May 23, 1967 W. MUNCH, JR., ET AL 3,321,567

WAVE SHAPING SYSTEM FOR ELECTRICAL MUSICAL INSTRUMENTS

Filed Oct. 20, 1965

3 Sheets-Sheet 1

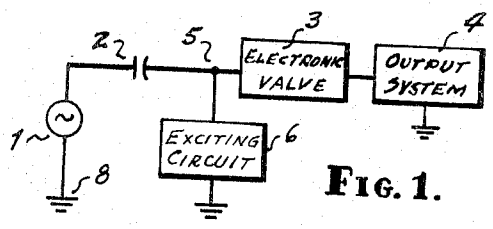


FIG. 1.

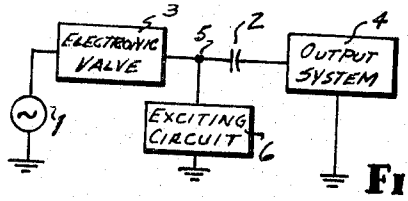


FIG. 2.

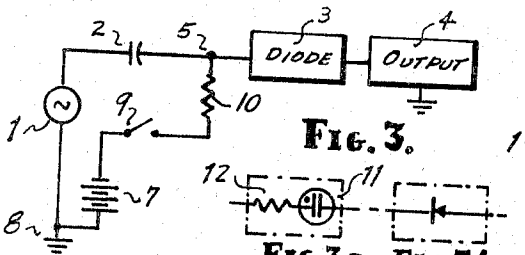


FIG. 3.

FIG. 3a. FIG. 3b.

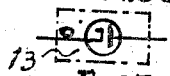


FIG. 3c.

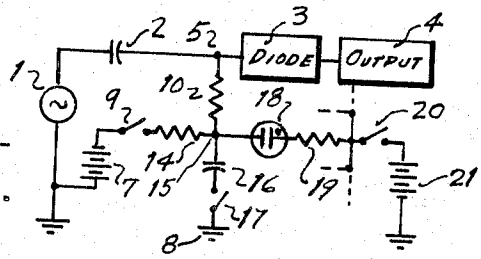


FIG. 4.

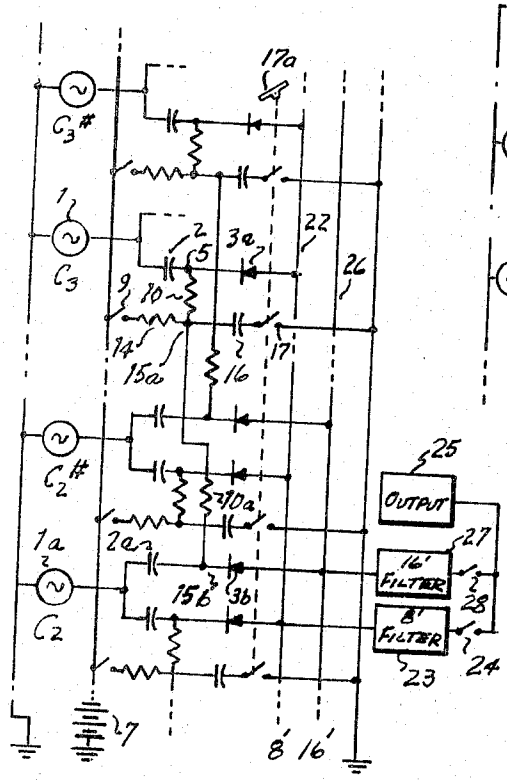


FIG. 5.

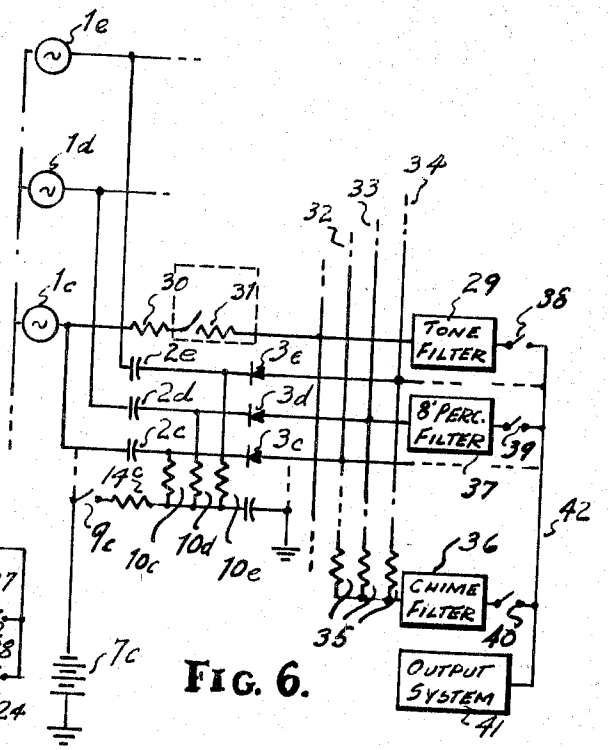


FIG. 6.

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May 23, 1967 W. MUNCH, JR., ET AL 3,321,567

WAVE SHAPING SYSTEM FOR ELECTRICAL MUSICAL INSTRUMENTS

Filed Oct. 20, 1965 3 Sheets-Sheet 2

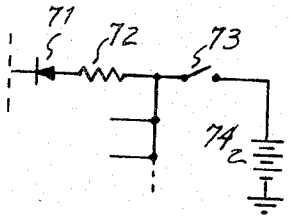


FIG. 8a.

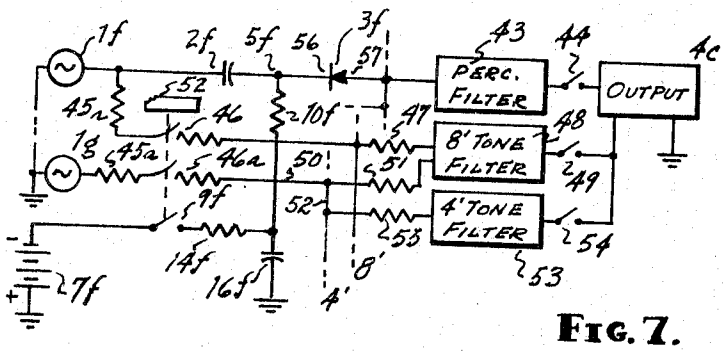


FIG. 7.

