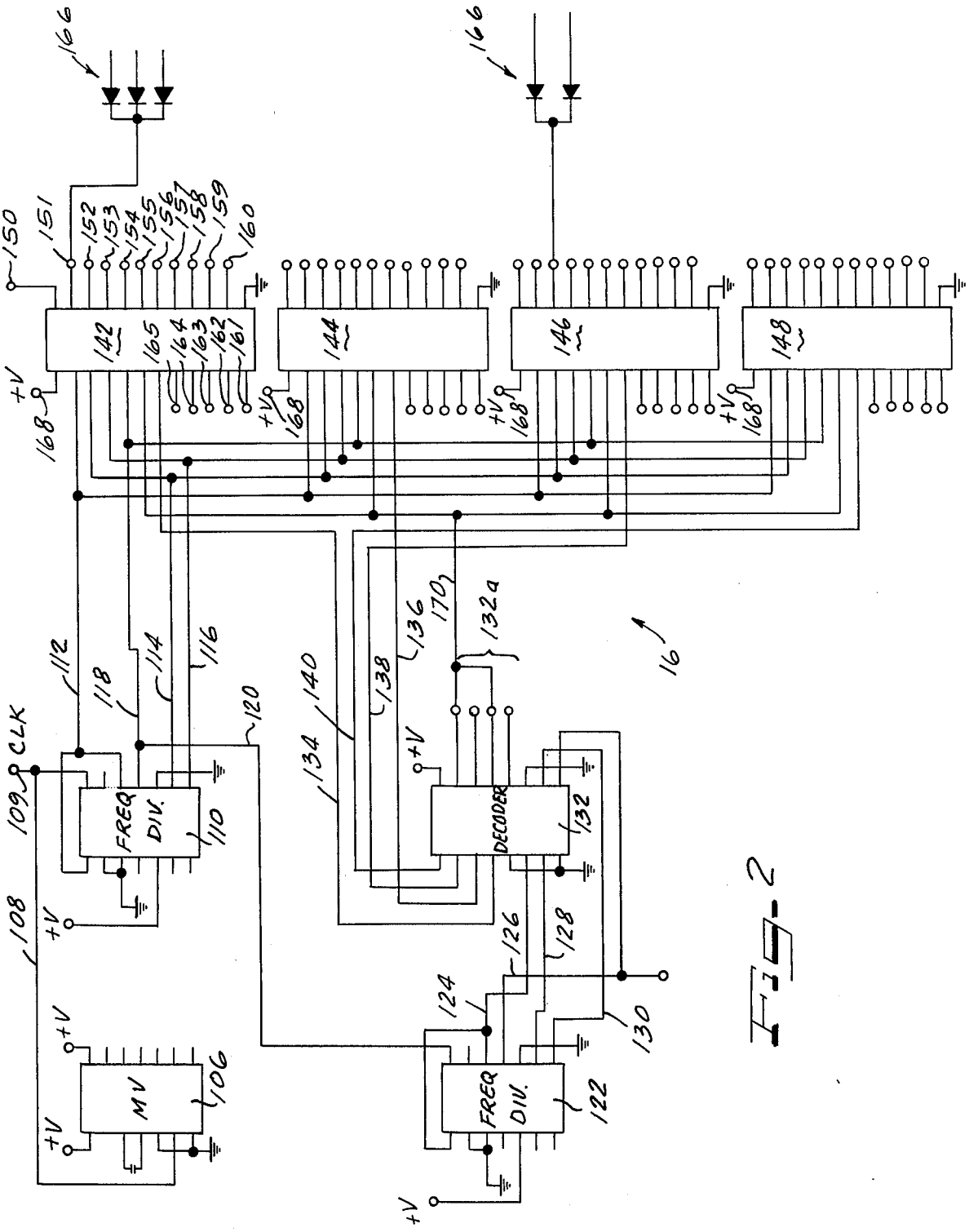

166
166
150
151
152
153
154
155
156
157
158
159
160
142
144
146
148
165
164
163
162
161
+V
168
CLK
109
108
112
114
116
118
120
FREQ DIV.
110
MV
106
136
170
132a
138
140
134
DECODER
132
126
128
124
130
122
16

