ABSTRACT: In an electric organ, the actuation of keys in accordance with corresponding, audible tones to be reproduced effects the gating of pulses into time slots of a time division multiplex signal, the time slots of the multiplex signal being structured in accordance with a desired assignment sequence to correspond to the keys and to be representative thereof for identifying each note capable of being generated by the organ. A set of note, or tone, generators with availability assignment control means for capturing a pulse in the multiplex signal are each rendered responsive to a given captured pulse for generating the tone represented by that pulse. A second multiplex system having time slot pulse assignments additionally provides for generation of a time division multiplex signal for control of voices and other characteristics to be imparted to the reproduced tones.
Fig. 1

Keyboard Counter

Keyboard
OCTAVE
NOTE (KEY)

Decoder (Fig. 2)

Switching Array

Encoder

Multiplexed Signal

Master Clock

From one stage of keyboard section 4

From eight stages of octave section 3

Fig. 2

Decoder 7 (Fig. 1)

Eight of 32 buses to switching array II

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FIG. 4

FIG. 5

FIG. 6

FIG. 9

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ATTACK/DECAY CONTROL UNIT

FIG. 18

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FIG. 11

KEY DEPRESSED SIGNALS FROM GENERATOR ASSIGNMENT LOGIC (FIG. 7B)

GATING SIGNALS FROM KEYBOARD COUNTER SECTION 4 (FIG. 11)

MULTIPLEXED SIGNAL

150

PEDAL

152-1

PEDAL

152-2

GREAT

SWELL

CHOIR

152-3

152-4

SWELL

CHOIR

TRANSIENT PERCUSSION KEYING SIGNALS

152

COHORT

156

158

161

STEADY-STATE PERCUSSION KEYING SIGNALS

KEYBOARD RESET
MULTIPLEXING SYSTEM FOR SELECTION OF NOTES AND VOICES IN AN ELECTRONIC MUSICAL INSTRUMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention resides broadly in the field of electronic musical instruments, and is particularly adaptable for use in electronic organs as a digital selection system for calling forth desired tones and voices from those available to be produced by the organ. The term “organ” is used throughout the specification and claims in a generic sense (as well as in a specific sense) to include any electronic musical instrument having a keyboard such as an electronic organ, electric pianos and accordions, and the principles of the present invention are, in fact, applicable to any musical instrument in which musical sounds are generated in response to the actuation of key switches regardless of whether those switches are actuated directly, i.e., by the musician’s fingers, or indirectly, e.g., by the plucking of strings. The term “key” is also used in a generic sense, to include depressible levers, actuable on-off switches, touch- or proximity-responsive (e.g., capacitance- or inductance-operated) devices, closable apertures (e.g., a hole in a “keyboard” of holes which when covered by a musician’s finger closes or opens a fluidic circuit to produce a tonal response), and so forth.

2. Description of the Prior Art

The function of an electronic organ is to faithfully reproduce, or to simulate by electronic means, the sounds or tones developed by a true pipe organ in response to playing of the organ by the organist in the selection of notes, and voices and other characteristics of those notes. Generally, true pipe organs are unavailable to the public at the substantial expense and size thereof and thus electronic organs have developed as a substitute which is more readily available to the public. Electronic organs which have been available heretofore have either been inadequate in their capacity and operating characteristics for simulating pipe organ sounds, and have been themselves excessively complex and expensive while presenting substantial maintenance problems.

One significant problem in the design and construction of prior art electronic organs resides in the amount of wiring required in order that the playing of each particular note in each octave available in the electronic organ effects an appropriate audible response from the organ. A simple electronic organ may have a pair of hand-operated keyboards, conventionally termed manuals, and each related to as a pedal board or keyboard, or division. More complex organs may have as many as five manuals and two pedal keyboards. Moreover, it is not unusual for each manual to have keys encompassing four or more octaves, while each pedal keyboard may range from one octave to two or more octaves. Although two or more manuals may be adapted to permit play of the same note, the note produced by each has its own distinctiveness characterized sound. In addition to the large number of keys and pedals available to be selected during playing of the organ, a typical electronic organ has several stops or tabs associated with each keyboard, including the manuals and the pedal boards, to permit selection of specific organ voices (particularly tone quality and timbre, or color).

Heretofore, the selectively actuated connections required between each key and the circuitry capable of generating the appropriate tone has been provided by a mass of cabling and electrical connecting points within the organ. Interestingly, it is not unusual for organ dealers to point with pride to the large number of conductors in the organ as a factor to impress the prospective customer. In truth, however, each conductor, and particularly its terminal connections, constitutes a potential source of failure, and the vast number of conductors and connections often represents a servicing nightmare. The more complex the organ, of course, the more complex and unwieldy is the assemblage of cabling and electrical connecting points. Accordingly, it is highly desirable to reduce, or minimize the number of wires and electrical connecting joints while still retaining the capability of proper response to each key selection.

When a key on any keyboard is depressed, it should call forth an audiofrequency tone corresponding to the appropriate note of the musical scale. The tone must be controlled as to its waveshape to produce the desired characteristics, or quality thereof and amplified and fed to an electroacoustic transducer (e.g., a loudspeaker) to develop the audio output. The subsystem of the organ for performing these functions is typically called a tone, or note, generator which may include, or have associated therewith, additional control circuits for controlling the note characteristics and for providing related functions. Since 12 musically related frequencies are required for each octave, a sufficient number of tone generators and associated circuitry must be available to produce the respective signals having the specific frequencies for every note in every octave to be covered by the organ. A variety of conventional methods have been employed to achieve this objective, the particular method utilized depending in part on the type of tone generator utilized. Although virtually all organs in which sounds related to notes of the musical scale are synthesized by electrical devices, in whole or in part, are customarily referred to as electronic organs, the tone generators may not be entirely electronic in nature. Any one of three principal forms of tone generator may frequently be found in the modern organ, viz., electronic, electromechanical, or mechanicoacoustical generators. The particular form of tone generator used is immaterial to the applicability of the present invention, as will be better understood from further consideration of this specification, although a specific form is preferred. Since electronic tone generators are achieving greater popularity than generator forms, primarily because of their lower cost, absence of moving parts, and greater variety of species, the electronic tone generator will be discussed as representative, and will indicate another aspect of the problem to which the present invention is directed.

Some organs include a separate electronic tone generator (oscillator) for each note on the keyboard, to achieve the desired tone range. This approach may require several hundred oscillators in a single organ, but it has some advantages. For example, each generator need be activated into oscillation only when its associated key on the keyboard is depressed; greater flexibility is available in timbre, than with other methods. No special scheduling or selection technique is required to permit access to a tone generator upon actuation of a key on a keyboard. Moreover, a more common approach to providing the desired tone range, because much less circuitry is required, and because the techniques are less expensive than the one-key one-generator approach, is the use of only 12 basic tone generators, each corresponding to a respective one of the 12 musically related notes in an octave, as required. If the master oscillators develop frequencies corresponding to notes of the highest octave of the organ, their respective output frequencies are successively divided by associated series of divide-by-two circuits to obtain the corresponding notes in the lower octaves. Similarly, where the master oscillators develop the frequencies associated with the lowest octave of the organ, respective sets of multiply-by-two circuits are used to obtain the corresponding notes in the higher octave.

Still another approach involves the sharing of a set of oscillators, much smaller in number than the total number of notes to be available for play, each generator capable of developing any one of the frequencies in a sequence of two or more adjacent frequencies in accordance with appropriate selection of frequency determining elements of the oscillator of the generator by actuation of a key. This arrangement is quite popular in small electronic organs. Thus, for example, while a small instrument may have well over 100 keys, only a dozen or so tone generators may be available; hence, only the latter number of tones can be developed in any given instant. Since it is unlikely that more than 10 tones will be selected simultaneously, the problem that arises is not the small
According to a further aspect of the present invention, the actuation of stop tab switches for selecting desired organ voices and footages or pitch lengths is also accomplished on the basis of a scanning of the stop switches and related components in a cyclic sequence. Information relating to the specific stop switches in action is furnished in a parallel format based on organ voices, to a voicing computer for accepting the incoming voice control data and for accessing a related memory to compute the desired composite voicing information for entry into a serial digital format in a time division multiplexed waveform.

This stop tab multiplexing aspect of the invention shares the same advantages as the keyboard multiplexing system.

Again, each of these features and aspects of the invention is applicable to substantially any key or switch operated electronic musical instrument, although the advantages of the invention are realized to a greater extent as the size or capacity of the instrument, and its capability of tone generation, increases. For example, the invention may be utilized to provide multiplexed signals in an electric accordion or an electric guitar, for example, by scanning the keyboard or the set of strings, respectively, of such instruments although only a single octave or perhaps less than one octave is available. In such cases, miniaturized, reliable logic circuitry can be employed which provides certain benefits over prior art circuit arrangements indicative of the actuation of the associated key.

BRIEF DESCRIPTION OF THE DRAWINGS

In describing the present invention, reference will be made to the accompanying Figures of drawings in which:

FIG. 1 is a simplified block diagram of a system for producing a time division multiplexed signal containing a recycling sequence of time slots each associated with a particular key of the organ and in which each time slot containing a pulse is indicative of the actuation of the associated key;

FIG. 2 is a circuit diagram of an exemplary decoder for use in the system of FIG. 1;

FIG. 3 is a more detailed circuit diagram of the switching array and encoder used in the system of FIG. 1;

FIG. 3A is a circuit diagram of an alternative encoder to that shown in FIG. 3, for use in the system of FIG. 1;

FIG. 4 is a circuit diagram of the input-output bus connecting means at each intersection of the switching array of FIG. 3;

FIG. 5 is illustrative of a multiplex waveform developed by the system of FIG. 1 in response to actuation of selected keys;

FIG. 6 is a simplified block diagram of generator assignment and tone generating apparatus for processing the multiplexed signal produced by the system of FIG. 1 to develop the desired tones as an audible output of the organ;

FIGS. 7A and 7B together constitute a circuit diagram of one embodiment of the tone generator assignment logic for the system of FIG. 6;

FIG. 8 is a block diagram of a tone generator suitable for synthesizing the frequency of every note capable of being played in the organ, for use with the assignment logic of FIGS. 7A and 7B in the system of FIG. 6;

FIG. 9 is illustrative of a complex waveshape of the type produced by a pipe organ, and of the sample points at which amplitude values are taken, for simulation at selected note frequencies;

FIG. 10 is a block diagram of an attack and decay control unit for use in the instrument;

FIG. 11 is a block diagram of a percussive control or keying system to provide appropriate percussion sound accompaniment in the instrument; and

FIGS. 12 through 18 are block diagrams of an overall stop rail multiplexing system and subsystems thereof, according to the invention.
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DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, the keyboard multiplexing system or note selection system includes a keyboard counter 1 which is implemented to provide a specified count for each key of each keyboard (including manuals and pedal divisions) of the organ. If, for example, the electronic organ in which the multiplexing system is used has four keyboards, such as three manuals and a pedal board, each encompassing up to eight octaves, then keyboard counter 1 should have the capability of generating \(4 \times 8 \times 12 = 384\) separate counts (digital words). It is essential that the counter be capable of developing a count representative of every key on every keyboard of the organ; however, it may be desirable to provide a counter that can produce a count greater than the number of available keys in order to have available keys not associated with any keys. Such redundancy is readily provided by simply utilizing a counter of greater capacity than the minimum required count.