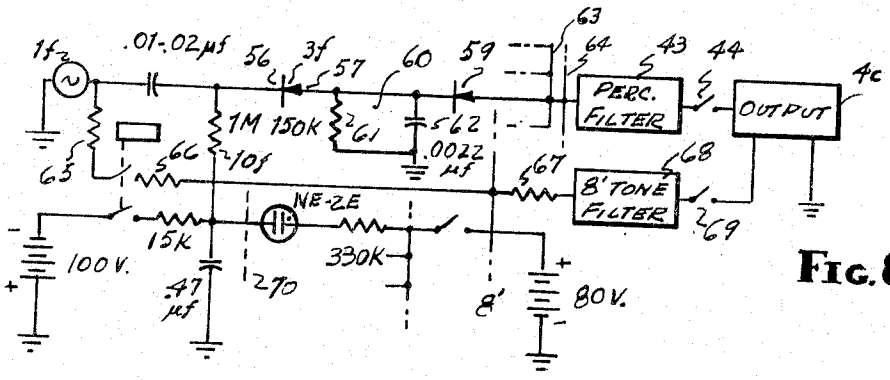


FIG. 8.

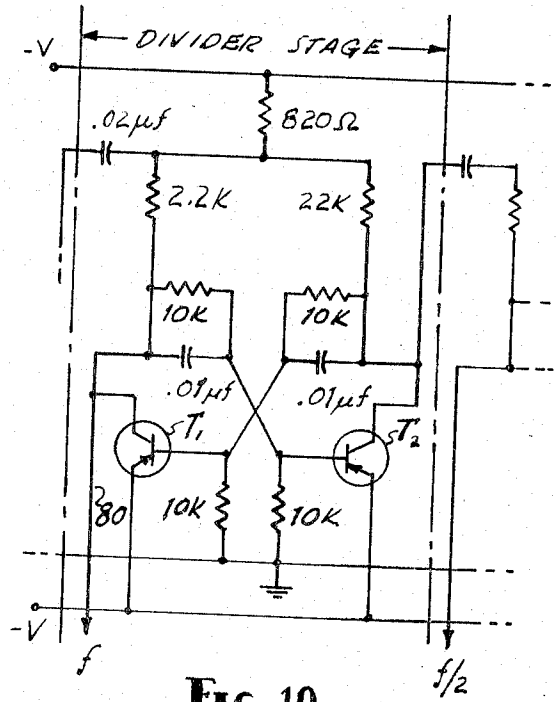


FIG. 10

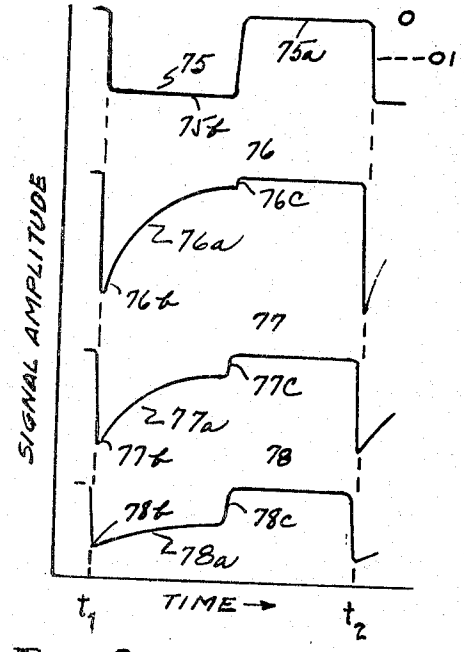


FIG. 9.

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WAVE SHAPING SYSTEM FOR ELECTRICAL MUSICAL INSTRUMENTS

Filed Oct. 20, 1965

3 Sheets-Sheet 3

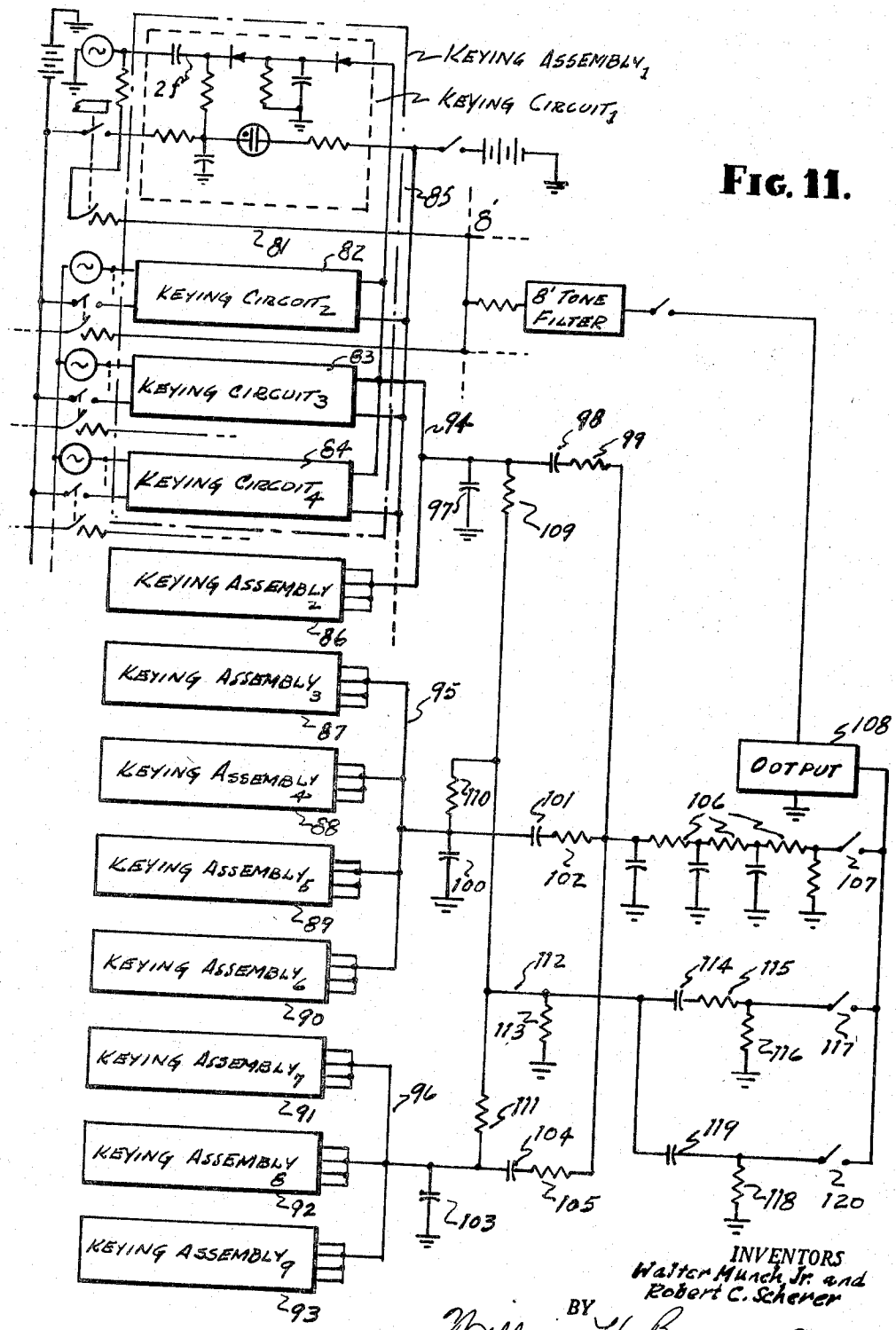


FIG. 11.