Fig. 2

Fig. 3

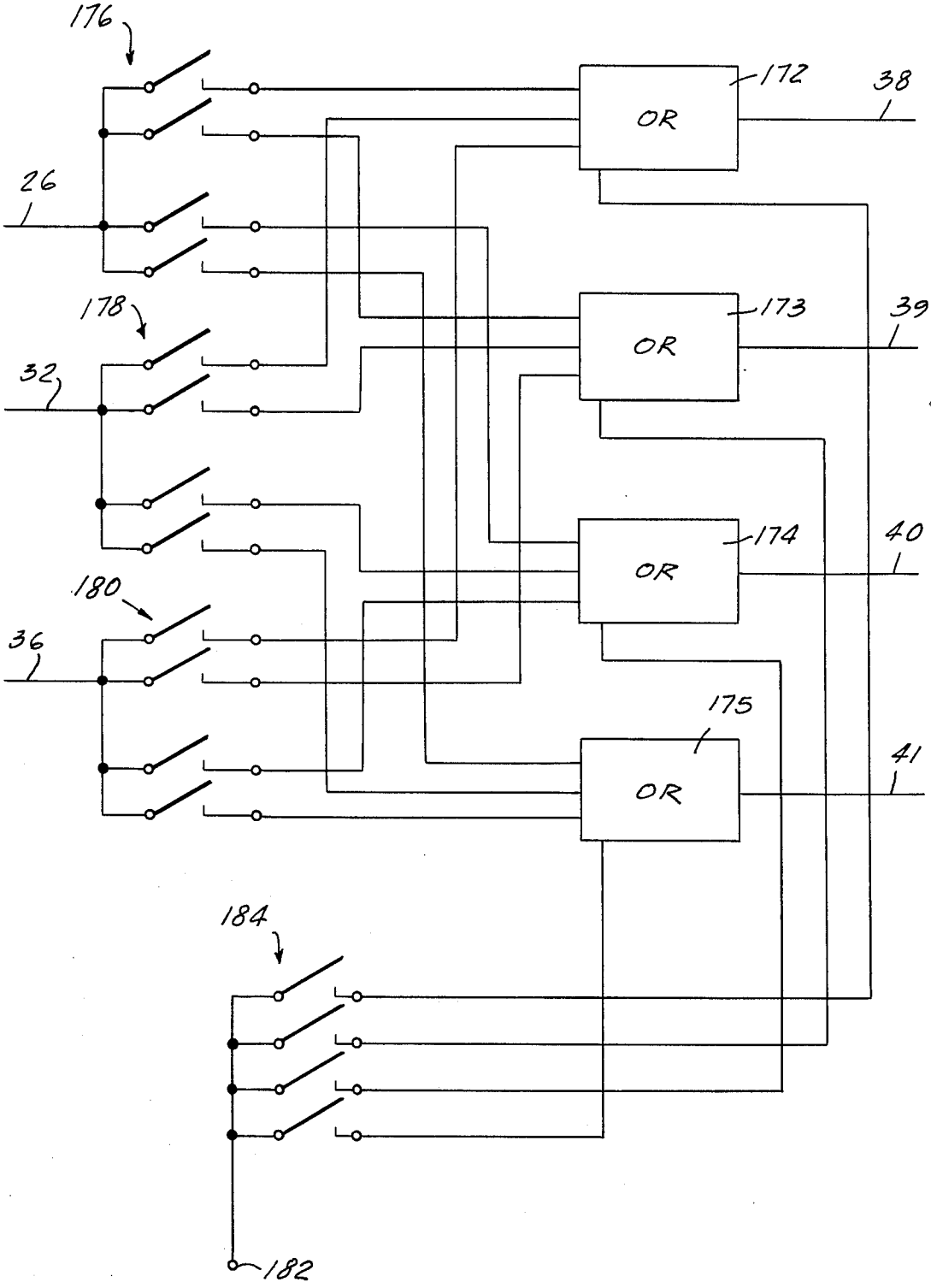


Fig. 4A

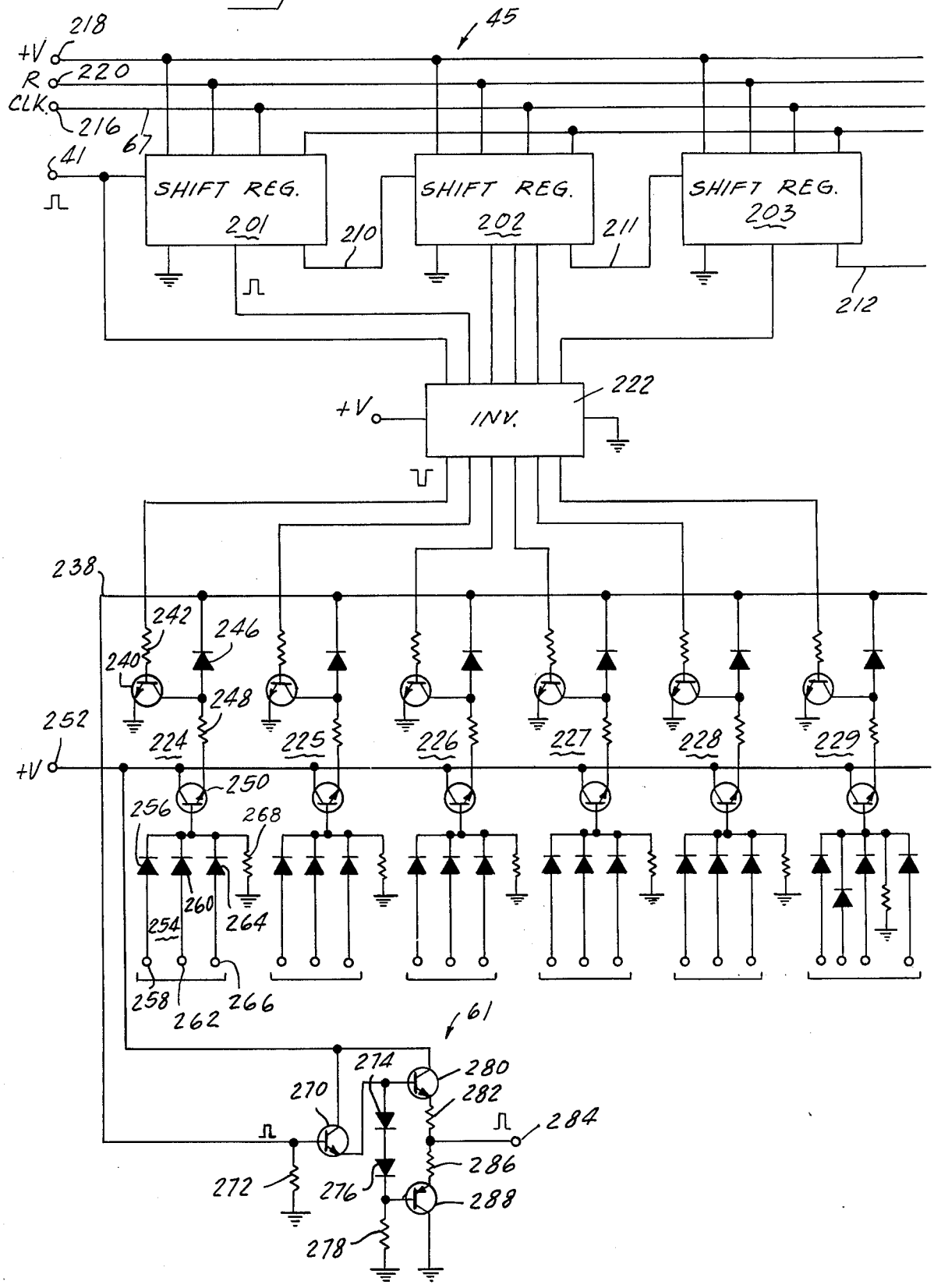

218
+V
220
R
CLK
216
67
45
41
SHIFT REG. 201
SHIFT REG. 202
SHIFT REG. 203
210
211
212
+V
INV.
222
238
242
246
240
248
224
225
226
227
228
229
252
+V
250
256
268
260
254
264
258
262
266
61
274
280
270
282
284
272
276
286
288
278