In any event, it is preferred that keyboard counter 1 be divided into three separate sections (or separate counters) designated 2, 3, and 4. The first section (designated 2) is constructed and arranged to count modulo 12 so as to designate each of the 12 keys associated with the 12 notes in any octave. The second section (designated 3) is adapted to count modulo 8, to specify each of the eight octaves encompassed by any of the four keyboards. The last section (designated 4) is designed to count modulo 4 to specify each keyboard of the organ. Therefore, the overall keyboard counter is arranged to count modulo 384, in that at the conclusion of every 384 counts, the entire set of keyboards has been covered (scanned) and the count repeats itself. To that end, each counter section may be composed of a separate conventional ring counter, the three counters being connected in the typical cascaded configuration (see, e.g., Ledley, Digital Computer and Control Engineering, McGraw Hill, 1966, pp. 488 et seq.) such that when section 3 reaches its maximum count it advances the count of counter section 3 by one and will automatically initiate a repetition of its own count. Similarly, attainment of its maximum count by counter section 3 is accomplished by advancement of the count of section 4 by one, and is immediately followed by a repetition of the modulo 8 count.

Advancement of the lowest counter section 2, i.e., the section of least significant count, is accomplished by application of clock pulses thereto from a master clock source 5. Clock source 5 is designed to deliver clock pulses at a sufficiently rapid repetition rate (frequency) to ensure resolution of depression (actuation) and release (deactuation) of any key on any keyboard, i.e., to supply a pulse at the instant of either of these events. Scanning of all keyboards of the organ at a rate of 200 or more times a second is deemed quite adequate to obtain this desirable resolution. For the exemplary keyboard arrangement and keyboard counter set forth above, this is equivalent to a minimum of \(200 \times 384 = 76,800\) counts per second. Accordingly, a master clock delivering clock pulses at a rate of 100 kcs./s. is quite suitable.

A total of four lines emanate from counter section 4, one line connected to each ring counter stage, to permit sensing of the specific keyboard which is presently being scanned. Similarly, eight lines are connected to the eight ring counter stages, respectively, of octave counter section 3 to detect the octave presently being scanned. Thus, a total of 12 lines extend from sections 3 and 4 of keyboard counter 1, and these 12 lines can carry signals indicative of 32 (8x4) possible states of the keyboard counter. The specific one of the 32 states, representative of a particular octave on a particular keyboard, of which they are being scanned is determined by use of the decoder circuit 7. Its simplest form, decoder 7 may be composed of 32 AND gates designated 8-1, 8-2, 8-3, ..., 8-32 (FIG. 2), each with two input terminals and an output terminal. The 32 gates are arranged in four groups of eight each, with every gate of a particular group having one of its two input terminals (ports) connected to one of the four lines of keyboard counter section 4. Distinct and different ones of the eight lines from counter section 3 are connected to the other input terminal of respective ones of the eight AND gates of that group. A corresponding situation exists for each group of AND gates, with the only difference being that each group is associated with a different output line of counter section 4. Using this arrangement, the decoder logic designates every octave of keys in the organ by a respective driver pulse when a count corresponding to that octave is presently contained in the counter.

The output pulses deriving from the AND gates (or drivers) of decoder circuit 7 are supplied on respective ones of 32 bus bars (or simply, buses), generally designated by reference numeral 10, to a keyboard switching array 11. From the preceding description, then it will be clear that array 11 has one input bus 10 for every octave of keys in the organ (including every octave on every keyboard), and that a drive pulse will appear on each input bus approximately 200 times per second, the exemplary rate of scan of the keyboards, as noted above, for obtaining adequate resolution of operation of the keys. Switching array 11 also has 12 output buses, generally designated by reference number 12, each to be associated with a respective one of the 12 notes (and hence, the 12 keys) in any given octave.

Array 11 is basically a diode switching matrix, in which spaced input buses 10 and spaced output buses 12 are orthogonally arranged so that an intersection or cross occurs between each input bus and each output bus (see FIG. 3), for a total of 384 intersections, one for each count of the keyboard counter 1. As is typical in this type of matrix, the crossed lines or buses are not directly interconnected. Instead, a "jump" diode, such as that designated by reference number 13 in FIG. 4, is connected between the input bus 10 and the output bus 12 at each intersection, the diode permitting a conduction (anode-to-cathode) in the direction from an input bus 10 to an output bus 12. Wired in series circuit or series connection with each diode 13 is a respective switch 14 which is normally open circuited and is associated with a distinct respective one of the keys of the organ, such that depression of the associated key produces closure (close circuiting) of the switch 14 whereas release of the associated key results in return of the switch to its open state. Alternatively, each of switches 14 may itself constitute a respective key of the various keyboards of the organ.

While switch 14 is shown schematically as being of mechanical single-pole, single-throw (SPST) structure, it will be understood that any form of switch, electronic, electromagnetic, electromechanical, or of the like, may be used, to vary the exact nature of the switch depending primarily upon the nature of the energization produced upon operation of the associated key. Switch 14, then, is adapted to respond to the particular form of energization or actuation produced upon operation of a key on any keyboard (or, as observed above, may itself constitute the key), to complete the circuit connecting associated diode 13 between a respective input bus 10 and a respective output bus 12 at the intersection of those buses, when the key is depressed, and to open the circuit connecting the diode between respective input and output buses at that intersection when the key is released. Positive pulses occurring at the rate of approximately 200 per second, for example, according to the timing established by master clock 5, are transferred from input bus 10 to output bus 12 via the respective diode 13 and closed switch 14 when the associated key is depressed. While a switch alone (i.e., without the series connected diode) would serve the basic purpose of transferring a signal between the input and output lines of array 11, the diode provides a greater degree of isolation from sources of possible interference (noise) and acts to prevent feedback from output to input lines.

In FIG. 3, the output buses 12 from switching array 11 are connected to an encoder circuit 15 to which are also connected the 12 output lines, generally designated by reference number 16, from keyboard counter section 2. To produce an
orderly arrangement in which each key of the organ is assigned a distinct and different time slot in a time-division multiplex waveform, the switches 14 associated with the respective keys are conveniently arranged in a specific sequence in the switching array 11. Assume, for example, that a specific output bus 17 of the switching array is to be associated with note A of any octave, a second output bus 18 is to be associated with note B of any octave, and so forth. Then switches 14 in the row corresponding to output bus 17 in array or matrix 11 are associated with the keys corresponding to the note A in each octave of keys in the organ. The column position of each switch 14 in matrix 11 corresponds to a specific octave of keys in the organ, and hence, to a specific octave encompassed by a specific key 22 of the organ. Each of the output buses 12, including 17, 18, and so forth, is connected to one of the two input ports or terminals of a respective AND gate of the 12 AND gates 20-1, 20-2, 20-3, ..., 20-12, of encoder circuit 15. An output lead 16 of counter section 2 is associated with the ring counter stage designating the count for a particular note (key) in a given octave is connected to the remaining port of an encoder circuit AND gate having as its other input a pulse on the output bus 12 associated with that same note. A similar arrangement is provided for each of the remaining 11 output lines 16 of counter section 2 with respect to the AND gates 20 and the output buses 12. Thus, for example, if output bus 17 (associated with the row of switches 14 in matrix 11 for note A) is connected to one input terminal of AND gate 20-1, the output of flip-flop 22 from the stage of counter 2 designating the count associated with note A is connected to the remaining input terminal of gate 20-1. The output terminal of each of AND gates 20 is connected to a respective input terminal of OR gate 23, the output of the OR gate constituting the output signal of the encoder circuit. By virtue of its structure, encoder circuit 15 is effective to convert the parallel output of array 11 to a serial output signal in accordance with the scanning of output buses 12 as provided by the advancing and repeating count sensed in the form of pulses (at a rate of about 200 per second) appearing on output lines 16. The end result of this circuitry is the production of a time-division multiplex (TDM) signal on a single conductor 25 emanating from encoder 15.

As an alternative to the specific logic construction shown for encoder 15 in FIG. 3, the encoder may have the circuit configuration exemplified by FIG. 3A. Referring to the latter Figure, the encoder includes a shift register 80 having 12 cascaded stages designated SR1, SR2, SR3, ..., SR12, each connected to a respective output bus 12 of switching matrix 11 for each respective output pulse appearing thereon. The shift register stages are loaded in parallel with the data read from two switching array 11 on output buses 12, in response to each of the pulses appearing (i.e., each time a pulse appears) on one of the 12 output leads 16 of note counter 2. That one output of the note counter which is to supply the load command for all 12 stages of shift register 80 is selected to permit the maximum amount of settling time to elapse between each advance of octave counter 3 and keyboard counter 4 and the loading of the shift register. In other words, it is extremely desirable that the data to be entered into the shift register from the switching array be stabilized to the greatest possible extent, and this is achieved by allowing the counters whose scanning develops this data, to settle at least immediately prior to loading. Thus, the first note counter stage, or one of the early stages, is selected to provide load-pulse pulses to shift register 80.

"Shift" pulses are supplied to the shift register by master clock 5, which also supplies note counter 2, to shift the contents of each shift register stage to the next succeeding stage except during those bit times when the shift pulse is preempted by a load pulse from the note counter. Accordingly, shift register 80 is parallel loaded, and the data contents of the register are then shifted out of the register in serial format on encoder output line 25 until a one-bit pause occurs when another set of data is parallel loaded into the shift register, followed again by serial readout on line 25. This serial pulse train constitutes the time-division multiplexed output signal of encoder 15 just as in the embodiment of FIG. 3, except that with the FIG. 3A configuration, decoder 7 (and the counters 3 and 4 supplying pulses thereto) undergo a greater amount of settling time.

It will be observed that this operation constitutes parallel-to-serial conversion of the information on output buses 12 to a time-division multiplexed waveform on the output line 25 of encoder 15.

In the TDM signal, each key has a designated time slot in the 384 time slots constituting one complete scan of every keyboard of the organ. In the specific example of the time base provided by master clock 5, the TDM waveform (shown by way of example in FIG. 5) is initiated about 200 times per second. The development of this waveform itself constitutes a principal feature of the present invention in that the waveform contains all of the note selection information, in serial digital form on a single output line, that had heretofore required the complex wiring arrangements previously discussed. This waveform development will be more clearly understood from an example of the operation of the circuitry thus far discussed. It should be observed first, however, that all of the logical and logic circuitry described up to this point can be accommodated within a very small volume of space by fabrication in integrated circuit form using conventional microelectronic manufacturing techniques.