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United States Patent Office 3,321,567
Patented May 23, 1967

3,321,567

WAVE SHAPING SYSTEM FOR ELECTRICAL MUSICAL INSTRUMENTS

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Filed Oct. 20, 1965, Ser. No. 498,581
7 Claims. (Cl. 84—1.13)

This application is a continuation-in-part of our co-pending application entitled, "Keying Systems for Electric Musical Instruments," Ser. No. 135,101, filed Aug. 28, 1961, now United States Patent No. 3,223,768, issued Dec. 14, 1965.

This invention relates to keying systems for electric musical instruments, by means of which continuously produced music signals corresponding to musical tones can be selected, as desired, for transmittal to an output system. The term output system as used herein should be understood, without other qualification, as including collecting and tone coloring circuits, amplifying and reproducing means. More specifically, the invention has to do with improved keying circuits employing simple, biterminal electronic valves commonly known as diodes, usually rendered conductive to an audio signal by the application of direct current potentials by means of key actuated make-break switches.

The diodes used in prior art systems have taken various forms, which may be classified as (1) vacuum diodes, (2) solid-state diodes including varistors, and (3) gaseous discharge devices, such as type NE–2 neon tubes. U.S. Patent 2,483,823 to George falls in the first category, while Rienstra 2,486,208 is in the second group. The third class is inclusive of Faulkner 2,811,069, Anderson et al. 2,811,887, and Anderson 2,823,310. Certain inherent disadvantages, from a commercial standpoint, have been present in various ones of the named systems. These include (1) the necessity for separate bias sources to maintain diodes non-conductive, (2) the presence of undesired D.C. keying transients in output systems during charging of coupling capacitors, (3) presence of signal feed-through in output systems when diodes are not being keyed, and (4) the use of many and/or expensive circuit components.

In view of the above named factors, it is a primary object of this invention to provide a keying circuit not requiring a separate bias source to maintain the diode in a non-conductive state.

It is a further object to provide such a circuit which will be free from undesired D.C. keying transients.

It is an important object to provide a keying circuit having a high signal-to-feed-through ratio.

It is a still further object to provide a simple, low cost keying circuit suitable for use, for example, in electronic organ systems requiring several such circuits per playing key.

In U.S. Patent 2,986,964 to Bissonette and Kramer there is disclosed an electronic musical instrument, wherein both steady state tones (of the type associated with a pipe organ) and "percussive" type tones may be derived separately or simultaneously, the latter type tones becoming apparent in staccato playing, and the former type having an effect only upon the initial, or key-down portion of the tone when percussive effects are being achieved. The teachings of the present invention may, for example, be employed in instruments of the Bissonette-Kramer type, for either or both keying systems. In other words, this invention in one facet may be used in the place of variable resistance key switches of the Kock-Jordan type, for example, as disclosed in their U.S. Patent 2,215,124, to obtain steady state tones. In another facet, percussive effects may be achieved in the manner, for example, disclosed in the Bissonette-Kramer case or in the U.S. Patent 2,918,576 to Munch. Both latter patents disclose vacuum triode gate circuits having means to cause gradual decay of the tones. Thus, it is an important object of this invention to provide improved, low cost keying circuits suitable for separate or concurrent use in obtaining steady state and/or percussive type tones.

The advent of transistors in generating circuits for electronic organs has led to low cost frequency dividers of a "flip-flop" type, whose output is characterized by square waves. This development has made attractive organ systems of the type disclosed in U.S. Patent 2,571,141 to Knoblaugh and Jordan, wherein musical signals of complex, but symmetrical wave form (characterized by a deficiency or absence of even order harmonics), are combined after keying and controlled as to amplitude in such manner as to provide tones having both even order and odd order harmonics. The multiple signal keying required in such a system for steady state tones can be accomplished by conventional keying means or in accordance with the teachings of this invention. However, if percussive type tones having a full complement of harmonics are to be derived from the same symmetrical wave generating circuits as those supplying the steady state tones, it is a distinct advantage to be able to perform the keying function for the percussive tones with a single make-break switch. It is therefore an important object of a preferred embodiment of the present invention to provide simple, low cost keying circuits capable of producing a wide range of percussive type voices in an electronic organ employing square wave generators.

It is a further object of the invention to provide improved keying circuits for use in electric musical instruments having continuously operating generators of other than square waves.

A primary object of this invention is to provide keying circuits which not only obviate the use of variable resistance key switches in producing conventional type organ tones, with envelopes as desired, but, also will make available so-called "sustain" characteristics to the tones.

It is a still further object of the invention to provide a low cost keying system such that chime or carillon type tones may be obtained.

An important object of this invention is to provide a keying system having a wave shaping function in converting square waves to waves of a generally sawtooth configuration. It is a related object of the invention, useful for scaling purposes, to provide a keying circuit by which the shape or output waves, from a square wave generator, may be determined by the choice of the coupling capacitance in series with the active elements in the circuit.

The objects of the invention set forth above, and others which will be set forth hereinafter or will be apparent to one skilled in the art upon reading these specifications, are accomplished in that construction and arrangement of parts of which certain exemplary embodiments will now be described. Reference is made to the accompanying drawings, wherein:

FIGURE 1 illustrates a circuit diagram, partly in block form, of a preferred embodiment of this invention.

FIGURE 2 shows a similar diagram of an alternate form of the invention.

FIGURE 3 is a schematic illustration, partly in block form, showing some detail as to an exciting circuit for the diode section of a keying system in accordance with this invention.

FIGURE 3*a*, 3*b*, and 3*c* illustrate respectively three different forms which the diode section of the system of this invention can take.