Fig. 4B

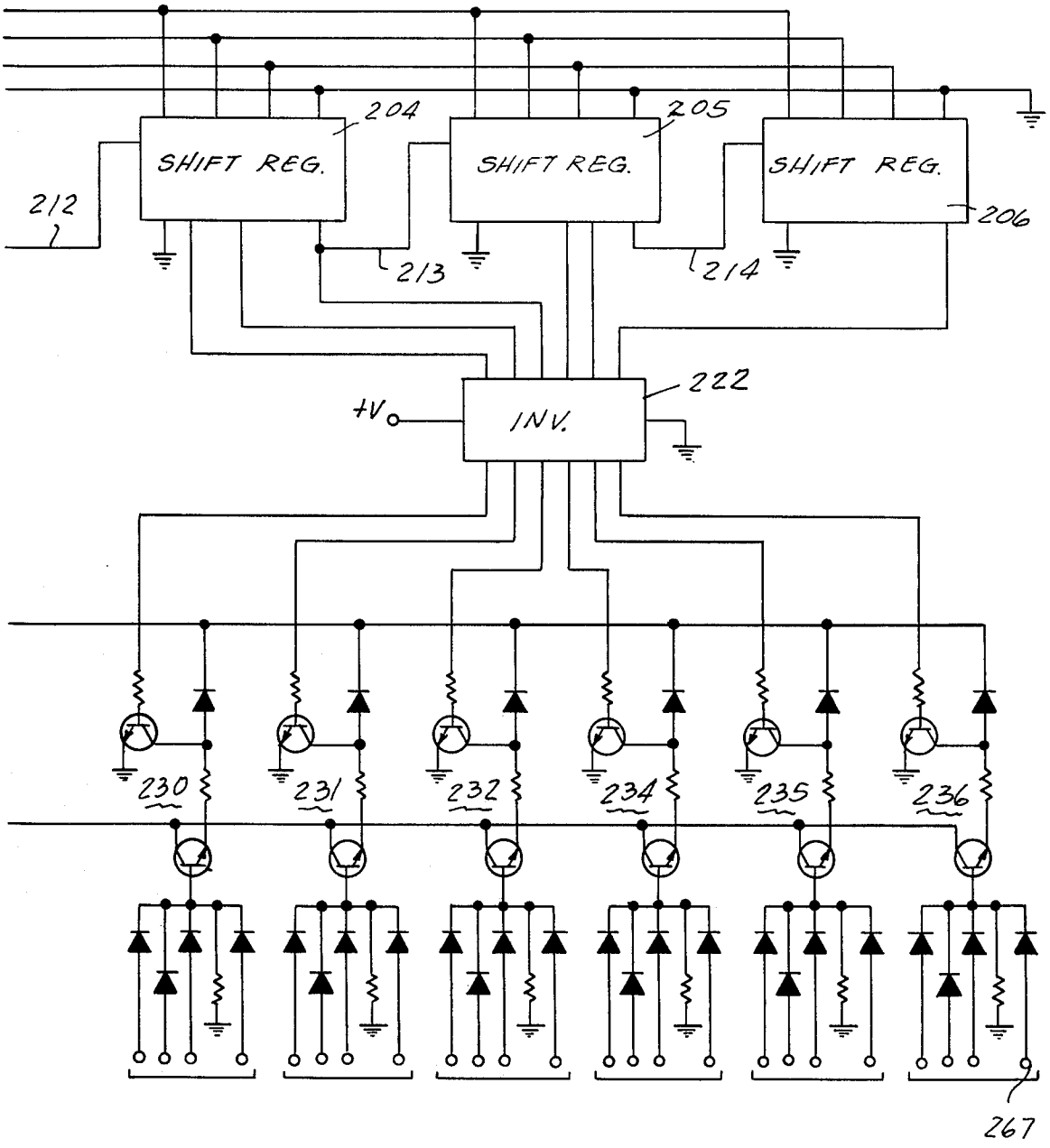

SHIFT REG.
204
SHIFT REG.
205
SHIFT REG.
206
212
213
214
+V
INV.
222
230
231
232
234
235
236
267

Fig. 5

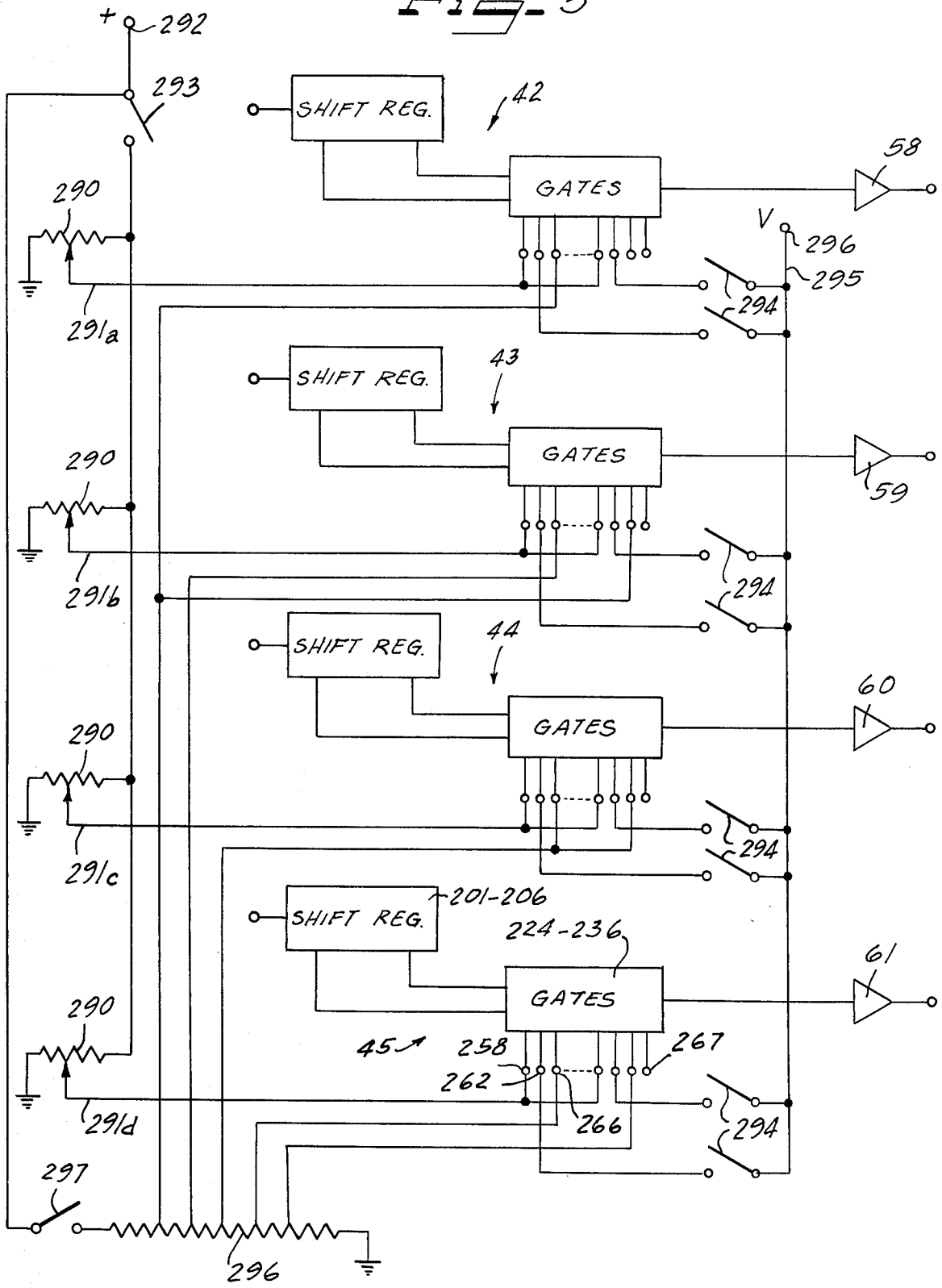
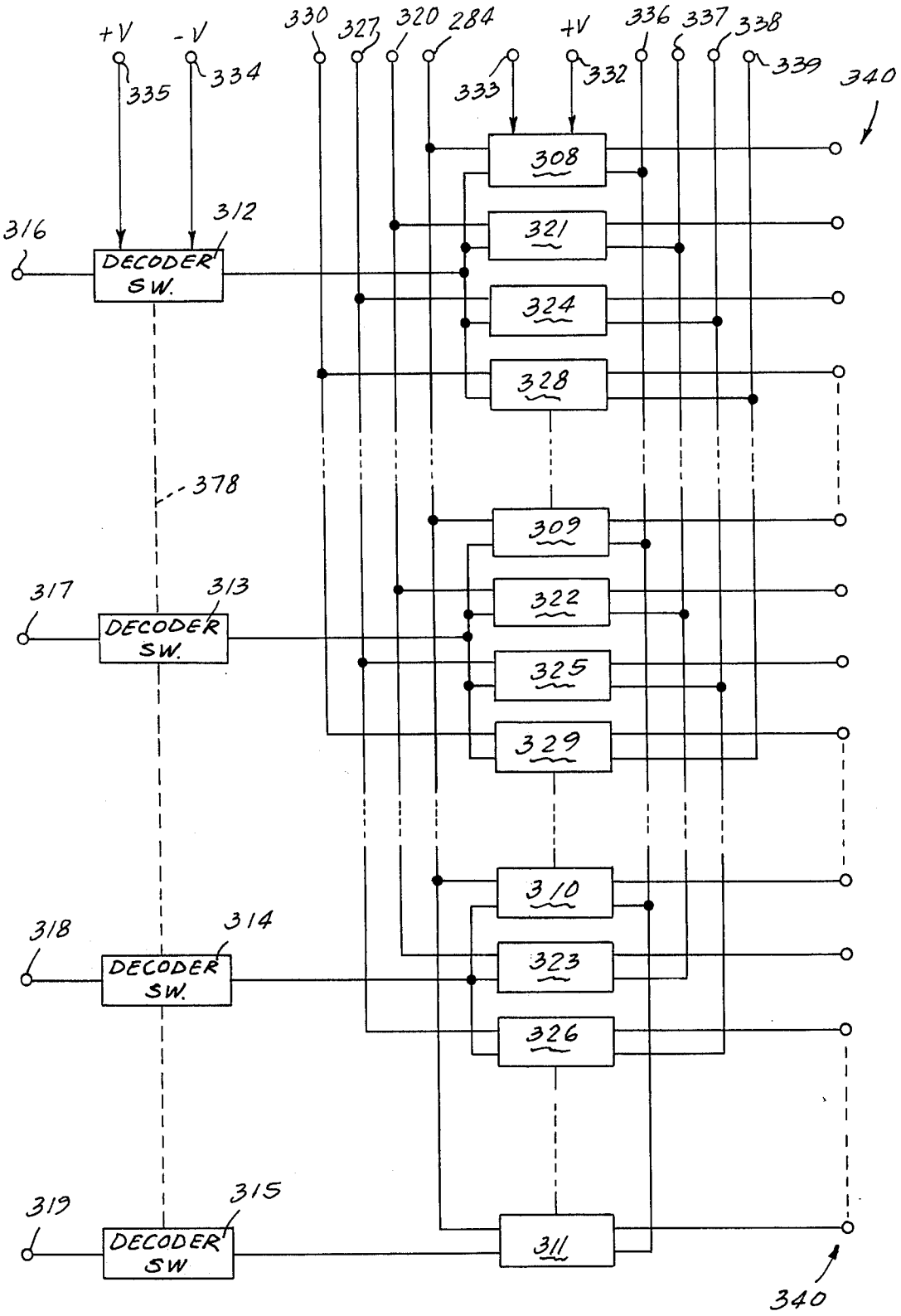

+
292
293
SHIFT REG.
42
GATES
58
290
V
296
295
294
291a
SHIFT REG.
43
GATES
59
290
294
291b
SHIFT REG.
44
GATES
60
290
294
291c
SHIFT REG.
201-206
224-236
GATES
61
290
45
258
267
262
266
294
291d
297
296

Fig. 6


+V
-V
335
334
330
327
320
284
333
+V
332
336
337
338
339
340
308
321
324
328
316
312
DECODER SW.
378
309
322
325
329
317
313
DECODER SW.
310
323
326
318
314
DECODER SW.
319
315
DECODER SW
311
340