When the main power switch for the electronic organ is turned on, all components are set to an initial state, and the master clock delivering pulses to keyboard counter 4 is set at the aforementioned rate. Upon depression of a key on any keyboard of the organ, including the manuals and pedal divisions, a respective switch 14 associated in series connection with a diode 13 at the intersection between the appropriate input bus 10 and output bus 12 of the switching array 11 is disabled, thereby connecting the output buses to supply pulses appearing on a given input bus 10 from decoder 7 to the appropriately connected output bus 12 for application to encoder 15. If, for example, the key that was depressed in associated with note C in the second octave, C4 appears in the appropriate time slot of the multiplexed signal emanating from encoder 15 and will repetitively appear in that time slot in each scan of the particular keys of the organ as long as that key is depressed. That is to say, a pulse appears on one of the output lines 10 associated with the second octave in the manual being played, in accordance with the scan provided by master clock 5, as the counter stage associated with that octave is energized in keyboard counter octave section 3 and the counter stage associated with that manual is energized in section 4 of the keyboard counter. The connection between the appropriate input bus 10 and output bus 12 of switching array 11 for the particular octave and keyboard under consideration is effected by the depression and continued operation of the key associated with the switch 14 for that intersection in the array. Since, as previously stated, each switch is associated with a particular note (key) and is positioned in a specific row of the switching array, a signal level is thereby supplied to the appropriate output bus 12 of the switching array arranged to be associated with that note. Each time the specified note is depressed, here the note C, is scanned in the sequence of count in the note section 2 of the keyboard counter, a second input is provided to the AND gate 20 receiving the signal level on output bus 12, and a pulse is delivered to OR gate 23. By virtue of this operation, the pulse which appears at the output of OR gate 23 always appears in the identical multiplexed time slot of the multiplexed signal for a specific note associated with a particular key on a particular keyboard of the organ.

If more than one key is depressed, regardless of whether one or more keyboards is involved, operation corresponding to that described above for a single depressed key is effected for every operated key. Thus, for example, assume that the key associated with note C, is played on one manual, the note D, is played on a second manual, and the notes E, and G, are
played on a third manual, the associated keys being depressed substantially simultaneously to produce desired simultaneous reproduction of all notes as the audio output of the organ. Under these conditions, the associated switches 14 in the switching array 11 are closed to provide through connections between the respective input busses 10 and output busses 12 for the specific octaves and manuals involved. As the appropriate AND gates 20 in encoder 15 are supplied with gating signals from the sequentially energized counter stages of note section 2, during the scanning operation provided by that keyboard counter section, pulse levels appearing on output busses 12 for which switches 14 have been closed are gated in the appropriate time slots of the multiplex signal on the output lead 25 from OR gate 23 of encoder 15, for the specific notes involved.

An example of the multiplex signal waveform thus generated is shown in FIG. 5. While the pulses appearing in the time slots associated with the specific notes mentioned above are in a random set or sequential order, their appearance is repetitive during the interval in which the respective keys are actuated. Hence, the effect is to produce a simultaneous reproduction of the notes as an audio output of the organ, as will be explained in more detail in connection with the description of operation of the tone generation section.

Referring now to FIG. 6, the multiplexed signal arriving from decoder 15 is supplied to generator assignment logic network 26 which functions to assign to a tone generator 28 to a depressed key (and hence, to generate a particular note) when the associated pulse first appears in its respective time slot in the multiplexed signal supplied to the assignment logic. If only 12 tone generators 28 are available in the particular organ under consideration, for example, the assignments are to be effected in a particular sequence (order of availability), and once particular pulses have been directed to all of the available generators (i.e., all available tone generators have been "captured" by respective note assignments), the organ is in a state of saturation. Thereafter, no further assignments can be made until one or more of the tone generators is released. The availability of 12 (or more) tone generators, however, renders it extremely unlikely that the organ would ever reach a state of saturation since it is quite improbable that more than 12 keys would be depressed in any given instant of time during performance of a musical selection. The output waveforms from the captured tone generators at the proper frequencies for the notes being played, are supplied as outputs to appropriate waveshaping and amplification networks and thence to the acoustical output speakers of the organ. If the tone generators 28 supply a digital signal associated with each tone, as is the case in one embodiment to be described, then the digital format is supplied to an appropriate digital-to-analog converter, which in turn supplies an output to the waveshaping network.

At any given instant of time, each tone generator 28 may be in only one of three possible states, although the concurrent states of the tone generators may differ from one tone generator to the next. These three states are as follows:

1. A particular note represented by a specific pulse in the multiplexed signal has been captured (i.e., claimed) by the tone generator;
2. The tone generator is presently uncaptured (i.e., unclaimed or available), but will be captured by the next incoming pulse in the multiplexed signal associated with a note which is not presently a tone generator cap; and
3. The tone generator is presently available, and will not be captured by the next incoming pulse.

It should be apparent from this delineation of possible states that any number of the tone generators provided (12, in this particular example) may be in one or the other of the states designated as states (1) and (3), above, but that only one of the tone generators can be in state (2) at any given instant of time. That is, one and only one generator is the next generator to be claimed. When the specific tone generator in state (2) is claimed by an incoming pulse, the next incoming pulse which is not presently claiming a tone generator is to be assigned to the generator that has now assumed state (2). For example, if the third tone generator (03) of 12 generators is captured by an incoming pulse (note representation) and the fourth generator (04) was and still is captured by a previous note selection, then tone generator 04 is unavailable to the next incoming pulse, and the privilege of capture must pass to the next tone generator which is not presently in a state of capture. If all of the tone generators are captured, that is, all are in state (1) as described above, then the organ is saturated and no further notes can be played until at least one of the tone generators is released. As previously observed, however, the saturation of an organ having 12 (or more) tone generators is highly unlikely.

Generator assignment system 26 is utilized to implement the logic leading to the desired assignment of the tone generators 28, and thus to the three states of operation described above. An exemplar embodiment of the generator assignment logic is shown in FIGS. 7A and 7B. Referring to FIG. 7A, a ring counter 30, or a 12-bit recirculating shift register in which one and only one bit position is a logical “1” at any one time, is used to introduce a claim selection, i.e., to initiate the capture, of the next available tone generator in the set of tone generators 28 provided in the organ. A shift signal appearing on line 32 advances the “1” bit from one register or counter stage to the next, i.e., shifts the “1” to the next bit position. Each bit position is associated with and corresponds to a particular tone generator, so that the presence of the logical “1” in a particular bit position indicates selection of the tone generator to be claimed next, provided that it is not already claimed.

Each time the logical “1” appears in a stage of shift register 30, a “claim select” signal appears on the respective output line 34 associated with the stage. This “claim select” signal is supplied in parallel to one input of a respective one of AND gates 35, on line 36, and to further logic circuitry (to be described presently with reference to FIG. 7B), on line 37. The output line of each of AND gates 35 is connected to a separate and distinct line of an OR gate 40 which, in turn, supplies an input to an AND gate 42 whose other input constitutes pulses from the master clock 5.

In operation of the portion of the generator assignment logic shown in FIG. 7A, assume that shift register stage 02 contains the logical “1.” That stage therefore supplies “claim select” signal 21 to the respective associated AND gate 35 and, as well, to further logic circuitry on line 37. If this further logic circuitry determines that the associated note generator may be claimed, a “claimed” signal is applied as the second input to the respective associated AND gate 35. Since both inputs of that AND gate are now “true,” i.e., the output pulses is furnished via OR gate 40 to the synchronization gate 42. The latter gate produces a “shift” pulse on line 32 upon simultaneous occurrence of the output pulse from OR gate 40 and a clock pulse from master clock 5. Accordingly, the logical “1” is advanced one bit position, from stage 02 to stage 03 of shift register 30, in preparation for the claiming of the next tone generator.

Suppose, however, that the tone generator 28 corresponding to stage 03 is already claimed by a previous note pulse in the multiplexed signal. In that event a “claimed” signal appears as one input to the associated AND gate 35, and with the “claim select” signal appearing as the other input to that gate by virtue of stage 02 containing the single logical “1,” another shift pulse is immediately generated on line 32 to advance the logical “1” to stage 04 of the shift register. Similar advancement of bit position of the “1” continues until an unclaimed tone generator is selected. If it should happen that no note is presently being selected on a keyboard of the organ at the time when an unclaimed tone generator is selected, the “1” bit remains in the shift register stage associated with the selected tone generator until such time that the signal is concurrently applied to the respective AND gate 35, i.e., until the selected tone generator is claimed, because until that time no further shift signals can occur.
Referring now to Fig. 7B, each tone generator also has associated therewith a respective portion of the generator assignment logic as shown in that figure. In other words, the circuitry of Fig. 7B, with minor exceptions to be noted in the ensuing description, is associated with the i'th tone generator (where i = 1, 2, 3, ... 12), and since each of these portions of the assignment logic is identical, a single showing and description will suffice for all. An AND gate 50 has four inputs, one of which is the multiplexed signal deriving from encoder 15 (this being supplied in parallel to the AND gates 50 of the remaining identical portions of the assignment logic for the other tone generators, as well), a second of which is the "claim select" signal appearing on line 37 associated with the i'th stage of shift register 30 (Fig. 7A), a third of which is a signal, on line 52, indicating that the pulse in the multiplexed signal has not captured any tone generator as yet, and a fourth which indicates that the note generator is uncalled. Of course, these signals are not present at the respective events which produce them are actually occurring, but if all four signals are simultaneously presented as inputs to AND gate 50, a "set" signal is applied to a claim flip-flop 53 to switch that flip-flop to the "claimed" state and simultaneously therewith to supply a "claimed" signal to the AND gate 35 associated with the i'th stage of shift register 30 and to the respective associated tone generator 55.

A modulo 384 counter 55 is employed to permit recognition by the respective portion of the generator assignment logic of the continued existence in the multiplexed signal of the pulse (time slot) which resulted in the capture of the associated tone generator. To that end, counter 55 is synchronized with keyboard counter 1 (also a modulo 384 counter) by simultaneous application there of clock pulses from master clock 5. The count of each counter 55 associated with an uncaptured tone generator is maintained in synchronism with the count of keyboard counter 1 by application of a reset signal to an AND gate 58 each time the keyboard counter assumes a zero count, i.e., each time the count of the keyboard counter repeats. However, that reset signal is effective to reset counter 55 only if the associated tone generator is uncaptured. The latter information is provided by the state of flip-flop 53, i.e., a "not claimed" signal is supplied as a second input to AND gate 58 whenever flip-flop 53 is in the "uncalled" state.

When the flip-flop (and hence, the associated tone generator) is claimed, however, it is desirable to indicate the time slot occupied by the pulse which captured the tone generator and for that reason a "reset" signal is applied to counter 55 at any time that an output signal is derived from AND gate 50. Thus, in the captured state, the zero count of counter 55 occurs with each repetition of the "capturing" pulse in the TDM waveform. Such information is valuable for a variety of reasons; for example, to prevent capture of an already captured tone generator when the zero count continues to appear simultaneously with a pulse in the TDM waveform, and to provide a "key released" indication when the zero count is no longer accompanied by a pulse in the TDM waveform. Capture prevention is effected by feeding a signal representative of zero count from counter 55 to the appropriate input terminal of an OR gate 60 associated with all of the tone generators and their respective generator assignment logic. The logical "1" supplied to OR gate 60 is inverted so that simultaneous identical logical inputs cannot be presented to AND gate 50. On the other hand, when the zero count is merely synchronized with the zero count of the keyboard counter and is not the result of capture of the associated tone generator it does not interfere with subsequent capture of that tone generator since it does not occur simultaneously with a pulse in the TDM signal. A "key released" indication is obtained by supplying the "zero count" signal to AND gate 50. This is also supplied any signal deriving from an inverter 63 connected to receive inputs from the TDM signal. If the zero count coincides with a pulse in the multiplexed signal, the inversion of the latter pulse prevents an output from AND gate 62, and this is proper because the coincidence of the zero count and the TDM pulse is indicative of continuing depression of the key which has captured the tone generator. Lack of coincidence is indicative that the key has been released, and results in the "key release" signal. Scanning of the keyboards is sufficiently rapid that any delay which might exist between actual key release and initiation of a key release signal is negligible, and in any event is undetectable by the human senses.