FIGURE 4 is a schematic illustration of the system of FIGURE 3 expanded to include portions affecting the decay of tones produced by this invention.

FIGURE 5 is a schematic and block diagram showing the application of keying circuits to an organ system of the type wherein octavely related oscillations are keyed into separate collectors for different footages.

FIGURE 6 is a schematic and block diagram illustrating the application of keying circuits in accordance with this invention to a system for producing tones simulating chimes and the like.

FIGURE 7 is a schematic and block diagram illustrative of an embodiment of this invention providing a percussive keying circuit for use with a system of the Knoblaugh-Jordan type mentioned above.

FIGURE 8 is a schematic and block diagram illustrating a preferred form of percussive keying circuit, together with provision for changing the rate of decay of the percussive tones, together with keying means for steady state type tones.

FIGURE 8*a* is a schematic and block diagram illustrating a variation or alternative to one portion of the circuit of FIGURE 8.

FIGURE 9 is a graph illustrating an input wave and three types of wave forms which may be achieved at the output of keying circuits in accordance with the teachings of this invention.

FIGURE 10 is a schematic diagram representing one divider stage in a generator circuit of a type suitable for use with this invention.

FIGURE 11 is a schematic and block diagram illustrating a complete system, partly schematic and partly block, for providing percussive tones of different character in an electronic organ having keying circuits also for steady state type tones.

A preferred basic form of this invention is shown in FIGURE 1, wherein a continuous signal corresponding to a musical tone is derived from a suitable source **1** via a coupling capacitor **2**, for application to a bi-terminal electronic valve, such as a diode, designated by the block **3**. An appropriate output system **4**, which may comprise, broadly, collecting and tone coloring means, a conventional amplifier and loudspeaker or other electroacoustic means is shown connected to the diode. To the point **5** is shown connected a block **6** representing an exciting circuit for the diode section **3**. The nature of the diode will be discussed hereinafter, together with the characteristics of the exciting means indicated at **6**. As the specification proceeds, it will become obvious that the requirements of a particular circuit will dictate whether the exciting circuit merely performs an on-off function with respect to the diode or whether the exciting circuit will produce in the output system **4** a tone envelope of a particular shape, such as one with the trailing decay characteristic of a percussive type tone.

An alternate form which this invention, in certain aspects, may take, is illustrated in FIGURE 2, wherein corresponding elements are similarly designated. The first of the two circuit loops connected across the source **1** of FIGURE 2 comprises the diode **3**, the capacitor **2** and output system **4**, as in FIGURE 1, although the order of the diode and capacitor is reversed. The second of the circuit loops connected across the source **1** in FIGURE 2 comprises only the diode **3** and exciting circuit **6**. In both figures the two circuit loops may be closed, as shown, by a common return path represented by the conventional ground symbol.

As will be explained in greater detail hereinafter, the tone signal from the continuously operating source **1** of FIGURES 1 and 2 is transmitted to the output system when the diode **3** is changed by the exciting circuit **6** from a state of substantially zero conductivity to one of appreciable conductivity.

Reference is now made to FIGURE 3, the circuit of which is similar to that of FIGURE 1, except that a simple D.C. exciting path is shown. Corresponding elements of the circuit are similarly designated and connected. The exciting circuit of FIGURE 3 comprises a D.C. source **7** connected at one side to a common return **8** and at its other side to a single-pole, single-throw switch **9**, which, in a closed position, can apply the D.C. potential to the point **5** via a resistor **10**. Although the diode **3** may take several forms, a preferred one in this invention being one of a solid state type, shown by the appropriate symbol in FIGURE 3*b*, certain teachings of this invention may also be applied using diodes of a gaseous discharge type, indicated in FIGURE 3*a* at **11**, in series with a relatively high resistance **12**. It will be obvious that a vacuum diode, indicated at **13** in FIGURE 3*c*, can also be used to practice the teachings of the invention although for economic reasons a solid state or gaseous diode may be preferred. A prime requisite, however, for all diodes used to practice certain teachings of this invention, is that they be characterized by one state of substantially zero conductivity and another state of appreciable conductivity with a positive resistance characteristic. Vacuum diodes and solid state diodes currently available already meet such a requirement. However, in the circuit configurations disclosed herein, a gaseous diode, such as type NE–2, must have in series therewith a relatively high resistance —say 5 megohms—sufficient to give a substantial portion of its current vs. voltage characteristic curve a positive slope. Such a keying circuit has already been disclosed, for use in a system for keying harmonically related signals through a common gate, in a copending application S.N. 40,232, filed July 1, 1960 (now Patent 3,176,060), by the same assignee, entitled, Gating System for Electrical Musical Instrument, in the name of Alfred J. Bissonette and one of the present inventors, Walter Munch, Jr. This assures that the gaseous diode will conduct throughout the audible portion of a gradual decay characteristic in, for example, percussive type tones, circuits for which will be discussed hereinafter.

In the circuit of FIGURE 3, the build-up and decay of the tone are affected by the size of the coupling capacitor **2**, that is the larger the capacitance, the slower the rate at which the tone develops and dies away. However, the configuration of FIGURE 1 may be preferable to that of FIGURE 2, because in the latter, the D.C. charging current to the capacitor **2** must flow through the output system **4** and may cause objectionable transient therein.

Reference is now made to FIGURE 4 for the manner in which the decay of the tones can be controlled, although it will be understood that the tone build-up may also be affected to some extent in FIGURE 4. In FIGURE 4, similar portions of the two circuits are similarly designated and connected, there being an additional resistor **14** in series with the resistor **10** through which the exciting voltage from the source **7** is applied to the diode **3** at the junction **5**. Between the junction point **15** and a common return path are connected a decay capacitor **16** and a single-pole, single-throw switch **17** which may be controlled by a stop tap **17***a*. Also connected to the junction point **15** is a gaseous diode **18**, which, by way of example, may be a commonly known type NE–2E, in series with a resistor **19**, another single-pole, single-throw switch **20** and a second D.C. source **21**.

When it is desired to impose a gradual decay upon a signal keyed by the switch **9**, the switch **17** must be closed prior to keying, thus bringing the capacitor **16** into the circuit. As the switch **9** is closed, voltage from the D.C. source **7** charges the capacitor **16** at a rate determined by the resistor **14** and the capacitor **16**. Thus, the build-up of the voltage at the point **5**, which determines the rate at which the signal from source **1** is gated to the output system **4**, is affected by the time con-

stant of the capacitor **16** and resistor **14**, as well as by the coupling capacitor **2** mentioned above. The selection of these tone build-up components—i.e., resistors **14** and **10**, capacitors **16** and **2**—can be made in accordance with electrical design principles to achieve the desired onset to a particular tone.