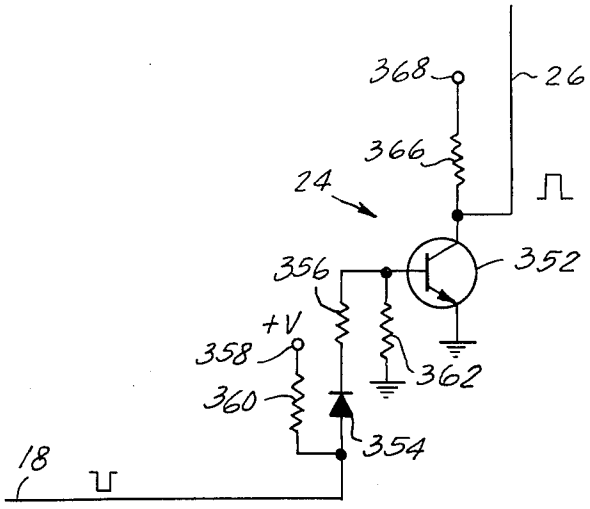


Fig. 7

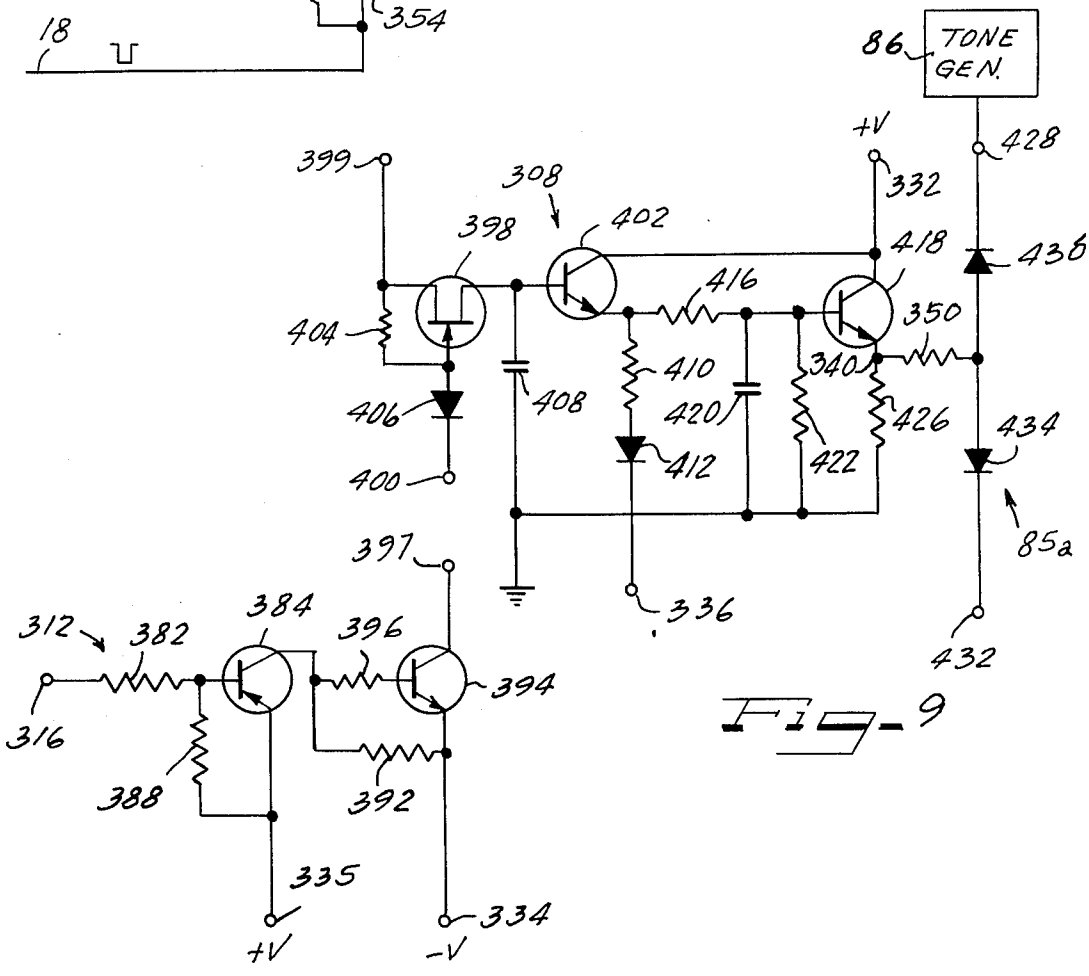


Fig. 9

Fig. 8

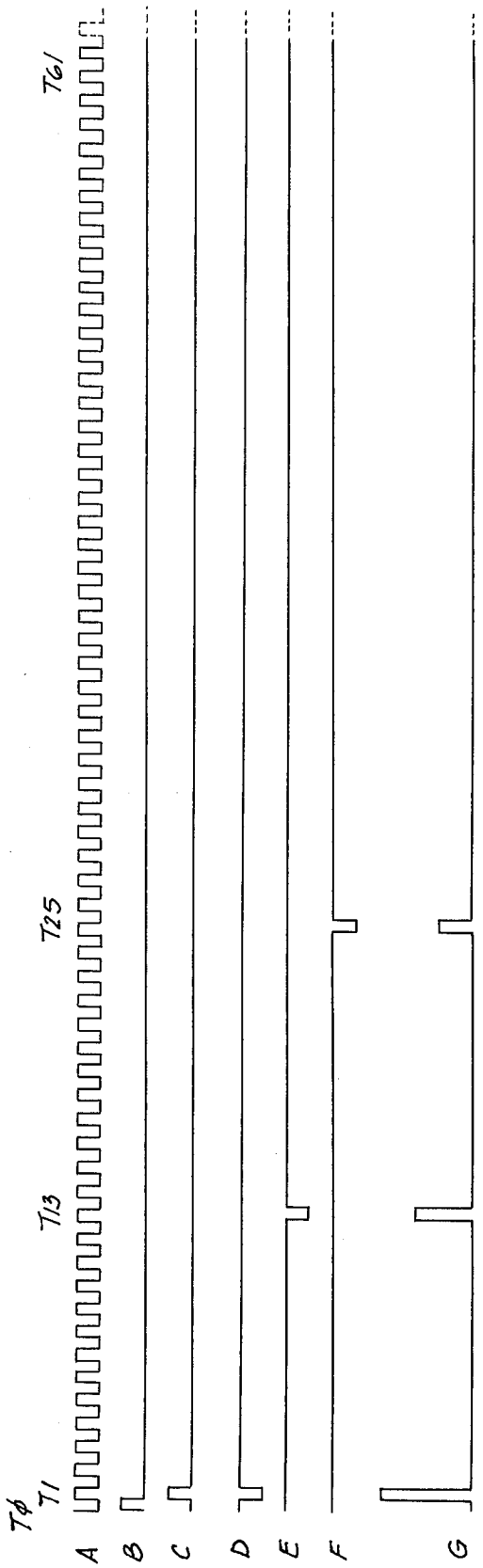

T0
T1
T13
T25
T61
A
B
C
D
E
F
G

FIG- 10

SCAN. 16
TIME POS. SEL. 440
442
444
446
448
450
452
GATE
GATE
456
SAMPLE & HOLD
SAMPLE & HOLD
454
455
462
TO REVERB CONTROL UNIT OF REVERB
SWITCH
SWITCH
458
460
DECODER SHIFT REG. 69
464
466
468
TO AMP GAIN CONTROL

FIG- 11

ELECTRONIC MUSICAL INSTRUMENT WITH VARIABLE AMPLITUDE TIME ELODED PULSES

This is a continuation of application Ser. No. 323,247, filed Jan. 12, 1973 and now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to electronic musical instruments such as electronic organs and the like, and more particularly to such instruments which have a plurality of key operated switches by which it is desired to control the selection of components of an output signal which is converted into musical sounds by a loudspeaker or the like.

2. The Prior Art

In the prior art, conventionally it has been necessary to employ a number of key switches for each key of the keyboard of an electronic instrument such as an electronic organ or the like. The multiple switches are required in order to simultaneously operate a number of different circuits, each of which are selectively energized by means of selection of manually operable tab switches or the like. As a result, wiring the keyboard of such an instrument is a relatively complex and time consuming task, and a great number of connections must be made to the various switches, which is both time consuming and costly. It is therefore desirable to eliminate the keyboard wiring arrangements which have been used in the past without sacrificing any functional feature.

SUMMARY OF THE INVENTION

It is an object of the present invention to use only a single switch for each key of the keyboard, to reduce the amount of wiring necessary in the assembly of the instrument, and to facilitate its manufacture and testing.

It is an object of this invention to be able to selectively control the amplitude of various components of the output signal which are produced in accordance with the depression of the keys of the keyboard, either independently or in accordance with some prearranged arrangement, and also to selectively enable the operation of a single key to produce a plurality of components in the output signal, to form chords and the like, without the need for more than one switch per key.

Accordingly it is a principal object of the present invention to provide apparatus which can select components for a composite output either singly or in groups, in response to operation of the keys of an electronic musical instrument, without requiring more than a single switch for each key.

Another object of the present invention is to provide apparatus which can selectively and individually regulate the amplitudes of the components of a composite output signal selected by operation of the keys, without requiring more than a single switch for each key.

Another object of the present invention is to provide an arrangement which enables simplification of all of the control functions of an electronic musical instrument.

These and other objects and advantages of the present invention will become manifest upon an examination of the followiing description and the accompanying drawings.

In one embodiment of the present invention there is provided an electronic musical instrument having a scanner for producing, during successive time intervals, trains of pulses encoded in time position corresponding to operated keys, a coupler control unit for selecting an amplitude for each of the pulses, a decoder for decoding the time position of the pulses, a plurality of sample and hold units responsive to the decoder for manifesting the selected amplitude for each of the pulses, and a plurality of keyers connected to the sample and hold devices and responsive thereto for producing a composite output signal with components corresponding to said operated keys, the components each having an amplitude corresponding to the selected amplitude.

ON THE DRAWINGS

Reference will now be made to the accompanying drawings, in which:

FIG. **1** is a functional block diagram of an illustrative embodiment of the present invention;

FIG. **2** is a functional block diagram of the scanner of FIG. **1**;

FIG. **3** is a functional block diagram of the data distribution unit of FIG. **1**;

FIG. **4** is the composite of FIGS. **4A** and **4B**, is a functional block diagram, partly in schematic circuit diagram form, of a coupler control unit employed in the apparatus of FIG. **1**;

FIG. **5** is a functional block diagram, of a plurality of coupler control units employed in the apparatus of FIG. **1**, showing the manner in which the amplitude controls are connected with the coupler control units;

FIg. **6** is a functional block diagram of the decoder switches and the sample and hold units of FIG. **1**;

FIG. **7** is a schematic circuit diagram of a level shifter employed in the apparatus of FIG. **1**;

FIG. **8** is a schematic circuit diagram of a decoder switch employed in the apparatus of FIG. **6**;

FIG. **9** is a schematic circuit diagram of a sample and hold unit employed in the apparatus of FIG. **6**, in association with a keyer;

FIG. **10** is a wave form diagram of certain signals produced by the coupler control unit; and

FIG. **11** is a functional block diagram of an arrangement for executing certain control functions by the use of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** is a schematic block diagram of an electronic musical instrument incorporating an illustrative embodiment of the present invention. Three groups **10, 12** and **14** of the key-operated switches are provided, which are, respectively, the key-operated switches of the upper manual or keyboard, the lower manual, and the pedals. The keys may comprise any type of suitable activating member. As is conventional in electronic organs, the upper and lower manuals have as many as 61 keys each and there are as many as 32 pedal keys. Each key and pedal has a single switch, which is a normally open, single-pole, single-throw switch, by which one of a plurality of output lines of a scanner **16** are connected from the scanner **16** to one of three data lines **18, 20** and **22.** The data line **18** is provided for the switches of the group **10**; the data line **20** is provided for the switches of the group **12**; and the data line **22** is provided for the switches of the group **14.**

As is more fully described hereinafter the scanner **16** has a total of 63 output lines which are energized se-

quentially in step-by-step fashion so as to apply pulses successively to each of the individual switches in the three groups **10, 12** and **14.** One line is used for a synchronization pulse; another supplies clock pulses for the system, and the other 61 lines are connected individually to the switches of the group **10** and also to the switches of the group **12.** The switches of the group **14** are connected to 32 of the output lines. As a result, the data lines **18, 20** and **22** each produce simultaneous pulse trains, with each pulse being in encoded in time position in accordance with an operated switch.

The data line **18** is connected to an input of a lever shifter **24,** the output of which is conveyed by a line **26** to one input of a data distribution unit **28.** Similarly the data line **20** is connected to the input of a level shifter **30,** the output of which is connected to the data distribution unit **28,** via a line **32.** In identical fashion, the data line **22** is connected through a level shifter **34** and a line **36** to a third input of the data distribution unit **28.**

The function of the data distribution unit **28** is to interconnect the inputs on the three lines, **26, 32** and **36** to one or more of a plurality of output lines **38, 39, 40** and **41,** in order to accomplish a variety of functions, as more fully described hereinafter. In one arrangement the data distribution unit **28** is effective to couple the input line **26** from the upper manual switches **10** to the output line **38,** which is connected to the input of an upper manual coupler control unit **42,** and to couple the input line **32** to an output line **39** which is connected to the input of a lower manual coupler control unit **43,** and to couple the input line **36** to an output line **40,** which is connected to the input of a pedal coupler control unit **44.** Alternatively, any of the three input lines **26, 32** and **36** may be coupled to an ouput line **41,** which is connecteed to the input of a flute coupler control unit **45.**

The function of each of the coupler control units **42–45** is to convert the pulse train at its input to a corresponding pulse train at its output in which the time position of the pulses is shifted in a selected way, and other pulses are selectively added to the pulse train at time positions which represent musical notes which are harmonically related to the notes represented by pulses of the input pulse train. In addition, the amplitude of each pulse is controlled by means of a amplitude control unit **46,** which is directly connected to all of the coupler control units **42–45.**

The output of the upper manual coupler control unit **42** is connected through an amplifier **58** to a plurality of the sample and hold units which are indicated diagramatically in FIG. **1** by a block **62.** The block **62** contains **61** separate sample and hold units one for each of the switches in one of the groups **10, 12** and **14,** as selected by the data distribution unit **28,** and all such **61** sample and hold units have one input connected to the output of the amplifier **58,** and another input connected individually to **61** separate decoder switches represented by the decoder switch unit **66.** The **61** decoder switches are each connected individually to outputs of a decoder shift register **69,** which is operated in synchronism with the scanner **16.** A series of clock pulses supplied from the scanner **16** to the shift register **69** over a line **67** advances the state of the shift register **69** and are also applied directly to each of the coupler control units **42–45.** Synchronization is insured by synchronization pulses which are supplied by the scanner **16** to the shift register **69** over a line **68.** The function of the shift register **69** is to drive the decoder switches **66,** enabling the sample and hold units **62** to be triggered in synchronism with the scanner **16,** to sample the amplitude of each pule of the pulse train produced by the amplifier **58.** During each cycle of the scanner **16,** which is synchronized with each cycle of theh shift register **69,** the voltage levels which are held by the sample and hold units **62** are resampled updated.