Furthermore, the generation of a false "key release" signal when the tone generator is presently uncalled, as a result of the occurrence of a zero count from counter 55 synchronized with the zero count of the keyboard counter and the simultaneous absence of a pulse in the TDM signal, can have no effect on the audio output of the organ since the associated tone generator is not captured and is therefore not generating any tone. In any case, the "key release" signal deriving from AND gate 62 is supplied to attack/decay decay logic of the tone generator to initiate the decay of the generated tone.

The "set claim" signal output of AND gate 50 that occurs with the simultaneous appearance of the three input signals to that gate is utilized to provide a "key depressed" indication to the attack/decay circuitry of the tone generator (and to percussive controls, if desired), as well as to provide its previously rectified functions of "setting" flip-flop 53 and "resetting" counter 55.

The assignment logic embodiment of Figs. 7A and 7B may be associated with only a small number of tone generators (12, in the example previously given), the exact number being selected in view of the cost limitations and the likely maximum number of keys that normally may be actuated simultaneously. In that case, each tone generator must supply every desired frequency corresponding to every note in every octave that may be played on the electronic organ. To that end, a digital tone generator of the exemplary construction shown in block diagrammatic form in Fig. 8 is employed.

Before describing the cooperative structural and functional relationships between the elements of the tone generator shown in Fig. 8, it is instructive to consider some of the available alternatives in the construction and operation of digital tone generators for ultimately generating a desired audio-frequency for a note corresponding to an actuated key. When a key is depressed on any keyboard of the digital electronic organ, a waveform is to be generated with a periodicity corresponding to the desired note frequency in the audible range. The waveform is computed in digital format consisting of a series of numbers (digital words) which represent the magnitude of the waveform at a series, or sequence, of uniformly spaced sample points. The digital sample point values thus generated are subsequently converted to analog form.

The sample points are preferably uniformly spaced because such a format permits the most direct analysis, and therefore the most direct synthesis, of the desired waveform. If desired, the uniform spacing of sample points may be such that there is provided an integral number of samples per cycle for each note frequency to be generated. Such a technique requires a sampling rate that varies directly with the frequency. Alternatively, the samples may be spaced uniformly in time, in which case the phase angle between samples points varies with the frequency of the note to be generated. Although the synthesis of a multiplicity of note frequencies can be implemented for either technique, using a single clock frequency, the preferred frequency synthesis technique is that in which the phase angle between the sample points varies with frequency, i.e., in which the sampling rate is fixed for all note frequencies to be generated, and the various generated note frequencies are produced as a result of the different phase angles.

FIG. 8 shows, in its embodiment, a specific exemplary structure of a tone generator for generating the required note frequencies of the organ from a memory containing amplitude samples of the desired waveform obtained at uniformly spaced points in time. The sample points are accessed at a fixed, signal clock frequency for all note frequencies to be generated.
and the phase angle between the sample points thereby varies with the frequency of the note to be generated. The tone generator includes, as basic components, a phase angle calculator 100, a phase angle register 101, a sample point address register 102, a read-only memory 103, an address decoder 103a, an accumulator 104, a sampling clock 105, and a comparator 107. As will be apparent hereafter, the phase angle calculator 100 and the read-only memory 103 may be shared by all of the tone generators 28. In addition, each tone generator is addressed individually and in sequence and thus once in each cycle of addressing all tone generators. For that reason, the sampling clock 105 may comprise a clock rate provided by a master sampling clock, successive clock pulses of which are directed to the series of tone generators. The sampling clock addressed to a given tone generator is thus at a rate comprising the pulse repetition rate of the master sampling clock divided by the number of tone generators provided in the system. Further, since the same read-only memory may be addressed by all tone generators, the accumulator 104 may be a composite structure associated with appropriate gating circuitry related to each tone generator for accumulating the information read from the memory 103 in response to accessing thereof by a given tone generator.

When a claim flip-flop of the tone generator assignment logic, such as flip-flop 53 (FIG. 7B), is switched to the claimed state in accordance with capturing of a pulse in the incoming multiplexed waveform by a given tone generator 28, the phase angle calculator 100 is instructed to determine the appropriate phase angle for the frequency of the note to be reproduced as identified by the captured pulse. A determination of the value of the phase angle constant, and hence, of the particular note corresponding to the key that has been actuated, is initiated by supplying both the count from the master keyboard counter 1 and the count of the modulo 384 counter 55 (e.g., of FIG. 7B) associated with the captured flip-flop, and which is reset to zero upon that capture, to a count comparator 107. Comparator 107 subtracts the count of counter 55 from the count of the keyboard counter 1 and supplies a number representative of the difference, and hence, representative of the time slot corresponding to a particular note (i.e., that note which captured the flip-flop), to phase angle calculator 100. The difference computed by comparator 107 will always be positive, or zero, because the computation is elicited from the comparator only when the associated flip-flop 53 is captured and at that moment counter 55 is reset to zero, whereas the keyboard counter probably has some greater count or contains at least count, i.e., zero.

One count supplied by the difference counter is compared by comparator 107, calculator 100 is informed as to the note for which the phase angle calculation is to be performed, i.e., the note and thus the frequency to be produced by the tone generator. The calculator 100 may compute the phase angle as a function of the frequency of the note to be reproduced and of the number of memory sampling points of the waveform in storage and thus as approximately equal to the phase angle of the fundamental between adjacent memory sampling points for the frequency to be produced. An alternatively embodiment of the phase angle calculator 100 is a conventional storage unit with look-up capabilities, or simply a memory from which the correct phase angle is extracted when the memory is suitably addressed with the identification of the count of the captured pulse. Alternatively, a combination of a memory with look-up capabilities and of a calculator capable of computing a determination of the phase angles may be employed. The synthesis of note frequencies in accordance with the digitally stored waveform sample points may be arbitrarily as accurate as desired and, in effect, provides a true equally tempered scale of the synthesized note frequencies wherein the notes within the scale differ by the power of 214. The degree of accuracy in a practical system, however, must be realized within a finite maximum information content and thus the stored phase angles are quantized and rounded off.

The phase angle thus developed is supplied to the stored in the phase angle register 101. Thus, upon capture of a given tone generator, a command counter 106 is activated by the flip-flop 53 which establishes the captured state of the tone generator control of the operation of the comparator 107 and, in turn, the phase angle determination function of the phase angle calculator 100 for the given note frequency to be generated, for supply of that phase angle to the register 101. Since this operation must precede the addressing function, a delay may be provided (or by use of a delay multivibrator 106) to actuate a switch 108 for passage of pulses from the sampling clock source 105 (which may be an appropriately gated pulse from a master sampling clock source) to the registers 101 and 102.

If desired, the sample point address register 102 may be cleared when claim flip-flop 53 reverts to a noncaptured state, so that it is prepared for entry of information from the phase angle register 101 upon each calculation. However, it is important to note that during accessing the memory it is the rate at which the value of register 102 increases and not the absolute value thereof which is significant in the control of the rate of read out of the memory 103 and thus the cyclic frequency of read out of the memory and, ultimately, the frequency of the note reproduced by the given tone generator.

Once each sampling clock time as determined by the sampling clock source 105, the phase angle value stored in phase angle register 101 is added to the previously stored value of the sample point address register 102. An address decoder 103a decodes preselected bit positions of the count established in register 102 to effect accessing, or addressing, of the memory 103. The transfer from the register 101 to the register 102 is a nondestructive transfer such that the phase angle value is maintained in the register 101 as long as that tone generator is captured by a given pulse. Thus, once each clock time, the phase angle register value, comprising a digital binary word, is added to the sample point address register value and correspondingly, for each such clock time, the memory location corresponding to the sample point address then existing in the register 102 is accessed. As a practical matter, only a relatively small, finite set of amplitudes can be stored in the memory 103, because of practical limitations on its capacity, and thus only a finite number of addresses are available. Furthermore, the registers such as 101 and 102 must be of a finite, practical length. In particular, the length of the phase angle register 101 is determined by the accuracy with which the frequency of the note to be generated. The frequency actually produced will be exactly the value of the phase angle in register 101 times the memory sampling rate. The sample point address register 102, on the other hand, must be sufficiently long to accept data from the phase angle register 101. The register 102, however, preferably includes additional bit positions which are not used, or not used at all times, for accessing the memory. In this respect, it will be apparent that one bit position in the register 102 is scaled at one cycle of the fundamental of the frequency of the note to be generated. A set of next successive less significant bits may therefore specify the sample point address in accordance with the function of the decoder 103a. The more significant bits of the register 102 may be used to count numbers of cycles of the waveform to be produced, not here pertinent. In addition, by selecting appropriate bit positions by means of decoder 103a, the frequency of the note reproduced may be readily adjusted to different octaves. That is, a one-bit positional shift constitutes division or multiplication by two, depending upon direction of shift. For example, if the most significant bit is numbered 1 and thus bit positions 2 through 6 comprise the sample point address bits, then a four-bit value is used for an 8-foot voice, then a 16-foot voice can be obtained by using bits 1 through 5 as the sample point address source. Correspondingly, a 4-foot voice can be obtained by using bits 3 through 7 as a sample point address bits.

The read-only memory 103 contains digital amplitude values of a single cycle of the complex periodic waveform to be reproduced for all note frequencies. That is to say, the
same complex periodic waveform is to be reproduced for each note played, the only difference being the frequency at which the complex waveform is reproduced.

Referring to FIG. 9, illustrating a typical complex waveform 110 of the type that may be produced by a pipe organ, the wave may be sampled at a multiplicity of points, shown as vertical lines in the Figure, to provide the amplitude data for storage in memory 103. If absolute amplitude data is stored in memory 103, then the data accessed is the actual amplitude of the output waveform at the respective sample points (i.e., with respect to a "zero" level at time axis 111). In the event, the digital amplitude data successively read from the memory may be applied directly to an appropriately digital-to-analog conversion system. On the other hand, if incremental amplitude information (i.e., simply the difference in amplitude between the present sample and the immediately preceding sample) is stored in memory 103, then the data accessed must be added to an accumulator (e.g., 104 in FIG. 8) to provide the absolute amplitude information at each sample point prior to digital-to-analog conversion. Each of the sample points of the memory 103 may comprise a digital word of appropriate magnitude of bits.

The digital words thus read out from the memory 103 are supplied to the accumulator 104 which provides a digital representation of the waveform at selected sample points over a cycle of the waveform and at a frequency corresponding to the note to be reproduced. As above described, this digital waveform representation may itself be operated upon for wave shaping control, attack and decay control, etc., and is then converted to a digital-to-analog converter for producing an analog signal suitable for driving the acoustical output means, such as audio speakers, of the organ.

Memory 103 may be a minicomputer diode array of the type disclosed by R. M. Ashby et al. in U.S. Pat. No. 3,377,513, issued Apr. 9, 1968, and assigned to the same assignee as is the present invention. The array may, for example contain an amplitude representation of the desired waveform in the form of an eight bit binary word at each of 408 or more sample points. Such a capacity permits the storage of up to 128 amplitude levels in addition to a polarity (algebraic sign) bit. In any event, the capacity of memory 103 should be sufficient to allow faithful reproduction of note frequencies.