Upon opening of the switch **9** (assuming switch **17** closed), the charge on the capacitor **16** is dissipated in the resistor **10**, diode **3** and output system **4**, at a rate determined by the time constant of the combined elements. Should a shortened rate of decay of the tone be desired, it can be accomplished by the "short sustain" circuit comprising, for example, the gaseous diode **18**, resistor **19**, switch **20**, and D.C. source **21**, as taught in a copending application of the same assignee, entitled Keying System for Electrical Musical Instruments, Ser. No. 4,444, filed Jan. 25, 1960, in the name of Walter Munch, Jr.

The voltage of the D.C. source **21** is substantially the same as the breakdown voltage of the diode **18** so that, upon actuation of the switch **9** and the firing of the diode **18** (voltages of D.C. source **7** and **21** being additive), the capacitor will discharge upon opening of switch **9**, to a level where the voltage at point **15** is substantially zero (at which point the diode **3** approaches non-conduction) before the diode **18** ceases to conduct. It will be obvious to one skilled in the art that the parallel path furnished by the diode **18** circuit will allow the capacitor **16** to discharge at a faster rate, resulting in a shorter decay time for the note keyed into the output system **4**.

Although a mere duplication of the circuits of FIGURE 3 or 4 will provide simple systems for playing a plurality of notes for polyphonic music, the system of FIGURE 5 illustrates an assembly employing but one switch per key, which will enable a musician to play a "16 foot" voice, for example, simultaneously with an "8 foot" voice, as is currently accomplished in commercially available organs using multiple "gradual contact" key switches.

Certain keying systems will now be described in connection with FIGURES 5 and 6. In these figures the conventional symbol for a solid state diode has been used; but it will be understood that any of the diodes illustrated or indicated in FIGURES 3*a*, 3*b* and 3*c* or the assemblies of diode elements and shunting impedances shown in FIGURE 8 may be substituted. FIGURE 8 is a diagram with noted values or parameters particularly appropriate to solid-state diodes.

Any of the known solid state diodes which respond to the requirements hereinabove set forth are available for the purposes of this invention. Without limitation, selenium diodes are preferred because they may be made cheaply. They may also be made in ganged formation as taught in the copending application of John B. Brombaugh, entitled, Keying Assembly for Electric Musical Instruments, Ser. No. 134,201, filed Aug. 28, 1961, now Patent No. 3,179,855.

Considering in FIGURE 5 the keying circuit for a source **1** for note C_3, components corresponding to those of FIGURE 4 are similarly designated and connected. The output diode **3***a* is connected to a collector **22**, also designated 8′, for all 8′ signals, to which is connected, as is known in the art, a tone color filter **23** of the type, for example, disclosed in the Kock Patent 2,233,948. A selector switch **24**, preferably actuated by a conventional stop tap (not shown), serves to direct the modified tone signals to a suitable output (amplifier and loudspeaker) system, designated by the block **25**. Other teachings of Kock in the mentioned patent, such as those pertaining to out-phasing, may obviously be included, if desired.

To the point **15***a*, corresponding to the junction **15** of FIGURE 4, is connected a resistor **10***a* for transmission of D.C. from the common source **7** to a point **15***b* in a keying circuit of similar character, comprising coupling capacitor **2***a* and diode **3***b* coupled, as shown to generator **1***a* of a continuous wave at a frequency corresponding to note C_2. Thus, it will be seen that a signal an octave below that of the signal transmitted to the 8′ collector **22** will be keyed into a collector **26**, which is designated 16′ in accordance with standard organ terminology. A 16′ tone-color filter **27** is shown as modifying the output of the collector **26** for transmittal to the output system **25** via a stop tab controlled switch **28**. Thus, with a simple make-and-break switch **9** (FIGURE 5), a plurality of signals of different "footages" can be keyed into different headers, whence they can be modified as to timbre, added together, added in out-of-phase relationship, if desired, and passed to an output system. Since the onset of the tones can be controlled by the circuit components as previously discussed, mechanical "gradual contact" switches need not be used; only one switch need be used with each key, and a long-life, substantially service-free system can be achieved.

The keying circuits of this invention can be further utilized to achieve chime and carillon effects in an electric musical instrument.

In FIGURE 6, a source **1***c* of continuous tone signals may supply a tone-color filter **29** of conventional design via a conventional decoupling resistor **30** and resistive key switch **31** for steady state organ-type tones. If desired, this keying circuit may be of the type previously disclosed herein in FIGURE 4, for example, or even FIGURE 5, if full exploitation is to be made of the teachings of this invention. In any event, chime or carillon tones and, if desired, conventional percussive effects may be achieved concurrently. While source **1***c* is supplying conventional organ type tones, with or without "sustain" of the nature disclosed in FIGURE 4, it may also be sending its output via coupling capacitor **2***c* to a keying diode **3***c* of, for example, a solid state type. Gating voltage for the diode **3***c* may be furnished from a common source **7***c* via switch **9***c*, resistor **14***c* and resistor **10***c* as shown. Similarly, keying voltage may concurrently be supplied to diode **3***d* and **3***e* via resistors **10***d* and **10***e*, respectively, from resistor **14***c* which has been energized by switch **9***c* from the source **7***c*. Consequently signals from source **1***c*, previously mentioned, and from harmonically related continuous wave sources **1***d* and **1***e*, as coupled into the named keying circuits by coupling capacitors **2***d* and **2***e*, respectively, concurrently appear on collectors **32**, **33** and **34** respectively. In accordance with known musical teachings, appropriate-amplitude harmonic components are synthesized by a suitable resistive summing network **35** into a composite chime or carillon type tone for modification, if desired, by an appropriate filter **36**.

If desired further, a conventional "percussive" tone, such as a "vibraharp," may be produced by passage of a signal from one collector **33**, for example, through a suitable filter **37**.

Thus, should the performer on an instrument of the type outlined in FIGURE 6 desire to produce tones of conventional organ character, or of general percussive nature, or of chimes, for example, he could, by actuation of stop switches **38**, **39** or **40**, respectively, derive the tones from a conventional output system **41**, the signals having been collected by a bus **42** for the subsequent conversion to sound. The percussive and chime tone would, of course, be achieved by staccato type playing of the keys. Also, in accordance with the teachings of the aforementioned Bissonette-Kramer patent, the key-down portion of the tones could be varied in color by concurrent use of the steady-state tone circuit by actuation of stop switch **38**.