Three other groups of sample and hold units **63, 64** and **65** are provided for sampling the outputs of amplifiers **59, 60** and **61,** respectively, which are derived from the coupler control units **43, 44** and **45.** The sample and hold units of each group have one input connected in common to the output of one of the amplifiers **59–61,** with the other input connected individually directly to an output of the decoder switches **66.** The voltage levels manifested by the sample and hold units in the block **62** are connected to a plurality of keyers **70,** one or more for each sample and hold unit in the block **62,** over a plurality of connection lines **71.** Each keyer in the block **70** is operative to connect a separate tone signal from a tone generator **72** to one or more output lines **73.** The tone generator **72** provides a plurality of independent tone signals which are available individually on a plurality of output lines **74,** which are connected individually to the keyers **70.** The lines **71** are connected individually to the keyers **70,** so that operation of any given keyer allows the tone signal present on its input line **74** to be conveyed to the output line **73.** The output lines **73** are connected to one or more voicing units **75,** each of which modifies the electrical signals present on the output line **73** in any desired manner. The outputs of the voicing unit or units **75** are connected by way of a line **76** to an output terminal **78** which is conveniently connected to a power amplifier and a loudspeaker system.

Two additional blocks **79** and **80** represent further groups of keyers which are provided for the sample and hold units **63** and **64,** respectively, and which serve to couple selected ones of the outputs of the tone generator **72** to voicing units **81** and **82,** respectively, the outputs of which are connected, respectively, to terminals **83** and **84.** Another set of keyers **85,** which are the flute keyers, is provided for the sample and hold unit **65,** but it serves to connect the various outputs of a tone generator **86** to an output, which is connected through a voicing filter **87** to an output terminal **88.**

As shown in Fig. **2,** which illustrates the scanner **16,** an astable multivibrator **106** functions as a free running square wave oscillator. The output thereof is produced on a line **108,** and comprises a series of clock pulses which are furnished to various other units. A terminal **109** is connected to the line **108,** and the line **67** (FIG. **1**) is connected to the terminal **109.**

The line **108** is connected to the input of a frequency divider unit **110** which functions to divide the pulse repetition rate of the pulse train appearing on the line **108** by **16.** The divider unit **110** has four outputs on lines **112, 114, 116** and **118,** which are provided respectively, with pulse trains having repetition rates equal to that of the pulse train on the line **108** divided by factors of 2, 4, 8 and 16 respectively. The four lines **112, 114, 116** and **118** are connected to four inputs of a scanner decoder unit **142** which functions to successively energize one of 16 outputs **150–165** in response to binary numbers represented by the 16 combinations of voltage levels on the lines **112, 114, 116** and **118,**

whenever a control voltage is present on a control input connected to a line **134.** Three other scanner decoder units **144, 146** and **148** have four inputs each connected to the lines **112, 114, 116** and **118,** but their control inputs are connected, respectively, to lines **136,** 138 and **140.**

The output on the line **118** is also connected by a line **120** to the input of a further divider unit **122** which is identical to the unit **110,** but which functions to divide the pulse repetition rate of the pulse train on the line **120** by a factor of 16. Four outputs on lines **124, 126,** 128 and **130** are connected from the unit **122** to various inputs of a unit **132** which functions as a dual one-of-four decoder. The unit **132** has eight outputs, four of which are connected to terminals **132***a* and the other four of which are connected to the lines **134, 136, 138** and **140.** The lines **134–140** are energized sequentially, each for the time required for **16** changes of state on the lines **112, 114, 116** and **118.** The units **142, 144,** 146 and **148** are energized successively, so that the **16** output terminals of each of the units **142, 144, 146** and **148** are energized in succession, making 64 pulses available successively on 64 individual outputs.

The terminals **150–165** of the unit **142,** and the corresponding terminals of the other units **144, 146** and **148,** constitute the output terminals of the scanner **16.** A plurality of diodes **166** have their cathodes connected in common to each of these outputs, and the anodes of the diodes **166** are connected individually to switches of the three groups **10, 12** and **14** (FIG. 1). The terminal **150** is used for synchronization purposes, but the next 32 output terminals are connected through isolating diodes **166** to the first 32 key operated switches of the upper manual group **10,** and to the first 32 key operated switches of the lower manual group **12,** as well as to the switches of the pedal group **14.** The next 29 outputs are connected to the remaining switches of the upper and lower manuals through other diodes **166.**

Each of the units **142, 144, 146** and **148** is connected to a terminal **168** by which it receives a source of positive voltage, and each is also connected to a line **170,** which is connected to two alternate ones of the terminals **132***a*, when the units **142, 144, 146** and **148** are to be rendered operative.

The four terminals **132***a* are energized successively, each for **64** successive clock pulses on the line **108.** Accordingly, the line **170** is energized for 64 pulse times while output pulses are manifested on the 64 output terminals of units **142, 144, 146** and **148,** and then remains unenergized for the following 64 pulse times, after which the operation is repeated. The length of a single cycle of operation is therefore 64 pulse times, and the synchronization terminal **150** is energized by the first output pulse of each cycle. The line **68** (FIG. 1) is connected to the terminal **150.**

The units **106, 110, 122** and **132** are each provided with a connection to a source of positive voltage, and also with a connection to ground.

As shown in FIG. **1,** the data line **18,** which is a common connection of the switches of the group **10,** is connected through the level shifter **24** to the line **26.** The level shifter **24** functions to stabilize the voltage level of the pulses making up the pulse train on the line **26** at a predetermined value, so that each pulse has the same amplitude and that amplitude is at an appropriate level for the logic circuits which follow. The other two level shifters **30** and **34** are identical. The output of the level shifters **24, 30** and **34** are connected to the data distribution unit **28,** which will now be described.

As shown in FIG. **3,** the three input lines **26, 32** and **36** which are connected from the level shifters **24, 30** and **34,** are each connected to a plurality of switches, by which the three inputs are each connected to one of four OR gates **172–175.** A group of four switches **176** connects the input line **26** individually to the four gates **172–175,** and the switches provided for the other input lines **32** and **36** are similarly connected. Two additional groups **178** and **180** are provided for the input lines **32** and **36,** and they are connected in identical fashion. Although the switches **176, 178** and **180** are shown as being mechanical single-pole, single-throw switches, they may alternatively take the form of electronic switches formed of gates, with suitable control signals for operating the gates derived by manually operable switches.

The four OR gates **172–175** are connected, respectively to the output lines **38, 39, 40** and **41,** and serve to furnish to such output lines the pulse trains of each of the input lines to which it is connected via the switches **176, 178, 180** and **184.**

Additional pulses, generated by an external device such as a rhythm device connected to an input terminal **182,** are selectively added to one or more of the gates **172–175** by operation of the switches **184.** In this way, a series of pulse trains representative of an externally generated pulse train may be added to any one or more of the ouput lines **38, 39, 40** and **41.** The line **41** is connected to the flute coupler control unit **45,** which will now be described.

FIGS. **4A** and **4B,** which together illustrate the flute coupler control unit **45,** show a shift register composed of a series of six shift registers **201–206** connected together in cascade. Each of the shift registers **201–206** comprises **10** stages, but a greater number of stages may be used in accordance with the principles of the present invention, if desired. The input line **41** is connected to the input of the first shift register **201,** and a line **210** connects the last stage of shift register **201** to the first stage of the shift register **202.** In similar fashion, lines **211–214** interconnect the last stage of each of the remaining shift registers to the first stage of the succeeding shift register.

A terminal **216** is connected directly to the line **67** (FIG. **1**) to supply clock pulses to each of the shift registers **201–206,** and a terminal **218** is connected to a source of positive potential to energize the various shift registers. Each unit is provided with a ground connection. One additional terminal **220** is provided and is directly connected to the line **68** (FIG. **1**) to reset the shift registers at the beginning of each pulse train. Various outputs of the shift registers **201–206,** as well as the input line **41,** are connected through individual ones of a plurality of inverters contained in an inverter unit **222** to the inputs of a plurality of gates **224–236.** Each of the gates **224–236** functions to connect a variable amplitude signal to an output bus **238,** in the manner which will now be described.

Each gate **224–236** comprises a transistor **240** having its emitter connected to ground and its base connected through a resistor **242** to one of the inverters of the unit **222.** A diode **246** is connected from the collector of the transistor **240** to the bus **238,** and a resistor **248** connects the collector of the transistor **240** to the emitter

of a second transistor 250, the collector of which is connected to a terminal 252, and the base of which is connected to a circuit 254 including a plurality of diodes 256, 260 and 264. The diode 256 connects the base of the transistor 250 to a terminal 258, a diode 260 connects the base of the transistor 250 to a terminal 262, and a diode 264 connects the base of the transistor 250 to a terminal 266. A resistor 268 is connected from the base of the transistor 250 to ground.