If the amplitude levels at the sample points of the waveform are read from memory 103 in the embodiment of FIG. 8, the same sample point may be addressed several times in succession. This is the result of the requirement that the memory be accessed at a fixed rate for every note frequency, a requirement which implies that for decreasing note frequencies an increasing number of sample points must be read out during each cycle; and since the number of sample points is fixed and no sample points can be skipped regardless of note frequency, this simply means repetition of the same sample point possibly several times in succession. This does not undesirably affect the ultimate waveform generated, however, because there is consistent plural sampling of each point of the stored waveform.

On the other hand, if incremental values of the waveform have been stored in memory 103, each increment can be read out only once during each cycle of the waveform. This is because an accumulation of incremental values is required, and repetition will produce a significant error in the accumulation and the ultimate waveform to be generated, regardless of the note frequency. Since the same sample point may be read out of memory 103 several times in succession depending upon the note frequency to be produced, just as in the whole sample point case noted above, for incremental values all but one readout for each sample point must be inhibited to prevent repetitive application to accumulator 104. To that end, a gate 1036 (shown dotted in FIG. 8) is positioned in the output line of memory 103 preceding accumulator 104 if an increment is read from that memory. Gate 1036 is enabled to pass the sample value being read from the memory only when the least significant bit in address register 102 changes. Since such change occurs upon a "carry" into that position, indicating advancement to the next memory address, a bit change sensor 102r may be used to detect the change and to enable gate 1035 at each advancement to a new address. The same sample point may still be accessed several times in succession, but only one such value will be "read out" (i.e., will be passed by the gate since it is disabled at all other times).

The phase angle calculations should be such that the highest note playable is that note for which a sample point value is read out each time the memory is addressed. Since the ratio between adjacent notes on the equally tempered musical scale is an irrational number, it is preferable that the largest number in the phase angle register be slightly smaller than the least significant one in the address register. If the phase angle number were larger, it would be necessary to occasionally skip a sample point and this would lead to inconsistency in the note frequency, whereas if the phase angle number were equal to the least significant bit in the address register the note frequency would be slightly higher (i.e., about one-half of a halftone higher) than the highest note that can be played. By requiring the phase angle number to be slightly smaller, the highest note capability of the instrument may be increased.

The same read-only memory 103 may be shared by all of the tone generators 28 of the data words (amplitude values of sample points) read therefrom are gated to respective wave shapers in synchronism with the addressing of the memory for the respective notes being played. In other words, simultaneous or concurrent play of two or more notes requires that these be distinguished by subaddressing of the sample points, if a single memory is to be shared for all the tone generators.

In the present embodiment, however, it is assumed that each tone generator has its own memory (and, incidentally, memories composed of microminiature diode arrays of the type disclosed in the aforementioned Ashby et al. patent are readily fabricated with more than 5,000 diode elements per square inch), which supplies its digital output to a respectively associated attack and decay control unit. The binary-valued amplitude samples are applied directly to the attack and decay circuitry of each sample is a whole value, or may be applied via an accumulator 104 of each sample is an incremental value. Alternatively, accumulation of incremental values may be performed after shaping, if desired.

Referring to FIG. 10, an embodiment of the attack and decay unit associated with each tone generator includes a multiplier 120 to which the sample values from memory 103 are applied for multiplication by an appropriate scale factor to control the leading and trailing portions of the note waveform envelope. As is well known, the faithful simulation of true pipe organ sounds by an electronic organ requires that the latter be provided with the capability to shape each tone envelope to produce other than an abrupt rise and fall. Without special attack and decay control, the note waveform produced by an electronic organ normally rises sharply to full intensity immediately upon depression of the respective key, and ceases abruptly when that key is released. At times, this may be a desirable effect to maintain during the play of a musical selection. In those cases, the attack and decay controls may be avoided entirely, or the scale factor supplied to multiplier 120, and with which the amplitude samples are to be multiplied, may be set at unity. More often, however, attack and/or decay are desirable for or in conjunction with special effects, such as percussion, sustain, and so forth.

The multiplying scale factor is varied as a function of time to correspondingly vary the magnitude of the digital samples, with which it is multiplied, on a progressive basis to simulate attack and/or decay. In the embodiment of FIG. 10, the total time duration and the time constant(s) for the attack or decay are controlled by a counter 122 which may be selectively supplied with uniformly timed pulses that are independent of the specific note frequency under consideration, such as pulses obtained or derived from the master clock, or with pulses having a repetition rate representative of or proportional to the note frequency. In this respect, the counter 122 may be con-
sidered as determining the abscissa of a graph of envelope amplitude versus time and representative of the attack or decay. The ordinate or amplitude scale of the graph is represented by the series of scale factors stored in a read-only memory 125 to be accessed by the counter itself, or by an address decoder 126 which addresses the memory for readout of scale factors on the basis of each count (or timed, separated counts) of counter 122.

To the counter may be of the reversible, up-down (forward-backward) type in which it is responsive to incoming pulses to count upwardly when its "up" (here, attack) terminal is activated, and to count downwardly when its "down" (here, decay) terminal is activated. The attack mode of the overall control unit is entered when the associated tone generator is captured by a hitherto unclaimed note pulse in the multi-vibrator signal. The capture of a tone generator is accompanied by a signal indicative of scale factor of (see FIG. 7B), from the assignment logic, and it is this signal which initiates the attack count of counter 122. In particular, the first "key depressed" signal (and possibly the only one) that occurs upon capture of a tone generator 28 is effective to produce a count in the first stage of ring counter 128, thereby suppressing a trigger signal from that stage to a monostable delay multivibrator 130 which is set to time (or delay time) of sufficient duration to ensure that the attack is completed despite release of the key prior to the normal end of the attack interval. It has been found that a delay time equal to or greater than approximately the time occupied by seven cycles (e.g., seven periods) of the lowest frequency note is quite adequate for multivibrator 130 to ensure this positive attack. During that interval, the "up" control of counter 122 is activated by the quasi-stable state of the multivibrator 130 and the counter continues to count incoming pulses until the multivibrator spontaneously returns to its steady state, or until the note envelope reaches the full desired intensity (magnitude), if earlier. This full intensity value may be preset into the attack/decay control logic or it may be determined by logical circuitry responsive to such factors as the force with which the respective key is struck (i.e., to velocity sensitive or touch responsive device outputs). In the embodiment shown in FIG. 10, the former arrangement is utilized in which a maximum desired count is set into a fixed counter 131 for continuous comparison in comparator 133 with the present count of updown counter 122. If the latter exceeds the former, a "disable" command is applied to the counter to terminate the attack.

Pulses to be counted by counter 122 may be obtained at a rate which is a function of note frequency, as by supplying the output of phase angle calculator 100 to a phase-to-frequency converter 135, or at a rate based on the master clock rate, whichever is desired. Selection of either rate is accomplished by appropriately setting a switch 136 coupled to an associated switch or key on or adjacent to one of the keyboards.

In operation of the attack/decay control unit of FIG. 10, after switch 136 has been set at the desired position, the pulses to be counted appear at the input of counter 122 but no count is initiated until a key is depressed and the associated pulse in the multiplexed signal from the keyboard results in the capture of a tone generator 28. The "key depressed" signal from the generator assignment logic initiates a count in ring counter 128, which had been reset by completion of decay the immediately preceding time the attack/decay control unit had been used. Preferably, the latter reset signal is obtained upon switching of the claim flip-flop 53 in the assignment logic 26 to the "not claimed" (delay complete) state. The up count of counter 122 is thereby terminated and continues to completion of attack regardless of whether or not the key remains depressed. If the count pulses are a function of note frequency, the duration of attack is based upon note frequency as well; otherwise, the positive attack interval is fixed regardless of note frequency.

With each count of counter 122 (or less frequently, by use of suitably timed "enabling" commands), address decoder 126 develops a related address code for accessing a digital scale factor stored in the appropriate address of read-only memory unit 125, to be combined as a product in multiplier 120 with the amplitude samples being read from tone generator 28 of FIG. 8. By presetting memory 125 such that the scale factors stored therein are logarithmically increasing (up to the equivalent of unity) with addresses decoded according to progressively increasing count in counter 122 (up to the maximum desired count, representing full note intensity), a logarithmic attack is provided in the note being played. Furthermore, since the initial attack is positive, i.e., continues to completion regardless of the present condition of the key which was struck to produce the attack, the logarithmic rise at the leading edge of the note waveform continues smoothly to full intensity of the note.

When the key is released, a "key release" signal is applied from AND gate 137 and gates 138 to initiate the decay mode of the attack/decay control unit by enabling the "decay" (down) count of counter 122. Accordingly, incoming pulses to the counter are counted downwardly from the count representative of full intensity, until a zero count is obtained unless decay is terminated earlier. As in the case of the attack mode, the counter of count 122 is periodically decremented by the multivibrator 130, while addressing the memory 125, there supplying logarithmically decreasing scale factors, from unity to zero, for multiplication with amplitude samples from the tone generator in multiplier 120. This procedure the desired fall in note intensity at the trailing portion of the note waveform. Alternatively to relying on zero count, scaler control logic may be implemented to signal completion of the decay mode.

If during decay the same note pulse should reappear in the multiplexed keyboard signal, indicating depression of the associated key virtually immediately after release thereof, a second "key depression" signal is applied to ring counter 128 thus increasing the count therein to the second stage and switching flip-flop 138 from the decay state to its other state, which reintroduces the attack mode. Since decay is incomplete in this particular instance, the count of counter 122 now proceeds upward from the minimum count which had been of delay MV 130), flip-flop 138 may be switched to its "attack" state upon full completion of decay, by the "not claimed" signal of flip-flop 53 in the assignment logic unit which produced capture of the associated tone generator. Concurrent operation of flip-flop 138 in the "attack" state and MV 130 in the quasi-stable state will result in above-described operation of the attack/decay control unit.

Upon completion of decay of a note whose representative pulse in the keyboard multiplexed signal resulted in capture of a tone generator, a "decay complete" signal is applied to the claim flip-flop 53 (FIG. 7B) of the respective assignment logic unit to cause that flip-flop to return to its "not claimed" state, and thereby to release the tone generator for claiming by another note. The "decay complete" signal may be supplied by the zero count of counter 122 or by any conventional detector for sensing the absence of further output from multiplier 120.

With reference now to FIG. 11, a keying system is provided for use with percussive tone generators (e.g., noise generators) to selectively produce sounds simulating those of percussion instruments. In the past, various types of pipe organs, such as theater organs, have been implemented with miniature reproductions of different percussion instruments, such as drums, cymbals, wood blocks, temple blocks, brush, and so forth, which could be actuated by the organist according to the desired rhythm or tempo. The keying system separates and amplifies to produce a percussive level consistent with the intensity of tones produced by the organ itself. Because of their miniaturized form, the percussion instruments were frequently referred to as "toys," and the beat or rhythm actuating devices by which the organist "played" those instruments were often called "toy countets." To some extent the latter name has...
remained in usage despite the much more prevalent use today of electronic organs in which special tone generators keyed by electronic signals are utilized to produce the desired percussion sounds for rhythm accompaniment of the organ.

The toy counter logic or percussion control logic of FIG. 11 is suitable for actuation of either the miniature percussion instruments or the percussion sound tone generators, depending upon which of these forms are provided, in conjunction with a keyboard multiplexing digital electronic organ of the type which has thus far been described herein. In particular, keying signals may be developed in the keyboard multiplexing system for use in generating the desired special percussion effects. Two types of keying signals, transient and steady state, are provided independently for each keyboard in the embodiment of FIG. 11.