It will be understood in FIGURE 6 that the resistive switch **31** and the make-and-break percussive switch **9***c* are coupled, i.e. they are actuated by the same playing key. Also, it will be understood by those familiar with electric organs that there may be other resistive switches similar to **31** connected to other harmonically related generators and to separate headers, such switches also being coupled to the same playing key, so that upon the

depression of such key, harmonically related oscillations may be simultaneously derived in different headers.

While FIGURE 6 shows circuits for the derivation of steady-state oscillations (ordinary organ tones) from generators by resistance-coupled gradual contact switches, it will be evident from FIGURE 5 how capacitatively coupled diode circuits using only a single make-and-break switch can be used instead of circuits employing gradual contact switches. Thus it becomes possible to construct an entire organ employing but two simple make-and-break switches per key, but deriving simultaneously a plurality of different oscillations in different headers both in the steady-state system of the instrument and in the percussive system thereof.

As mentioned earlier in these specifications, square-wave sources of a "flip-flop" nature have become desirable particularly from a cost standpoint. (An example of a preferred form of square wave generator is shown in FIGURE 10 and will be discussed hereinafter.) In FIGURE 7, the bare essentials of a one note keying system for concurrent production of conventional organ tones and percussive type tones from a square wave source are illustrated. A source **1***f* of continuous square waves is shown coupled through coupling capacitor **2***f* to gating diode **3***f*, rendered conductive upon actuation by a playing key **52** of switch **9***f*, which supplies D.C. from source **7***f* via resistors **14***f* and **10***f*. As previously taught, a percussive tone may be derived in an output system **4***c* via a suitable filter **43**, selected, as desired, by stop switch **44**, the capacitor **16***f* providing the gradual decay. Tones of steady-state type may be derived in the output system **4***c* by keying the square wave signal from the source **1***f* through a decoupling resistor **45**, resistive key switch **46**, decoupling resistor **47** and tone filter **48**, as selected by stop switch **49**. If it is desired that this be a "full' tone, with both even-order and odd-order harmonic components, additional signal may be combined via a path **50**, supplying in a manner similar to that of the 8′ component, a 4′ component via decoupling resistor **45***a*, resistive switch **46***a* and level-adjusting, decoupling resistor **51**. In the interest of simplicity of drawings, further component circuits, such as might be desired for adding 2′ and 1′ signals at further reduced levels, are omitted, although it will be understood that it is within the scope of this invention that they be included. Also, via the path **50** to collector **52**, a 4′-only tone of a square wave type, or of a type derivable therefrom by suitable filter means **53**, known in the art, may be made available in the output system **4***c* by a stop switch **54**. A decoupling resistor **55** may be required at the input of the filter **53**.

It is within the scope of this invention that the FIGURE 7 keying circuits for steady-state tones be of the diode type as taught in connection with FIGURE 5. Also, it will be understood that the diode **3***f* may be reversed in position if the D.C. source **7***f* is also reversed, if desired.

Regarding the operation of the diode circuit of FIGURE 7, when the switch **9***f*, which may be operated in the conventional manner by a key **52** of a keyboard musical instrument, is in the open position, the continuously operating generator **1***f* applies a square wave to the left hand plate of capacitor **2***f* and a common return path. It will be obvious that during such excursion of the square wave as would tend to make the cathode **56** of the diode **3***f* positive, no current will pass through the diode **3***f*. During that portion of the excursion of the square wave which would tend to make the anode **57** of the diode **3***f* positive, a signal would be confronted with an open circuit with respect to direct current (the capacitor **2***f*, the switch **9***f* and capacitor **16***f* are all substantially an open circuit with respect to D.C.). Any current which flows through the diode **3***f* from right to left by virtue of leakage in the capacitors **2***f* and/or **16***f*, charges up these capacitors and raises the potential of the point **5***f* to a level sufficient to keep the diode **3***f* in a non-conducting state. Thus, in the condition indicated in FIGURE 7, no signal other than a low level of "leak-through" will be present in the output system **4***c*. Herein lies the important "self-bias" teaching of this invention, which greatly simplifies and lowers the cost of the circuitry. It can be seen also that if the circuits of FIGURES 2, 3 or 4 contain unilaterally conductive diodes, such as solid-state and vacuum types, the points **5** in these circuits will be carried to a level sufficient to bias the diodes off by virtue of charge built up on the coupling capacitor **2**.

Returning to the operation of the circuit of FIGURE 7, upon closure of the switch **9***f*, the capacitor **16***f* is charged to the level of the D.C. source **7***f* at a rate determined by the resistance **14***f* and capacitor **16***f*. The D.C. level of the point **5***f* is thus below that of the anode **57** of the diode **3***f*, rendering it conductive and permitting passage of the negative excursion and at least a portion of the positive excursion of the square wave applied to the circuit by the generator **1***f*. So long as the key switch **9***f* is closed, signals from generator **1***f* will be present in the output system **4***c*. Upon opening switch **9***f*, the capacitor **16***f* will discharge through the resistor **10***f*, the diode **3***f* and output system **4***c* until such time as the diode **3***f* reaches its non-conductive state.

If the signal-to-leak-through ratio of the circuit of FIGURE 7 is high enough to meet the needs of a given usage, this embodiment is the simplest form of our invention. However, if such diodes are employed that their capacitance would result in higher-than-tolerable leak-through, two or more diodes may be used in series. However, we prefer, in accordance with an important aspect of our invention to employ a bypass impedance between the junction of two diodes and a common return path, as illustrated in FIGURE 8. This greatly improves the signal-to-leak-through ratio and enables the use of low cost diodes. In this figure also is illustrated means for concurrently deriving steady-state organ tones in the output system.

Referring now to FIGURE 8, the left hand portion of the circuit is similar to that of FIGURE 7 and similar elements are correspondingly connected and numbered. However, to the anode **57** of diode **3***f* is shown connected a second diode **59**, which may have similar characteristics to which is connected the output system **4***c*. Between the junction of the diodes **3***f* and **59** and a common return is connected an impedance, generally indicated at **60**, of such value that it will be low with respect to the reverse impedance of the diodes **3***f* and **59** and high with respect to the forward impedance of diode **59**. A preferred form of impedance **60** is illustrated as composed of a resistor **61** and a capacitor **62**. The impedance of this combination is so chosen, because it is desired that in the non-conductive state, any signal from the source **1***f* which tends to leak through the diode **3***f* will find a ready path to a common return and will be negligible in the output system. In the conductive state of the diodes, the impedance of the path provided by the combination **60** will be of sufficient magnitude so as not to interfere with the operation of the circuit.