The terminal 252 is connected to a source of positive voltage and the voltage level at the emitter of the transistor 250 is conditional upon the voltage applied to the three input terminals 258, 262 and 266. The highest of the three input voltages, reduced by the small voltage drop across its diode and the value of the base-emitter voltage drop of the transistor 250, appears at the emitter of the transistor 250. Normally the voltage level applied to the base of the transistor 240 through the resistor 242 is at a high value, so that the transistor 240 is saturated, clamping its collector substantially to ground through the transistor 240. When a negative pulse is applied to the base of a transistor 240 through the resistor 242 however, the transistor 240 is cut off, and whatever value of potential exists at the emitter of the transistor 250 is connected to the output data bus 238 through the resistor 248 and diode 246. Accordingly, the time that an output pulse is produced by each of the gates 224–236 is defined by the occurrence of a pulse at the base of the transistor 240, and the value of the output voltage on the bus 238 at that time is dependent upon the highest voltage applied to the terminals 258, 262 and 266. The three inputs 258, 262 and 266 are responsive respectively to three separate sources of voltages, as described hereinafter in connection with FIG. 5.

The output bus 238 is connected to the base of a transistor 270, and to ground through a resistor 272. The collector of the transistor 270 is connected to the terminal 252. The transistor 270 functions as an emitter follower, and its emitter is connected to ground through a series circuit including diodes 274 and 276 and a resistor 278.

The emitter of the transistor 270 is also connected to the base of an npn transistor 280, the collector of which is connected to the terminal 252 and the emitter of which is connected through a resistor 282 to an output terminal 284. In similar fashion, the output terminal 284 is connected through a resistor 286 to the emitter of a pnp transistor 288, the collector of which is connected to ground, and the base of which is connected to the junction of the diode 276 and the resistor 278. The voltage level at the output terminal 284 is the same as the voltage on the bus 238. In response to the application of a pulse in response to operation of one of the gates 224–236, the emitter current of the transistor 270 increases, driving the transistor 280 further into conduction and cutting off the transistor 288 and producing a positive pulse at the output 284. The circuit including the tansistor 270, 280 and 288 functions simply as a current amplifier for producing a pulse of relatively high current at the output terminal 284 in response to the operation of each gate. This amplifier is the amplifier 61 shown in FIG. 1. The amplifiers 58–60 provided for the other three data channels are identical to the amplifier 61.

The significance of the shift registers 201–206 and the connection of various output terminals thereof to the gates 224–236 will now be described. It will be recalled in reference to the description of the scanner that the operation of any key of the three groups of keys 10, 12 and 14 determines the time position of the pulse passed by its associated switch. It is the function of the shift register made of the shift register units 201–206 to delay such a pulse in order to shift its time position in the pulse train to a position representative of a higher musical tone, such as a harmonic or overtone of the tone represented by the original pulse passed by the key operated switch. When the original pulse, together with the pulse which is delayed and therefore shifted in time position by means of the shift register units, are both selected by their respective gates, the single pulse produced by the key operated switch is transformed into two pulses representative of two notes, just as if the keys corresponding to both of such notes had been depressed. Moreover, if only the gate associated with the delayed pulse is selected, then a single pulse is presented to the output bus 238, but delayed in time so that it represent a higher musical tone. Thus, by selecting various ones of the gates 224–236, any of the groups of switches 10, 12 and 14 (FIG. 1) may be operated fpr selecting musical tones over a wide range of frequencies.

The gate 224, which passes pulses which are not delayed, may be referred to, in organ terminology, as the 16 foot gate, with the other gates 225–236 respectively referred to as the 10⅔ foot gate, the 8 foot gate, the 6 2/5 foot gate, the 5⅓ foot gate, the 4 foot gate, the 2⅔ foot gate, the 2 foot gate, the 1 3/5 foot gate, the 1 1/3 foot gate, the 1 foot gate, and the ½ foot gate. Each footage reduction to one-half the previous value represents a delay of the input pulse train by 12 pulse times, or 12 musical notes, or one octave. Accordingly, the ½ foot gate increases the encoded time position of input pulses by five octaves, by delaying the input pulses by sixty pulse times. Reductions by factors other than one-half represents partials or non-octavely related harmonics.

FIG. 10 further illustrates how the shift registers 201–206 operate to delay pulses. The clock pulses are illustrated in line A of FIG. 10, which is a graph of voltage level with time. Line B of FIG. 10, is a graph of the pulse which is applied to the terminal 220 to reset the shift registers 201–206. The line C of FIG. 10 shows a pulse at time T1, representing a depressed or operated key which passes the first output pulse from the scanner 16. The line D of FIG. 10 shows the same pulse at the first output of the inverter unit 222. Lines E and F of FIG. 10 show the same pulse at the outputs of the inverter unit 222 which are connected to the inverter unit from two outputs of the shift registers 201–206, namely, the outputs which are energized 12 and 24 pulse times after a pulse is applied to the input of the shift register 201. These pulses occur at times T13 and T25, respectively.

The line G of FIG. 10 represents the pulse train present on the bus 238 when the gates provided for the pulses at T1, T13 and T25 are activated by appropriate gating voltages on their input diodes. When the gating voltage is highest for the first gate, and lowest for the third gate, the height of each pulse of the pulse train are as shown in the line G of FIG. 10, in which the height of each pulse is proportional to the highest voltage applied to the diodes of the gate which passes it.

A separate shift register is provided for each of the three other coupler control units 42, 43 and 44 (FIG.

1). Accordingly, by energizing different ones of the gates 224–236 in each coupler control unit, one can play single tones with the keys of one manual, while the keys of the other manual produce other pulse trains, and the switches of the pedals produce an entirely different pulse train.

The possible chord combinations are limited only by the number of gates 224–236 which are provided for each of the coupler control units 42, 43, 44 and 45 and the output stages of the shift registers 201–206 to which the gates are connected. All of the output stages to which the gates of FIGS. 4A and 4B are connected are harmonically related, as this is desirable for flute voicing. For the other three coupler control units 42, 43 and 44, however, gates similar to the gates 224–236 may be connected to any outputs of their associated shift registers, and for at least one of the coupler units it may be desirable to employ a plurality of switches (not shown) to permit the gates to select desired combination of outputs of the shift register units for connection to the bus 238.

A feature of operation of the coupler control units of the present invention is that the amplitude of the pulse at any particular time position in the pulse train is not necessarily affected by the number of gates 224–236 which are operative to produce pulses at the same time position of the pulse train on the output bus 238. For example, when the key for a certain musical tone has been operated, and the key for a harmonic thereof has also been operated, and when both the 16 foot gate 224 and the gate for that particular harmonic have been selected by appropriate control signals, then the same time position in the pulse train is energized simultaneously by both of the gates. The value of the voltage on the output bus 238 at this instant is dependent only upon which of the two energized gates is connected to the higher voltage level through one of its input diodes. If both gates are connected to the same voltage level, the output voltage level on the bus 238 is the same as if only one of the gates was selected. If, however, the voltage levels which are applied through the two input diodes of the selected gates are dissimilar, the higher voltage value is selected and connected to the bus 238. The significance of this feature is that the amplitude of each pulse of the pulse train on the output bus 238 does not depend on the number of gates passing such a pulse, but only on the gating votage level. This feature also allows for an override condition which permits a high amplitude pulse to override the effect of a lower amplitude pulse, for percussion effects, and the like.

Referring now to FIG. 5, an arrangement for supplying gating potentials to the several coupler control units 42, 43, 44 and 45 is illustrated. Each of the coupler control units such as 45 includes a shift register such as 201–206 and a plurality of gates, such as the gates 224–236 illustrated in FIGS. 4A and 4B, shown in FIG. 5 in block diagram form. Each of the gates 224–236 has three input terminals corresponding to the input terminals 258, 262 and 266 of FIG. 4A, and the gates corresponding to the gates from the 4-foot gate down to the lowest footage gate are provided with a fourth input terminal 267, as illustrated in FIGS. 4A and 4B. The first control terminals of all of the gate inputs are connected individually to the taps of a plurality of potentiometers 290 via lines 291*a*, 291*b*, etc. and one end terminal of all of the potentiometers 290 are connected by a switch 293 to a source of positive voltage at a terminal 292. The other end terminals are connected in common to ground. The potentiometers 290 may be draw bar controls, which control the pulse height, and thus, the amplitude of all components of the composite output signal selected by means of the various gates, as long as there is no higher voltage present on the input gates. The second input terminal of each of the gates, corresponding to the terminal 262 of FIG. 4A, is connected via individual switches 294 to a terminal 296 over a line 295. The voltage level at the terminal 296 is less than that applied to the terminal 292, so that the potentiometers 290 can furnish an override input to the gates to which the lines 291 are connected, but the voltage level on the line 295 overrides that on the lines 291 when the potentiometers 290 are set to any lower level.

The third input of selected ones of the gates is conducted to preselected taps of a voltage divider 296, which is connected through a switch 297 to the terminal 292 at one end, and which is connected to ground at its other end. The switch 297 is called a preset switch, because it activates a preselected combination of gates with preselected voltage levels, to give preselected combinations of output tones. Although only one preset switch 297 is illustrated, it will be understood that as many as desired may be provided, each with its own voltage divider connected to a desired combination of gates.

The fourth input 267 of the gates 229-236 which are provided with a fourth input is derived from an external source (not shown). Such a source may be energized as desired, and connected by means of switches (not shown) to preselected combinations of gates for producing special effects, such as percussion and the like. When the voltage level applied to this input is higher than any other input level applied to the various input gates, the signal from the external source overrides any other signal or combination of signals applied to the gates at the same time.

As described in connection with FIG. 1, the amplifiers 58–61 are each connected to the common input of a group of sample and hold units. FIG. 6 illustrates, in functional block diagram from, the sample and hold units of the blocks 62–65 of FIG. 1. Each sample and hold unit includes, as a part thereof, a sustain keyer control, the operation of which is to enable a tone or note to be sustained, when desired, after an operated key has been released. The several sample and hold units which are grouped together as the blocks of FIG. 1, are rearranged in FIG. 6 to better illustrate the relationship of the various sample and hold units to the individual switches of the decoder switches 66 (FIG. 1). The sample and hold units inlcuded in the block 65 of FIG. 1 are the units 308–311 connected in common to the input terminal 284 which is connected to the ouput of the amplifier 61. Although 97 sample and hold devices are preferably included in the unit 65, only four are illustrated in FIG. 6, representative of the first, 32nd, 61st and 97th units. Each has a trigger input connected individually to a corresponding one of the decoder switches 66. The sample and hold unit 308 has its trigger input connected to the switch 312, while the sample and hold units 309–311 are connected respectively to decoder switches 313–315. The decoder switches 312–315 are each individually connected to an output of the shift register 69 (FIG. 1) via terminals 316–319, respectively. The shift register 69 is not

shown in detail because it preferably has the same construction as the shift register shown in FIGS. 4A and 4B, except that 97 stages are provided, and each stage has an output connected to one of the 97 outputs are required.