The transient signal consists of a pulse which occurs upon depression of a key on any keyboard of the organ, and only upon depression of a key. To that end, the "set claim" signal (or "key depressed" signal) that occurs as an output of AND gate 50 in the tone generator assignment logic (FIG. 7B) upon coincidence of input signals to that gate, is used to indicate the depression of a key on one of the organ keyboards. Clearly, since the "set of claim" signal can be produced only when a tone generator 28 is available (and results in capture of that tone generator), no such signal can occur if the organ is saturated, i.e., if all tone generators are in use, regardless of depression of a key. Except in the event of saturation, which is unlikely, each time a key is depressed a signal is supplied to an OR gate 150 of the percussion control logic. In the exemplary organ embodiment thus far described, 12 tone generators are provided and hence 12 "set claim" signals, each associated with a separate and distinct tone generator assignment logic unit, can be produced. Accordingly, OR gate 150 has an input terminal for each "set claim" signal, for a total of 12 input terminals. Each time a signal appears as an input to the OR gate, indicating depression of a key, an output signal is supplied by the OR gate in parallel to four AND gates 152-1, 152-2, 152-3, and 152-4, for the specific example of an organ having four keyboards (three manuals and a pedal board).

Sequential gating signals are supplied to the four AND gates 152 over the respective intervals in which the associated keyboard is being scanned by connecting the second input terminal of each AND gate to a respective output lead of keyboard counter section 4 (FIG. 1). Thus, the transient keying signal that occurs upon depression of a key is gated on an output line associated with the keyboard on which that key is located. This signal, in the form of a pulse, may be used to actuate actual miniature percussion instruments or to actuate percussion sound generators. The specific manner in which the keying signals are employed for that purpose may follow conventional practice, using conventional percussion systems. Reference is made, by way of example, to U.S. Pat. Nos. 3,309,454 to Cutler et al., 3,358,069 to Hearne, 3,433,880 to Southard, and 3,439,569 to Dodds et al., as representative of known techniques for use of keying signals to initiate percussion sounds. In the case of the transient keying signal, zero count detector 60 and associated components of the tone generator assignment logic preclude the "key depressed" signal from recurring with each repetition of the respective pulse in the multiplexed signal during the interval over which the key remains depressed, as previously explained in conjunction with the description of FIGS. 7A and 7B.

The other type of keying signal, viz., the steady state signal, is derived directly from the multiplexed signal appearing as an output from encoder 15 (FIG. 1). The multiplexed signal is applied in parallel to four AND gates 156-1, 156-2, 156-3, and 156-4 (again, for the specific case in which four keyboards are available), and the pulses associated with keys on each respective keyboard are gated only during the occurrence of gating signal for that keyboard as supplied from key counter section 4 to the other input terminal of each of the AND gates 156. An output of one of the AND gates is applied as a set signal to a respective one of four flip-flops 158-1, 158-2, 158-3, and 158-4. Thus, each flip-flop 158 is set by the occurrence of a pulse in the multiplexed signal during the time period provided by the corresponding keyboard all of flip-flops 158 are reset simultaneously upon occurrence of the keyboard counter reset signal.

Assumption by a flip-flop 158 of its set state results in a signal applied to a respective one of a set of AND gates 160, and similarly, the resetting of flip-flops 158 results in signals representative of that state of the flip-flops to others of the AND gates 160. Each pair of AND gates 160 associated with a specific flip-flop 158 is also associated with one of a further set of flip-flops 161-1, 161-2, 161-3, 161-4, so that upon occurrence of the keyboard counter reset signal the respective states of flip-flops 158 are transferred to corresponding ones of flip-flops 161. The effect is that of a sample and hold system, to provide the desired steady state percussion keying signals from each keyboard, each such keying signal being taken only from the "set" state output terminal of the respective flip-flop 161.

As in the case of the transient keying signals, the steady state keying signals may also be utilized to supply desired percussion sounds by known techniques. Each keyboard of the organ usually has associated with it a set of stops or tabs, alternatively referred to as stop tabs, stop keys, or stop switches. In a generic sense, the stops as well as the keys of each keyboard may be referred to as switches. The stops associated with each keyboard are utilized to select appropriate pitch length or footage and the desired organ voice, including the tonal quality, or timbre, and the harmonic content of the sound to be reproduced by the electronic organ. Stops may be actuated in various combinations, if desired, and may also be preset or programmed to permit the organist to reactuate one or more stop combinations during performance of a particular musical piece, by means of a so-called "combination action." The terminology "stop rail" is also used to refer to a set of stop or tab switches by which the organist may select particular voices prior to and/or during play of the organ.

A system for multiplexing information representative of the selection of particular tab switches in each stop rail and for the storage of such voice information to be subsequently accessed by the organist during performance of the musical selection, is illustrated by way of example in FIG. 12. Referring to that Figure, the stop rail multiplexing system includes a stop rail counter 200, a stop rail decoder 202, a stop switching array 202, a stop rail encoder 203, a set of voice memories 204, a voice memory selector 205, an address decoder 206, a voicer 207, a set of registration memories 208, and a set of couplers 209.

The stop rail counter 200 comprises four separate sections as is indicated with greater clarity in FIG. 13. The most significant section or portion of the stop rail counter is referred to as the registration memory (RM) counter 211 and the remaining stop rail counter portions are of decreasing significance, from the RM address counter 212 and voice group counter 213, down through the voice counter 214 which constitutes the least significant portion of stop rail counter 200. Voice counter portion 214 is a modulo-4 ring counter which is advanced by pulses derived from the master clock and which sequentially energizes its output leads, designated V1, V2, V3, V4, in accordance with advancement of its count. All four output leads of voice counter 214 are connected to encoder 203 and to voice memory selector 205, whereas only the last stage, V4, is connected to voicer 207, for a purpose to be described presently.

The next most significant portion of the stop rail counter 200, namely, the voice group counter 213 is a modulo-10 ring counter, having 10 stages and associated output leads designated GS1, GG1, GS2, GS3, GG2, GP1, GP2, and GP3, advancing from the least to the most significant stage of that counter portion. For the sake of clarity, the first letter of each of these designations indicates "group," and the next two characters indicate particular voice groups such
as swell flute (SF), great flute (GF), swell (S), great (G) and pedal (P), although it is to be understood that there is no intention here to restrict the voicing section to voices of these particular types. All output leads of voice group counter 213 are connected to decoder 201 and to voice memory selector 205, whereas the last stage, GP2, is connected to voice counter 207. The voice group counter sequences through all of these groups once during each of its cycles, and advances to the next successive stage (group) once for each cycle of voice counter 214. In other words, the voice counter must sequence through all four of its stages before the count is advanced by one in voice group counter 213.

The next more significant counter section or portion of the stop rail counter 200 is the RM address counter 212 which, in this particular embodiment, is a modulo-64 six-bit binary counter utilized to specify the addresses of the registration memories 208, the latter constituting the working storage from which digital waveforms are read under control of the note generators for generating the audio output. In the present example, five registration memories are employed, these being designated swell flute, great flute, swell, great and pedal. In particular, the registration memories are to be loaded with data from the voice memories 204 which contain the fixed, stored data representing individual voices, and thereby to form a composite of individual voices which are keyed simultaneously and sounded in the same audio channel. Stop rail counter 200, decoder 201, switching array 202, and encoder 203 together provide the stop rail tab switch information to voice counter 207 in the form of a multiplexed signal. The multiplexed signal is used for selecting the appropriate voice data from voice memories 204 to provide the composite data in registration memories 208. Specifically, it is the function of voice counter 207 to accumulate the voice data from voice memories 204 to form the composite data for entry into the registration memories 208. It will be realized from the preceding description that the registration memories must be updated as necessary to enter the composite voice data therein, and it is to that end that the outputs of the RM address counter 212 and of the RM counter 211, a modulo-5 ring counter, are supplied to register memories 208.

The registration memories are updated once at a time in sequential order as determined by RM counter 211, its outputs RSF, RGF, RS, RG, and RP being sequenced in the order recited with advancement by one stage upon conclusion of each cycle of the count of RM address counter 212. It is the function of the RM address counter 212 to specify the addresses of the registration memories such that each memory location is updated sequentially in the order of those addresses. The latter counter advances once for each cycle of the count of voice group counter 213. The outputs of RM counter 212 are supplied to the registration memories 208 and to decoder 201, whereas RM address counter 212 supplies all of its outputs to the registration memories for specifying the addresses therefor, and as well supplies the outputs from the first five of its stages to address decoder 206 and the output of the fifth stage alone to voice 207.

The exemplary embodiment of the stop rail multiplex system may be provided with 40 voices, arranged in 10 groups of four voices each for the sake of convenience. Each group of voices is associated with only one of the five registration memories, although more than one group may be associated with a particular one of those memories. Except for the coupling information provided by couplers 209, a voice group is loaded only into that registration memory with which it is associated. The relationship between voice groups, couplers, and registration memories is illustrated in the following Table.

<table>
<thead>
<tr>
<th>Group</th>
<th>Registr-</th>
<th>Swell to</th>
<th>Swell to</th>
<th>Great to</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>stra-</td>
<td>Great Coupler</td>
<td>Great Coupler</td>
<td></td>
</tr>
<tr>
<td></td>
<td>tion (RM)</td>
<td>(SUC)</td>
<td>(SPC)</td>
<td>(GPC)</td>
</tr>
<tr>
<td>1</td>
<td>GSF</td>
<td>RS</td>
<td>RG</td>
<td>RP</td>
</tr>
<tr>
<td>2</td>
<td>GGF</td>
<td>RO</td>
<td>RG</td>
<td>RP</td>
</tr>
<tr>
<td>3</td>
<td>GB2</td>
<td>RO</td>
<td>GP1</td>
<td>RP</td>
</tr>
<tr>
<td>4</td>
<td>GS2</td>
<td>RS</td>
<td>RG</td>
<td>RP</td>
</tr>
<tr>
<td>5</td>
<td>GSF</td>
<td>RS</td>
<td>RG</td>
<td>RP</td>
</tr>
<tr>
<td>6</td>
<td>GGF</td>
<td>RO</td>
<td>RG</td>
<td>RP</td>
</tr>
<tr>
<td>7</td>
<td>GB2</td>
<td>RO</td>
<td>GP1</td>
<td>RP</td>
</tr>
<tr>
<td>8</td>
<td>GS2</td>
<td>RS</td>
<td>RG</td>
<td>RP</td>
</tr>
</tbody>
</table>

The four voices in each group are specified in sequence by the voice counter 214.