The diodes may be arranged in groups of eight each for a series of four percussive type circuits of the kind illustrated in FIGURE 8, the collector **63** indicating the common output terminal of the four pairs of diodes. A collector **64** may direct the output of several keying groups to a percussive tone filter **43**, stop switch **44** and output system **4***c*. Concurrent keying of a steady-state tone may be accomplished by any of the keying systems hereinabove described, the one illustrated merely being exemplary. A decoupling resistor **65** is in series with a resistive switch **66**, decoupling resistor **67**, tone color filter **68** and stop switch **69** to the output system **4***c*.

Specific values of an exemplary circuit are indicated in FIGURE 8, including those for a "short sustain" circuit as described in connection with FIGURE 4. An alterna-

tive to such circuit is also illustrated in FIGURE 8*a* which shows a circuit portion to replace the portion of FIGURE 8 to the right of the dashed line **70**. In this circuit, a solid state diode **71**, for example, a commercially available silicon diode, is shown in series with an appropriate resistor **72**, single-pole, single-throw switch **73** and D.C. source **74**.

Reference is now made to FIGURE 9 for an explanation of the manner in which keying circuits of this invention can also be designed to act as wave shaping devices as well as for keying in systems having generators of square waves, although it will be realized that other type waves may be modified by the circuits in accordance with known differentiating and clipping techniques, for example. The wave **75** is representative qualitatively of a signal applied, say in FIGURE 7, by a generator **1***f* to the capacitor **2***f*. If the time constant of the combination comprising the capacitor **2***f* and the resistance offered to the signal from the point **5***f* through to the output system (with the diodes in the conductive state) is short with respect to one period of the square wave (represented by the distance between time t_1 and t_2 on the chart of FIGURE 9), the shape of the output current wave will appear qualitatively to be somewhat as indicated at **76**. The curved portion of the wave is seen to rise quickly and taper off in an exponential manner. If the time constant of the circuit is longer with respect to one period of the square wave **75**, the wave shape of the output current will be somewhat as indicated at **77**. With still further increase in the time constant of the circuit (readily changeable by increasing the capacitance of the coupling capacitor **2***f*), the output current wave approaches that of a square wave, as illustrated at **78** in FIGURE 9.

Expanding the explanation of the wave forms of FIGURE 9, the curve **75** represents the voltage wave form supplied by generator **1***f*. Specifically, the wave form portion **75***a* may be assumed to have zero value, and portion **75***b* may be assumed to be negative going, for the sake of example. If there were no capacitor **2***f*, current pulses at load **4***c* would then consist of half cycles flowing in from its ground terminal, followed each by a half cycle of zero current, and would derive from voltage source **7***f*, under control of tone source **1***f*. On the other hand, with capacitor **2***f* in circuit, but diode **3***f* replaced by a lead, and gating source **7***f* disabled, average D.C. current to the load would be zero, and would consist of square waves or differentiated waves which would be symmetrical about a zero axis, i.e. the load current would be symmetrical about line **O1** and would be a square wave, provided the circuit involved had a long time constant, i.e. were capable of passing a square wave. If not, there would be differentiation of the square waves, but in respect to each of the halves thereof.

The diode **3***f* acts as a clipper, preventing load current reversal, i.e. clamping the circuit with respect to ground, in one direction of current flow. The capacitor **2***f* is one element of a differentiator, i.e. of an RC charging circuit, for the output of tone source **1***f*.

Curve **76***a* is a differentiated form of wave form **75***b* for a circuit time constant smaller than one-half period of the wave form, and **77***a* and **78***a* show the effect of increasing the time constant.

Each of the wave portions **76***a*, **77***a*, **78***a* must have the same area, but have different peak values, as at **76***b*, **77***b*, and **78***b*, and different slopes, as a function of the different time constants employed.

The peaks **76***b*, **77***b*, and **78***b* are of successively decreasing amplitude, while rises **76***c*, **77***c* and **78***c* increase, as is required to maintain equal areas of differentiated wave forms. The average current through the capacitor **2***f* must be zero, for each cycle. This is not to say, however, that the current in the load averages to zero, since it is supplied from source **7***f*, and the generator voltage acts as a chopping or modulating voltage applied to diode **3***f*, considered as a modulator. The presence of diode **3***f* constrains current to the load to consist of unidirectional pulses, which may have a variety of shapes according to the value of capacitor **2***f* in relation to load resistance and signal period, since it is the latter which establishes the modulating wave form. A variety of modulating wave shapes can give rise to a variety of tone colors, since each wave shape has its own peculiar frequency spectrum.

In summary, then, load current consists of a differentiated version of one half of a square wave, the other half of the differentiated square wave being clamped to zero value, in passage to the load, by a diode clipper or clamp. Load current derives from source **7***f*, flow from which is controlled by the differentiated wave forms derived from tone source **1***f*.

Thus it will be seen that the object having to do with wave shaping by a keying circuit will have been achieved by this invention. It will be obvious to one skilled in the art that tone color circuits of conventional character for sawtooth waves may be employed to produce a wide variety of voices.

An exemplary square wave generator suitable for use in practicing the invention is illustrated in FIGURE 10, wherein is shown one stage of a frequency divider chain for generating signals corresponding to a series of octavely related notes. The circuit is similar in certain respects to a tube multivibrator disclosed in U.S. Patent 2,418,521 to G. A. Morton et al., but is transistorized. Since the circuit components are given in FIGURE 10 and since the operation will be familiar to one skilled in the art, detailed description and operation will not be discussed herein. The transistors T_1 and T_2 may be, for example, General Transistor Co. type 2N–317. The lead **80** is the signal take-off point for the stage.

Referring now to FIGURE 11, there is illustrated a complete percussive system for an electronic organ. It will be seen that the uppermost portion of the figure is a duplicate of the circuit of FIGURE 8, the "Keying Circuit$_1$" portion enclosed by dashed lines corresponding to one section of the "Keying Assembly" of the aforementioned Brombaugh application. The keying circuit for steady-state type tones, indicated generally at **81**, may be similar to that of FIGURE 8 or, if desired, a keyed diode system, such as illustrated in FIGURE 5, may be used. Of, if preferred, a keying circuit similar to that of FIGURE 8, employing diode pairs, may be used without the gradual decay capacitor **16***f* and the "short sustain" circuit previously described. The blocks **82**, **83** and **84** represent additional keying circuits similar to "Keying Circuit$_1$," the dot-dash lines **85** indicating the boundary of those elements constituting one "Keying Assembly." The blocks **86–93**, representing keying assemblies designated with subscripts 2–9, complete those constituting a percussive system in an exemplary instrument.