The sample and hold units inlcuded in the block **62** of FIG. **1** are the units **321-323** of FIG. **6**, which have a common connection to an input terminal **320** in FIg. **6**, which is connected to the output of the amplifier **58**. The sample and hold units **321–323** have their trigger inputs connected respectively to the switches **312–314**. Only 61 sample and hold units are provided for the upper manual tones supplied from the generator **72**, and they are connected to the first 61 decoder switches **312–314**.

Sixty-one sample and hold units are also provided for the lower manual tones supplied from the generator **72**, including the units **324–326**, having a common connection to the input terminal **327**, from the amplifier **59**, They have their trigger inputs connected to the same decoder switches as are the sample and hold units **321–323**.

Only 32 sample and hold units are provided for the pedal keys, shown as block **64** in FIG. **1**. They include units **328** and **329** (FIG. **6**) which have one input connected in common to a terminal **330**. The trigger inputs are connected individually to the first 32 decoder switches including switches **312** and **313**.

All of the sample and hold units have a connection at a terminal **332** to a source of positive voltage and a connection at a teminal **333** to ground. These connections, excdpt for the unit **308**, have been omitted for clarity. All of the decoder switches are connected to a source of positive voltage at a terminal **335** and to a source of negative voltage at a teminal **334**.

All of the sample and hold units of FIG. **6** have outputs connected to individual keyers via terminals **340**, and the sustain keyer control provided for each sample and hold unit functions to maintain an output level equal to the amplitude to the input at one of the input terminals **284, 320, 327** and **330**, at the time its trigger input is actuated. This output level is maintained until the next trigger input pulse from one of the decoder switches effects a new sampling. A separate one of the input terminals **336–339** is provided for each group of sample and hold units **62–65**, so that the sustaining of tones by each group can be controlled independently. When a low potential is applied to any of the input terminals **336–339**, the voltage level manifested by the sample and hold units connected to such input decays at a predetermined rate following sampling. When the voltage level at a terminal is constrained to fall slowly to a loer level, the output level manifested by the unit also falls slowly. In this manner the envelope of the sound signal selected by any sample and hold unit is controlled as desired, by controlling the reference voltage level applied to the appropriate input terminal **336–339**. The reference voltages supplied to the terminals **336–339** are called sustaining inputs, because they slectively function to cause various tones to be sustained.

The sustaining inputs are preferably under the control of activating members, such as tab switches within the reach of the operator of the instrument. One of such tab switches selects a constant voltage level for application to a sustain input terminal to maintain the sustain voltage level relatively constant as long as that tab switch is in its operated position. Another tab switch connects a sustain input terminal to a function generator (not shown) which generates in response to the depression of any key of the keyboard, a pulse having a selected waveform, which, in one arrangement, has a sharply increasing leading edge followed by a decaying trailing edge. Such a waveform may be used to simulate the striking or plucking of the strings of a stringed instrument or the like. Other waveforms may be generated by other function generators and applied to the sustain input terminals **336–339** by other keys or switches within the control of the operator.

FIGS. 7–9 are schematic circuit diagrams of some of the units employed in the apparatus described above. FIG. **7** illustrates the circuit diagram of the level shifter **24**. The input from the line **18** is connected to the base of a transistor **352** through a series circuit including a diode **354** and a resistor **356**. The diode **354** is normally biased into conductive relationship by a current flowing from a positive source of voltage connected to terminal **358** through a resistor **360** and then through another resistor **362** to the ground. When a negative pulse is present on the line **18**, as a result of one of the switches of the group **10** passing a pulse from the scanner **16**, the output voltage falls, biasing off the diode **354** and decreasing the voltage of the base of the transistor **352**. Accordingly, a positive output pulse is produced on the output line **26**. The collector of the transistor **352** is connected to a positive source of voltage at a terminal **368** through a resistor **366** and its emitter is connected directly to ground. The pulses produced on the output line **26** in response to pulses on the input line **18** all have the same height, and correspond generally to the level of the voltage applied to the terminal **368**. Therefore, even though the data pulses may differ in amplitude, or be affected in their amplitude by the switches of the group **10**, the level of every pulse in the pulse train is rendered equal by means of the level shifter **24**. The level shifters **30** and **34** which are connected to the lines **20** and **22** are identical to the level shifter **24**.

A schematic diagram of the decoder switch **312** (FIG. **6**) is illustrated in FIG. **8**. The input terminal **316** is connected through a resistor **382** to the base of a transistor **384**, the emitter of which is connected to a source of positive voltage at the terminal **335**. The emitter and base of the transistor **384** are interconnected by a resistor **388**. The collector of the transistor **384** are interconnected by a resitor **388**. The collector of the transistor **384** is connected to a source of negative potential at a terminal **334**, through a resistor **392**. The collector of the transistor **384** is also connected to the base of a transitor **394** through a resistor **396**, the emitter of the transistor **394** being connected to the terminal **334**. Accordingly, the circuit including the transistor **384** and **394** functions as a switch and serves to place a predetermined voltage level on the collector of the transistor **394**, in response to the presence of a pulse supplied to the input terminal **316**. The output terminal **397**, is connected to the collector of the transistor **394**.

The sample and hold unit **308** is illustrated in FIG. **9**, in association with a sustain keyer control and one of the keyers **85***a*. An FET **398** has one terminal connected to an input terminal **399**, and another terminal connected to the base of a transistor **402**. The terminal **399** is connected to the gate terminal of the FET **398**

by a resistor **404**, and a diode **406** connects the gate terminal to an input terminal **400**, which is adapted to be connected to the output terminal **397** of the switch **312** (FIG. **8**). A capacitor **408** is connected from the base of the transistor **402** to ground, and the emitter of the transistor **402** is connected to the sustain keyer control circuit, which includes a resitsor **410** and a series connected diode **412** through which the emitter of the transistor **402** is connected to the terminal **336**. The emitter is also connected through a resistor **416** to the base of a transistor **418**, and to ground through a parallel circuit including a capacitor **420** and a resistor **422**. The collectors of the transistors **402** and **418** are both connected to the terminal **332** which is connected to a source of positive potential, and the emitter of the transistor **418** is connected to ground through a resistor **426**. The emitter is connected to the output terminal **340** of the sustain keyer control circuit, and is also connected through a resistor **350** to a terminal **428** through a diode **430** and to an output terminal **432** through a diode **434**. The diodes **430** and **434** form a portion of the keyer **85** (FIG. **1**). The terminal **428** is connected to one output of the tone generator **86** (FIG. **1**). The oppositely poled diodes **43C** and **434** prevent the generator **86** from being connected to the output terminal **432**. When a positive potential is applied to the anodes of the diodes **430** and **434**, however, at the terminal **340**, the diodes become forward biased through the resistor **350**, and a connection is established between the generator **86** and the output terminal **432**. The level of the voltage applied to the terminal **340** determines the amplitude of the signal connected with the output terminal **432**, and this is dependent upon the level applied to the input terminal **399**.

In operation, the FET **398** charges the capacitor **408** to the level of the voltage on the input terminal **399** at the time that a trigger pulse is provided to the trigger input **400**. The voltage stored on the capacitor **408** is then maintained until the next trigger pulse, when the charge on the capacitor **408** is adjusted to the new level on the input terminal **399**, if the is different from the level at the time of previous trigger pulse. In the meantime, the transitor **402** is rendered conductive to a degree dependent upon the voltage across the capacitor **408**, and charges the capacitor **420** to this voltage. The transistor **418** functions as a high input impedance current amplifier to produce a current through the resistor **426** in response to the voltage across the capacitor **420**. There is substantially no discharge of the capacitor **420** between sampling periods, as long as the voltage level at the terminal **336** is high. When discharge of the capacitor **420** is desired, a ground or negative potential is applied to the terminal **336**, and as a result, the capacitor **420** is discharged through the diode **412**, at a rate determined by the value of the resistor **410** and the voltage level applied to the terminal **336**.

As described above, the system of the present invention is adapted to produce a series of pulse trains which are operative to select components of a composite output signal, and the amplitudes of such components, and to manipulate the pulse trains in order to shift the position of the pulses of the pulse trains and to generate new pulses for inclusion in the pulse trains at time positions related to the orginal pulses. The relative amplitudes of each of the variously generated pulses may be controlled separately, except that the highest ampligude selected for any given pulse position represents the amplitude of the component of the tone at that frequency in the output signal.

The usefulness of the present invention is not limited to any particular arrangement of switches but provides for extreme flexibility in connecting the various components of the combination together. For example, any of three groups of switches **10, 12** and **14** may be connected in place of the other group by manipulation of the data distribution unit **28**. Thus, any tones which can be produced by operation of the upper manual keys for example, can be produced instead by operation of the lower manual keys simply by arranging the data distribution unit **28** to connect the group of switches associated with the lower manual to the coupler control unit **42** provided for the upper manual. Similarly, the group **14** of switches associated with the pedals can be substituted for those of the upper or lower manual. Moreover, any desired waveforms can be connected to the sustain inputs of the sample and hold units in order to simulate waveform envelopes of various instruments. Finally any desired combination of voltages may be connected to various ones of the gates **224–236** in order to produce various combinations of tones with selected combinations of amplitudes, in order to produce harmonic combinations and the like which are pleasing to the ear or which are desired for special effects. The flexibility of the apparatus of the present invention allows for all of the arrangements mentioned above, while employing a minimum amount of structure to accomplish such functions.