Stop rail decoder 201 is implemented to modify the group counter 213 outputs and the RM counter 211 outputs in accordance with the coupler switch information from couplers 209, to drive stop rail array 202. Preferably, a decoder 201 is implemented to produce the 10 logical outputs designated by the logic equations listed below.

\[
\begin{align*}
\text{DSF} &= \text{GSF} + \text{RFS} + \text{SGC} + \text{RSPC} \\
\text{DGF} &= \text{GFG} + \text{RGF} + \text{RGP} \\
\text{DS1} &= \text{GSI} + \text{RSF} + \text{SGC} + \text{RSPC} \\
\text{DS2} &= \text{GS2} + \text{RSF} + \text{SGC} + \text{RSPC} \\
\text{DS3} &= \text{GS3} + \text{RSF} + \text{SGC} + \text{RSPC} \\
\text{DG1} &= \text{G11} + \text{RGF} + \text{RGP} \\
\text{DG2} &= \text{G22} + \text{RGF} + \text{RGP} \\
\text{DP1} &= \text{GP1} + \text{RP} \\
\text{DP2} &= \text{G22} + \text{RP} \\
\text{DP3} &= \text{GP1} + \text{RP} \\
\end{align*}
\]

Stop rail array 202 is a matrix of switches constructed in an analogous manner to the construction of the keyboard array of FIG. 1. In particular the stop rail array is wired with 10 input buses driven respectively by the decoder outputs, and with four output buses designated VS1, VS2, VS3, and VS4. At each intersection of an input bus and an output bus of the stop rail array there is a series connection of a normally open switch and a diode poled anode-to-cathode in the direction from the input bus to the output bus, corresponding to that arrangement shown in FIG. 4 for the keyboard switching array of FIG. 1. In the stop rail array, however, the switches are controlled by the voice selection stop tabs.

Encoder 203 is implemented to accept the four parallel outputs VS1 through VS4 of the stop rail array 202 and the four parallel output lines V1 through V4 of voice counter 214, and to produce therefrom a multiplexed signal consisting of information in the form of pulses indicating which of the voice selection stop tabs has been actuated, to institute the selection of the voice composite data. To that end, and as shown in FIG. 14, the stop encoder 203 may include four AND gates 220-1, 220-2, 220-3, and 220-4, each of which has a pair of input terminals and an output terminal, the latter connected in parallel with outputs of the other AND gates to supply inputs to an OR gate 222. Each AND gate 220 will receive from each of its inputs the signal appearing on a respective one of the four output buses VS1, VS2, VS3, VS4 from array 202, and as the other input a signal appearing on the lead from a respective one of the four stages of the voice counter 214. Thus, as the voice counter is sequenced through its four stages, the signals appearing on the four output buses of array 202 are gated in the same sequence to OR gate 222 thereby forming a serial digit format as the multiplexed signal MS containing voice selection data for application to voice 207.

In an exemplary embodiment, voice memories 204 may comprise a set of 40 fixed memories, each provided with a select line VS1 and a four-bit address VA1 to VA4. Each of the 40 voice memories consists of 16, seven-bit words defining a half cycle of the waveform to be produced. The arrangement of voice memories is shown in exemplary form in FIG. 15, the 40 fixed memories being read one at a time in accordance with the selection performed by the voice memory selector unit 205 which supplies selection outputs VS1 through VS40 thereto. When a voice memory is read, one seven-bit word is addressed and the seven bits are read out in parallel. While there are only 16 words in each voice memory, there are 64 registration memory addresses, and the address decoder 206 is implemented so that as the RM address counter 212 advances
from 0 to 63, the voice memory address is advanced from 0 to 15, from 15 to 0, from 0 to 15, and again from 15 to 0. Since each set of 16 seven-bit words defines a half cycle of the desired waveform, this addressing of the voice memory is effective to provide complete cycles of that waveform.

An embodiment of voice memory selector 205 is shown in FIG. 16. Preferably, it consists of a set of 40 AND gates arranged in groups of 10 such that each group of AND gates receives respective inputs from the 10 output lines of voice group counter 213 and each successive set of four of those AND gates receives its other input from a respective one of the output lines of voice counter 214 so that a voice memory selection is performed by a coincidence of the group counter and the voice counter active outputs. The 40 voice selection outputs VS1 to VS40 are supplied in the activated sequence to voice memories 204.

An exemplary embodiment of address decoder 206 is shown in FIG. 17. Preferably, that decoder comprises a set of four exclusive OR gates each receiving as one of its inputs an output from a respective one of the first four stages of the RM address counter 212, and all receiving, as the other input, the output of the fifth stage of the RM address counter. Thus, four addresses VA1 to VAA are supplied in sequence as voice memory addresses, as either one, but not both, of the inputs of the respective exclusive OR gate is activated, and the arrangement is such that the advancement of voice memory addresses is in the forward and reverse sequence noted above to produce complete cycles of the waveform.

The voice data consisting of the seven-bit parallel output VD1 through VD7, provided by the selected memories, is supplied as an output of the voice memories 204 to voice 207. The voice counter accumulates this voice data in accordance with control exercised by the multiplexed signal MS from encoder 203. A preferred embodiment of the voice is shown in FIG. 18. Voice data read out of the voice memories as the latter are sequentially addressed, is read into voice 204 either (1) directly into a parallel adder 232 if no signal RAS is applied to one's complement gate 230 and a pulse appears in the multiplexed signal MS to enable gate 231; or (2) complemented as the result of application of signal RAS from the RM address counter 212 to gate 230, and then read into the parallel adder 232 in response to an appropriate concurrent pulse in the multiplexed signal at gate 231; or (3) entirely inhibited by virtue of the absence a pulse in the multiplexed signal applied to gate 231, so that a binary zero is read into the parallel adder. Thus, if bit five of the RM address counter 212 is "true," the data from the voice memories is complemented. If the multiplexed signal is "true," indicating that the respective voice was selected by the tab switches, and by the couplers, then the voice data or its two's complement is read into adder 232. Otherwise, a zero is read into the adder.

With reference to the specific logic for the voice 207 as shown in FIG. 18, the one's complement gate 230 may consist of seven exclusive OR gates (not shown), each having two inputs, one a voice data bit, and the other the bit five of the RM address counter 212. The output of gate 230 is either the voice data or a bit-by-bit complement. Enable gate 231 may consist of eight AND gates (not shown), seven of which have two inputs, one constituting an output from a respective one of the seven exclusive OR gates in complement gate 230 and the other constituting the multiplexed signal MS. The eighth AND gate is supplied with the multiplexed signal as one of its inputs and bit five (RAS) of the RM address counter. The output of the eighth AND gate in enable gate 231 is entered into the least significant bit carry input to parallel adder 232 to perform the two's complement of the data. Parallel adder 232 receives both the outputs of enable gate 231 and of a copy register 234. Copy register 234 in turn receives the contents of parallel adder 232 to hold the sum of the selected voices as they are accumulated. The copy register is reset during the selection of the 40th voice by a reset signal which occurs upon coincidence of the V4 output of voice counter 214 and the GP3 output of voice group counter 213 as inputs to an AND gate 235. The accumulated sum appearing in parallel adder 232 is written into the appropriate registration memory in accordance with an enable signal produced by coincidence of the reset signal and a master clock pulse, and in accordance with the selection provided by the RM counter counter 211 and the address provided by RM address counter 212.

Thus, when a particular stop switch is operated, a pulse appears in the corresponding preassigned time slot of the multiplexed signal output of encoder 203 as a consequence of a completed circuit connection having been established between an input bus and an output bus of switching array 202 allowing a signal from the scanning counter to pass through that connection. This pulse produces the previously described operation in voice 207 to load the registration memories with the proper voice information in accordance with address information supplied by RM counter 211 and RM address counter 212.

What is claimed is:

1. In an electronic musical instrument having keys selectively actuable to cause the production of sounds corresponding to respective notes of the musical scale, the combination comprising:

   means for repetitively and sequentially scanning said keys to detect the actuation of any one or more thereof,

   means responsive to actuation of one or more of said keys as detected by said scanning means to generate a digital signal containing assignments of the notes associated with the respective actuated keys, and

   means responsive to the assignments of notes in said digital signal for selectively producing the sounds corresponding to said assigned notes.

2. In the electronic musical instrument of claim 1, said combination further including:

   means coupled to said digital signal generating means for selectively keying percussive rhythm accompaniment in accordance with said note assignments.

3. An electronic musical instrument, comprising:

   a plurality of switches selectively operable to develop signals for calling forth respectively associated notes as audible sounds from said instrument, and

   means responsive to operation of switches among said plurality of switches for processing the respective developed signals in a digital multiplexed waveform to select the corresponding sounds to be produced from said instrument.

4. An electronic musical instrument according to claim 3 further including:

   means responsive to said digital multiplexed waveform for keying percussion sound accompaniment from said developed signals.

5. An electronic organ for simulating the sounds produced by a pipe organ, said electronic organ comprising:

   a plurality of switches,

   means responsive to said actuation and deactuation of said switches for encoding information representative thereof in a digital format of control data indicative of order and combination of actuation and deactuation of said switches,

   means responsive to said digital format for entering the control data produced in that format into selected time intervals of a time-division multiplexed signal, and

   means responsive to the control data of said time-division multiplexed signal and representative of the selective actuation and deactuation of said switches for developing signals from which to generate the pipe organ sounds desired to be reproduced by the electronic organ.

6. The electronic organ according to claim 5 wherein said switches comprise keys on each keyboard of said organ, and wherein said signal encoding means includes tone generating means for producing signals representative of the notes of the musical scale for each octave encompassed by the keyboards of said electronic organ.

7. The electronic organ according to claim 6 wherein there are provided plural said keyboards and wherein said means responsive to actuation and deactuation of switches includes:

   means for cyclically scanning said plural keyboards in a sequence of scanning intervals respectively correspond-
3,610,799

ing to each said keyboard of said organ, and
means responsive to selective actuation and deactuation of the keys to derive pulses representative of such selective actuation and deactuation on parallel paths representa-
tive of the keys of an octave for each of the plural octaves of each keyboard in successive, and during respective successive portions of the respectively corresponding scanning interval, as said digital format of control data.

8. The electronic organ according to claim 7 wherein:
said scanning means sequentially scans the notes over an oc-
tave of the musical scale cyclically and repetitively, and
said means responsive to said digital format is responsive to
said sequential note scanning of said scanning means and
to said derived pulses occurring on said parallel paths for
conversion of the parallel format of pulses to a serial for-
mat constituting said time-division multiplexed signal
containing said control data.

9. The electronic organ according to claim 5 wherein:
said switches comprise stops for selecting desired organ vo-
ces.
said signal developing means includes a memory containing
digital voice information corresponding to a plurality of
desired voices available to be produced, and
said means responsive to the control data selectively ac-
cesses said memory in response to actuation of one or
more of the stops in the corresponding locations thereof
to supply the respective digital voice information con-
tained in the accessed locations for developing the sounds
to be reproduced.

10. The electronic organ according to claim 9 wherein said
stops are arranged in groups corresponding to groups of said
voices, and said means responsive to actuation and deactua-
tion of switches includes:
means for cyclically and sequentially scanning said groups
of stops corresponding to said groups of organ voices, and
said means responsive to selective actuation and deactua-
tion of said stops produces said pulses representative of
such selective actuation and deactuation in a multiplexed
signal, as said digital format of control data.

11. The electronic organ according to claim 10 wherein said
means responsive to the control data of the multiplexed signal
for developing signals includes:
means for assigning each said switches to bring forth respec-
tive notes of the musical scale to a distinct and different
time slot in a sequence of cyclically repeated time slots,
and
means responsive to selective operation of a switch to pro-
vide a signal representative of such operation of said
switch in the respective assigned time slot for that switch
in each cycle of repetition of said sequence of time slots
during which said switch is operated.