It can be seen that three keying assemblies, each with four keying circuits, comprise the required components for one octave of notes. Blocks **91–93**, for example, would cover an octave. In accordance with previous partial teachings, the coupling capacitor **2***f* of the top note of a block **91** (assuming it to be lower in frequency than the top note of block **88**) would preferably be approximately twice the capacitance of the coupling capacitor for the top note of block **88**. This, for scaling purposes, assures a similar wave form in a square wave system for notes throughout a gamut.

By collecting from three representative groups of keying assemblies as at **94**, **95** and **96**, the outputs of these collectors may be brought to separate preliminary filtering circuits comprising, for the output lead **94**, a bypass capacitor **97**, a series capacitor **98** and a decoupling resistor **99**. A similar preliminary filter for the group collected at **95** comprises a capacitor **100** to a common return, a series capacitor **101** and a decoupling resistor **102**. Similar elements are present for the collector **96** at **103**, **104**

and **105**. This separate collection of keying circuits provides for preliminary low pass filtering, so that a common low pass filter **106** of conventional character may be used for the whole gamut. As is conventional in the art, a switch **107** may be actuated by a stop tab (not shown) for transmittal of a percussive type tone, such as "vibraharp," to an output system **108**, which may be a conventional power amplifier and loudspeaker system. For percussive type wave forms of higher complexity, the adding network comprising resistors **109**, **110** and **111** connect the outputs from the collectors **94**, **95** and **96** and bring them through a lead **112** to a high pass filter comprising the shunt resistor **113** and series capacitor **114**, series resistor **115** and shunt resistor **116** to the output system **108** via stop switch **117**. An output of still higher complexity can be derived by way of a filter formed by shunt resistor **118** for series capacitor **119** of lower capacitance than that of capacitor **114**, to the output system **108** via stop switch **120**. These latter two voices may, for example, be designated as organ, harp and string percussion.

Thus that object having to do with percussive voices for a square wave generator system has been achieved.

Throughout these specifications numerous omissions of extraneous material have been made in the interests of simplification of the diagrams and descriptions thereof. An example of this lies in the tone color circuits of certain figures, wherein only one block has been shown. It will be understood that a plurality of output systems may be used, as required for example, one for steady-state and one for percussive-type tones. Thus many modifications may be made in the invention without departing from the spirit of it.

The invention having been described in certain exemplary embodiments, what is claimed as new and is desired to be secured by Letters Patent is:

1. In a music system,
a frequency divider stage constituting a tone generator,
said frequency divider stage comprising a multivibrator having a signal output terminal,
a resistive load, and
a wave shaping circuit connected between said output terminal and said load,
a capacitor,
a gating diode circuit,
a source of direct current gating voltage connected to said gating diode circuit,
said wave shaping-circuit including said capacitor and said gating diode circuit in series between said signal output terminal and said resistive load,
said capacitor and the resistance of said resistive load having a time constant short relative to one half cycle of the output of said multivibrator.

2. The combination according to claim **1** wherein is provided means connected to said source of direct current gating voltage for at will selectively rendering said gating diode conductive and non-conductive.

3. In a music system,
a tone generator providing a square wave output,
a resistive load connected to said tone generator,
a wave shaping circuit connected between said tone generator and said resistive load,
a capacitor,
a gating diode circuit,
a source of direct current gating voltage connected to said gating diode circuit,
said wave shaping circuit including said capacitor and said gating diode circuit in series between said signal output terminal and said restive load,
said capacitor and the resistance of said resistive load having a time constant short relative to one half cycle of said square wave.

4. In a music system,
a frequency divider stage constituting a tone generator,
said frequency divider stage comprising a multivibrator,
said multivibrator having a signal output terminal,
a load, and
a wave shaping circuit connected between said output terminal and said load,
said circuit including in series
a diode gate,
a capacitor, and
a resistive circuit having resistance,
said capacitor and said resistance having a time constant short relative to one half cycle of the output of said multivibrator.

5. In a music system,
a frequency divider stage constituting a tone generator,
said frequency divider stage comprising a multivibrator,
said multivibrator having a signal output terminal,
a load, and
a wave shaping circuit connected between said output terminal and said load, said circuit including in series a capacitor,
said capacitor and the resistance of said load having a time constant short relative to one half cycle of the output of said multivibrator, wherein is further provided
a diode gate in series with said wave shaping circuit and said tone generator, and
means for at will and selectively rendering said diode gate conductive and non-conductive.

6. In an electronic organ,
a plurality of continuously running tone generators for producing organ tones,
first paths extending from each of said tone generators and each including
a solid state diode gate connected in cascade with said generator, and
a resistive load circuit connected in cascade with all said gates,
means normally maintaining said solid state diode gates all fully non-conductive,
a single source of direct bias voltage,
key switch means interposed between said source of direct bias voltage and said solid state diode gates,
an operating key for each of said key switch means, the operating keys being operable to close said switches on depression of said keys, said keys being normally biased into undepressed state, the polarity and amplitude of said bias voltage being selected to selectively render said solid state diode gates conductive to the outputs of said tone generators on selective closures of said key switches responsive to depressions of said operating keys, wherein each of said paths includes in series
a capacitor,
each of said paths having a time constant by virtue of said capacitor and resistive load circuit,
said tone generators providing tones of different frequencies, and said time constants being each scaled to be short relative to one half cycle of the outputs of associated tone generators in series therewith, said time constants being selected to afford at least approximately all the same shapes of waves.

7. In an electronic organ,
a plurality of continuously running square wave oscillators individually tuned to the frequencies of the musical scale,
a single electro-acoustic load,
means selectively connecting said oscillators to said load,
said means comprising individual solid state diode gates each connected between a different one of said oscillators and said load,
bias means normally maintaining all said gates in non-conductive condition,

a single source of direct gating voltage,

separate key switches for selectively and at will connecting said single source of direct gating voltage to said gates in such polarity as to render the selected gates conductive,

a storage capacitor associated with each gate, and

means for distorting said square waves to have a corresponding array of partials for each of said oscillators,

said last means including a time constant circuit in cascade with each of said gates having a time constant short relative to the signal passed by the gates.

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