The apparatus of the present invention may advantageously be employed in executing certain control functions associated with a musical instrument, under the control of activating members such as tabs, stops, knobs, draw bars, etc, such as for controlling the gain of an amplifier, controlling the amount of reverberation in the output signal, and the like. A circuit for executing the control functions just mentioned is shown in FIG. **11**.

A time position selector unit **440** is adapted to be connected to the scanner **16** via lines **442**, and to produce output pulses on one of a plurality of lines **444** and **446**, corresponding to certain time positions in the cycle of operation of the scanner **16**. These time positions are preferably just before the end of the scanner cycle, and, when the scanner cycle is 128 pulse times in length, as described in connection with the embodiment illustrated in the drawings, the control function time positions are selected from the last six time positions in the cycle, because the first 62 time positions are employed to generate the reset pulse and the pulses connected to the key switches, while the shift registers of the coupler control units function to delay some of the first 62 pulses for up to 60 additional pulse times. Therefore the first 122 pulse times of each scanner cycle may be occupied with pulses which function to select designated notes and tones, but the last six time positions are not so used. Of course, if the scanner cycle were enlarged to mroe than 128 pulse times, more time positions would be available for control functions.

The time position selector unit **440** preferably comprises a plurality of gates, responsive to various outputs of the units **122** and **132**, to produce a pulse on one of its output lines **444** and **446** in response to recognition of the combination of voltage levels on such outputs which are characteristic of a selected time position.

The line 444 is connected to an input of a gate 448, which is constructed in the same manner as the gates 224–236 which have been described in connection with FIGS. 4A and 4B. A potentiometer 450, connected between a source of positive potential at a terminal 452 and ground, has its tap connected to the input of the gate 448 through one of its input diodes, and accordingly controls the height of pulses passed by the gate 448. Such pulses are passed to a sample and hold units 454 and 455 over a line 456. The sample and hold units 454 and 455 receive trigger input pulses from the decoding shift register 69 via switches 458 and 460, in the same manner which has been described for the other sample and hold devices. The trigger pulse from the switch 458 operates the sample and hold unit 454 at the proper time to sample the pulse from the gate 448, whereupon the output line 462 of the sample and hold unit 454 manifests an output control signal which controls the amount of reverberation employed in the output signal. The control of reverberation in response to the level of the control signal is well understood by those skilled in the art, and is therefore not described in detail.

In similar fashion, the line 446 is connected to the input of a gate 464, which passes pulses having their height controlled by a potentiometer 466 to the line 456. The sample and hold device 455 decodes these pulses and manifests an output control voltage on a line 468, which controls the gain of an amplifier (not shown) in the conventional manner. By employing other outputs of the unit 440, which occur at different pulse times, other control functions may be executed in the same manner. The pulses which perform the various control functions are transmitted to the sample and hold units 454 and 455 over the same line 456, but may optionally be transported thereto over separate lines, in which case the switches 458 and 460 may be omitted and the trigger pulses for the sample and hold devices 454 and 455 derived directly from the gates 448 and 464.

The circuitry of the present invention is eminently suitable for being constructed by employing integrated circuits, in which many of the components are combined into a few small units.

It will be understood the variations and modifications may be effected without departing from the spirit and scope of the novel concepts of this invention.

All of the components illustrated in the drawings are standard components which are readily available from a variety of manufacturing sources. The following commercially available units may be employed for the several functional blocks which appear in the drawings:

Multivibrator 106	Motorola Model 4024
Frequency Divider 110	TI Model SN 7493
Frequency Divider 122	TI Model SN 7493
Decoder 132	Motorola Model 4007
Decoder 142	Motorola Model 8311
Decoder 144	Motorola Model 8311
Decoder 146	Motorola Model 8311
Decoder 148	Motorola Model 8311

We claim as our invention:

1. In an electronic musical instrument having a tone generator adapted to produce a plurality of musical sounds on a plurality of outputs, a system comprising:

a. a plurality of switching means, each adapted to be placed in one of at least two different states;

b. means for generating a multiplexed coded signal representing the state of a plurality of said switching means, the portion of said coded signal for each of said switching means having an amplitude representation;

c. a coupler control unit connected to receive said coded signal and adapted to modify the amplitude representation of selected portions of said coded signal to produce a modified coded signal; and

d. means responsive to said modified coded signal for selecting individual ones of said outputs of said tone generator for inclusion as components of a composite output signal, the amplitude of each of said components being responsive to the amplitude representation of a corresponding portion of said modified coded signal.

2. In an electronic musical instrument having a tone generator adapted to produce a plurality of musical sounds on a plurality of outputs, a system comprising:

a. a plurality of switching means each adapted to be placed in one of at least two different states;

b. means for generating a train of pulses encoded in time position in response to the state of a plurality of said switching means, said pulse train having a separate time position for each of said switching means;

c. a coupler control unit connected to receive said pulse train and adapted to modify the amplitude representation of selected pulses of said pulse train to produce a modified pulse train; and

d. means responsive to said modified pulse train for selecting individual ones of said outputs of said tone generator for establishing a connection therefrom to a common output, the amplitude of each of said selected tone generator outputs being responsive to the amplitude representation of a pulse of said modified pulse train corresponding to said selected tone generator output.

3. Apparatus according to claim 2, including means for connecting said selected tone generator outputs to a plurality of different common outputs.

4. In an electronic musical instrument having a tone generator adapted to produce a plurality of musical sounds on a plurality of outputs, a system comprising:

a. a plurality of switches adapted to be placed in conductive and non-conductive states;

b. A scanner connected to said switches for generating, during successive time intervals, a train of pulses encoded in time position within said train in response to the states of said switches;

c. A coupler control unit connected with said scanner for selectively modifying the amplitude of the pulses of said train;

d. a plurality of sample and hold units each having a first input connected to receive said pulse train from said coupler control unit, each having a trigger input, said sample and hold units functioning to sample the level of a pulse of said pulse train at a single time position thereof and to thereafter manifest an output related to said sampled level;

e. a decoder shift register adapted to operate in synchronism with said scanner for producing pulses sequentially at a plurality of outputs connected individually to one of said trigger inputs; and

f. a plurality of keyers, one for each of said sample and hold units, and responsive thereto for selecting individual outputs of said tone generator for inclu-

sion as components of a composite output signal, the amplitude of each said component being responsive to the output manifested by one of said sample and hold units.

5. Apparatus according to claim **4,** including

a. a second plurality of switches adapted to be placed in conductive and non-conductive states, said second plurality of switches being connected to said scanner for producing, during successive time intervals, a second train of pulses separate from the first said train but contemporaneous therewith;

b. a second coupler control unit connected with said scanner for selectively modifying the amplitude of the pulses of said second train;

c. a second plurality of sample and hold units all having a first input connected to receive said second pulse train from said second coupler control unit, each of the sample and hold units of said second plurality having a trigger input connected individually to one of said outputs of said decoder shift register; and

d. a second plurality of keyers, one for each of the sample and hold units of said second plurality and responsive thereto for selecting individual outputs of said tone generator for inclusion as components of a second composite output signal, the amplitude of each component of said second composite output signal being responsive to the output manifested by one of the sample and hold units of said second plurality.

6. Apparatus according to claim **5,** wherein the first plurality of switches are individually operated by keys of a first keyboard, and wherein said second plurality of switches are individually operated by actuating members located remotely from said first keyboard.

7. Apparatus according to claim **4,** wherein said plurality of switches are operated individually by keys of a keyboard, each of said switches comprising a single pole switch and all of said switches having a common connection to said coupler control unit.

8. Apparatus according to claim **4,** wherein said scanner includes a source of clock pulses, and a unit for sequentially manifesting output signals on a plurality of output terminals, each of said switches being connected individually to one of said ouput terminals.

9. Apparatus according to claim **4,** wherein said coupler control unit includes a shift register for receiving said train of pulses and shifting said pulses sequentially through the stages of said shift register in synchronism with said scanner, and a gate connected to an output of one of the stages of said shift register for selectively delaying said pulse train.

10. Apparatus according to claim **9,** including a second gate having its input connected to the input of the shift register for selectively bypassing said shift register.

11. Apparatus according to claim **10,** wherein the outputs of said gates are connected together to provide an ouput pulse train having shifted pulses and unshifted pulses.

12. Apparatus according to claim **9,** including a circuit for presenting a preselected voltage to said gate, said gate operating to cause said shifted pulses to assume said preselected voltage.

13. Apparatus according to claim **11,** including a circuit for each of said gates for independently presenting preselected voltages thereto.

14. Apparatus according to claim **13,** wherein said gate includes a first transistor having its base connected to said preselected voltage, its collector connected to a source of voltage, and its emitter connected to an output bus through a series connected resistor and diode, and a second transistor having its base connected to an output of said shift register, its collector connected to the junction of said resistor and said diode, and its emitter connected to a reference potential, whereby said second transistor is normally saturated but cut off by a pulse from said shift register, and said first transistor is operative to clamp said output bus to said preselected voltage while said second transistor is cut off.

15. Apparatus according to claim **14,** including a plurality of diodes having their cathodes connected to the base of said first transistor, whereby the highest voltage applied to the anodes of said diodes is the preselected voltage.

16. Apparatus according to claim **4,** including a sustain control unit connected to each of said sample and hold units, said sustain control unit being operative to control said sample and hold unit to manifest an output proportional to said sampled level when a first control voltage is connected to sustain input, and operative to cause the manifested output to fall to a lower level when a second control voltage is connected to said sustain input.

17. Apparatus according to claim **16,** including a timing circuit connected with said sustain control unit for causing said manifested output to fall to said lower level at a predetermined rate when a reference potential is connected to said sustain input.

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