12. A digital electronic musical instrument having switches
selectively operable to bring forth respective notes of the
musical scale, comprising:
means for generating tones corresponding in frequency to
notes of the musical scale, and
means synchronized with said time slot assigning means for
recognizing the note associated with a signal in a time slot
of said cyclically repeating sequence of time slots as
furnished by said switch operation-responsive means,
each time the last-named signal repeats, and for con-
straining said means for generating tones to produce a
tone corresponding in frequency to the recognized note.

15. In an electronic musical instrument in which informa-
tion representative of the actuation of selected switches to
bring forth respectively associated notes of the musical scale is
furnished in the form of a time-division multiplexed signal
containing a cyclically repeating sequence of time slots as-
associated respectively with switches, and in which a pulse in a
time slot is indicative of the actuation of the switch associated
with that time slot,
means for generating tones corresponding in frequency to
notes of the musical scale, and
means responsive to said multiplexed signal and
synchronized with the time slots in said multiplexed signal
for recognizing the note associated with a time slot con-
taining a pulse and for directing said tone generating
means to produce a tone corresponding in frequency to
the recognized note throughout the time interval over
which the pulse in the last-named time slot is repeated.

16. In an electronic organ simulating true pipe organ sounds
and having a plurality of keys selectively operable to call forth
notes of the musical scale, the combination comprises:
a plurality of tone generators substantially smaller in
number than the number of notes which an instrument is
printed to be capable of generating,
means for generating a time-division multiplexed waveform
constituting a cyclically repeating sequence of time slots,
means for assigning each note to a corresponding time slot
and responsive to operation of a respective key to provide
a signal in said corresponding time slot, and
means for determining the availability of said tone genera-
tors and responsive to the note assignment signals in said
time-division multiplexed waveform for assigning to the
operated keys, as indicated by pulses appearing in their
respective time slots, tone generators capable of produc-
ting tones corresponding to the respective notes asso-
ciated with the operated keys.

17. The combination according to claim 16 wherein each of
said tone generators is operable to produce a tone corre-
sponding in frequency to the frequency of each note in every octave of sounds encompassed by said electronic organ.

18. In an electronic organ having a memory unit for storing
digital representations of organ voices selectively produced by actuation of corresponding tab switches asso-
ciated with the keyboards of the organ in generation of
sounds thereby, and wherein the voices are arranged in groups
of plural voices, the combination comprising:
means for producing a multiplex waveform having a plurality
of time slots,
means for scanning the organ voices of each of the groups of
organ voices in a succession of time intervals correspond-
ing to the groups,
means for responding to an actuated tab switch in a given
group during an interval over which that group is scanned
by said scanning means to supply a signal in a respective
time slot of the multiplexed waveform, and
means responsive to signals in said multiplexed waveform
representative of selection of desired voices for retrieving
said digital representations of the respective desired voices
as stored in said memory unit for subsequent audible
reproduction of sounds by the organ in accordance with
the selected voices.

19. An electronic musical instrument comprising:
means for generating sounds corresponding to notes of the
musical scale,
means for keying said instrument to call forth desired ones
of said notes, and
means responsive to said keying means for producing and
providing to said generating means keying signals in a
time-shared signal format in which the positions of the
27. An electronic musical instrument comprising:
means for generating sounds to be produced by said instrument, a plurality of switch means for selected desired sounds, and
means responsive to the operation of said switch means for introducing signals indicative of the selected sounds corresponding to the operated switch means into a serial digital format, and
means responsive to the serial digital format of signals for recognizing the selected sounds thereby indicated for activating said generating means to produce said selected sounds as an audible output of said instrument.

28. The electronic musical instrument defined by claim 27 wherein said generating means includes:
means storing a plurality of amplitude samples of at least one cycle of a complex waveform conforming to the waveforms of said sounds, and
means responsive to signals in said serial digital format for retrieving samples of said waveform from said storing means at a rate consonant with the frequency of the sound indicated by the respective signal.

29. The electronic musical instrument defined by claim 31 wherein said sound generating means further comprises:
means affording a plurality of possible voices in which the selected notes may be produced, and
said plurality of switch means comprises a plurality of stops for selecting said voices.

30. The electronic musical instrument defined by claim 29 wherein said signal introducing means comprises:
means for cyclically and repetitively generating a succession of time slots in a serial digital format, each said time slot being associated respectively with a particular one of said voices, and
said means responsive to operation of one of said voice selection switch means produces a digital signal in the time slot associated with the voice selected by that switch means, to bring forth the desired sounds of the selected voices from said sound generating means.

31. The electronic musical instrument defined by claim 30 wherein said sound generating means includes:
means for storing digital data representing a plurality of individual voices, means for accepting and storing an accumulation of digital data representing a composite of said individual voices for notes produced as an audible output of said instrument, and MEANS FOR ACCEPTING AND STORING AN ACCUMULATION OF DIGITAL DATA REPRESENTING A COMPOSITE OF SAID INDIVIDUAL VOICES FOR NOTES PRODUCED AS AN AUDIBLE OUTPUT OF SAID INSTRUMENT, AND
means responsive to signals in said serial digital format for deriving the digital data from said individual voice storing means according to the selected voices indicated by said signals and for accumulating the derived individual voice digital data and supplying said data accumulations to said data accepting and storing means.

32. The electronic musical instrument defined by claim 27 wherein said instrument includes a keyboard of plural keys for actuating corresponding ones of said switches to produce said sounds as corresponding notes of the musical scale and there is further provided:
means selectively operable for enabling the production of percussive sounds in conjunction with actuation of the keys of the keyboard for producing corresponding notes, gating means enabled by said enabling means for responding to a signal in said serial digital format corresponding to actuation of a key on said keyboard of said instrument for producing a steady state percussive control signal in response to each repetition of that signal for successive ones of the serial digital formats of signals, and
means responsive to the succession of steady state percussive control signals for producing percussive sounds in rhythm with the note indicated by said key actuation.

33. The electronic musical instrument defined by claim 27 wherein said instrument includes a keyboard of plural keys for
actuating corresponding ones of said switches to produce said sounds as corresponding notes of the musical scale and there is further provided:
means selectively operable for enabling the production of percussion sounds in conjunction with actuation of the keys of the keyboard for producing corresponding notes, gating means enabled by said enabling means for responding to a signal in said serial digital format corresponding to actuation of a key on said keyboard for producing a single transient percussion control signal for the initial one only of a succession of said signals in successive ones of the serial digital formats of signals, and percussion sound producing means activated in response to said single transient percussion control signal and thus only to the initial actuation of a key.

34. An electronic musical instrument having switches operable to generate notes of the musical scale, comprising:
main counting means for generating a cyclically repeating multiplex signal having a plurality of time slots at least as great in number as the number of switches, and wherein each switch is assigned to a corresponding time slot, means for scanning said switches to produce a pulse in the corresponding time slot for each actuated switch, a plurality of tone generating means each selectively operable to produce all notes of the musical scale encompassed by the organ, assignment control means responsive to the pulses of said multiplex signal for individually assigning said tone generating means to generate the corresponding notes as selected by operation of said switches and for determining the availability of further said tone generating means for further assignments in response to successive note selections, a further counting means associated with each said tone generating means and synchronized in its counting rate with said main counting means, means for normally synchronizing the count of said further counting means with the count of said main counting means, and said synchronizing means being responsive to assignment of said associated tone generating means by said assignment control means to reset and initiate counting by said associated counting means simultaneously with the time slot of the pulse to which the generator is assigned, and means for comparing the count of each said further counting means with said main counting means to identify the time slot position of the assigned pulse and thus the corresponding note to be produced.

35. An electronic musical instrument as recited in claim 34 further comprising:
means responsive to the reset count of said associated counter and the time slot position of the multiplex signal to determine the continued presence of the assigned pulse therein in successive cyclical multiplex waveforms for maintaining the generator assignment during continued operation of the switch and to recognize release of the switch upon the absence of that pulse.

36. An electronic musical instrument as recited in claim 34 wherein said assignment control means includes:
means associated with each tone generator and set by said assignment control means for storing an indication of the assigned state thereof, means for resetting said associated counter upon reset of said main counter to establish synchronization of the counting cycle therewith, and said synchronizing means is disabled from resetting said associated counter by said assigned stage storing means when the latter is set.

37. An electronic musical instrument as recited in claim 34 having a plurality of keyboards of plural keys actuable to operate corresponding ones of said switches, further comprising:
means associated with each said keyboard for selecting percussion sounds to be generated in response to actuation of keys thereof, gating means respectively associated with each said keyboard and selectively enabled in response to said scanning means during scanning of the keyboard, and each said gating means is rendered conductive, when thus enabled, by a signal corresponding to actuation of a key of that keyboard to produce an output percussion control signal.

38. An electronic musical instrument as recited in claim 37 wherein there is further provided:
means responsive to the assignment of each said tone generator to supply said signal to said gating means for producing a transient percussion control signal upon the initial key actuation.

39. An electronic musical instrument as recited in claim 37 wherein said gating means receive and are rendered conductive upon receipt of pulses in said multiplex signal, and wherein there is further provided means for storing a steady state indication of the key actuation in response to successive pulses of a given time slot in successive cycles of the multiplex signal to produce a steady state percussion control signal for the duration of actuation of each corresponding key.

40. An electronic musical instrument as recited in claim 34 having a plurality of keyboards of plural keys actuable to operate corresponding ones of said switches, further comprising:
means for storing a plurality of individual voices in which the notes may be produced, stop tab means individually associated with said keyboards for selecting corresponding, desired voices in which the notes of each said keyboard are to be reproduced, plural registration means corresponding to said keyboards for registering the selected ones of said voices derived from said voice storing means to afford an operating memory of selected voices, said tone generating means accessing said operating memory for deriving the notes to be produced in the desired voices, means for scanning said stop tabs to produce a time-division multiplex signal having time slot positions corresponding to said stop tabs and producing a pulse in each time slot for which the corresponding stop tab is actuated, means operating in a repeating cycle and synchronized with said scanning means to enable entry of voices into said plural registration memory means individually and in succession, and further means synchronized with said enabling means and said scanning means to derive from said voice memory, individually and in succession, the voices identified by the pulses of said stop tab multiplexing signal for registration in the registration memory respectively corresponding to the keyboards for the actuated stop tabs.

41. An electronic musical instrument as recited in claim 40 wherein said further synchronized means comprises:
means for combining plural voices read from said voice memories in accordance with plural pulses in said stop tab multiplexing signal corresponding to plural stop tab actuations for a given keyboard, for storing a composite voice of the selected, plural voices in said registration memory.

42. An electronic musical instrument as recited in claim 40 wherein the plural voices are arranged in groups of plural voices and the groups are normally assigned to corresponding ones of the registration memories, and there are further provided:
coupling means for modifying the synchronization of said scanning means relative to said enabling means for permitting stop tab selection of moices and entry of those voices thus selected into a registration memory to which they are not normally assigned.
CERTIFICATE OF CORRECTION

Patent No. 3,610,799 Dated October 5, 1971

Inventor(s) George A. Watson

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 28, lines 47-51 - Delete "MEANS FOR ACCEPTING AND STORING AN ACCUMULATION OF DIGITAL DATA REPRESENTING A COMPOSITE OF SAID INDIVIDUAL VOICES FOR NOTES PRODUCED AS AN AUDIBLE OUTPUT OF SAID INSTRUMENT, AND" as this is a repetition of the lines preceding it.

Column 30, line 70 - "voices" should be "voices".

Signed and sealed this 2nd day of May 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCALK
Commissioner of Patents