

April 13, 1965

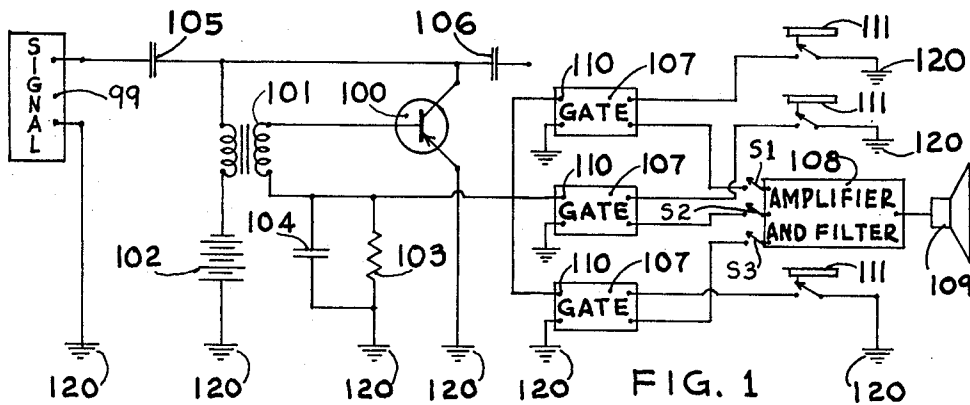
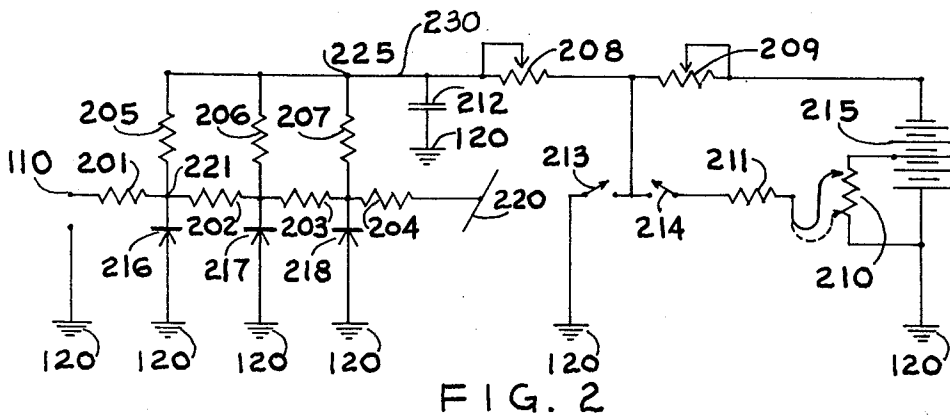
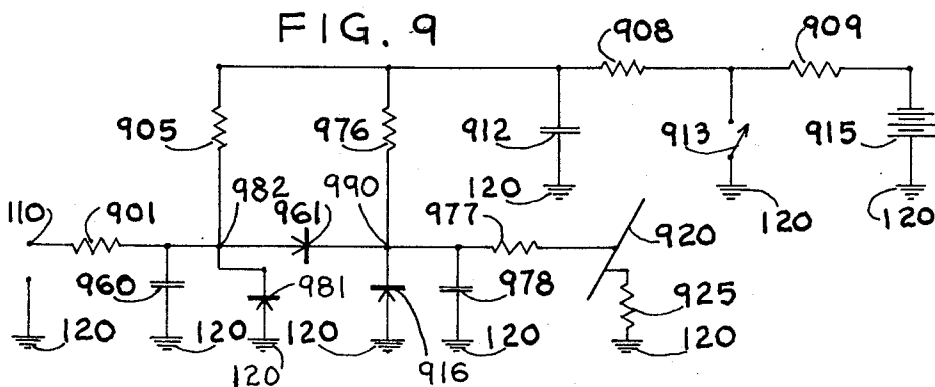
R. H. PETERSON

3,178,499

ELECTRONIC MUSICAL INSTRUMENT

Filed May 29, 1961

3 Sheets-Sheet 1



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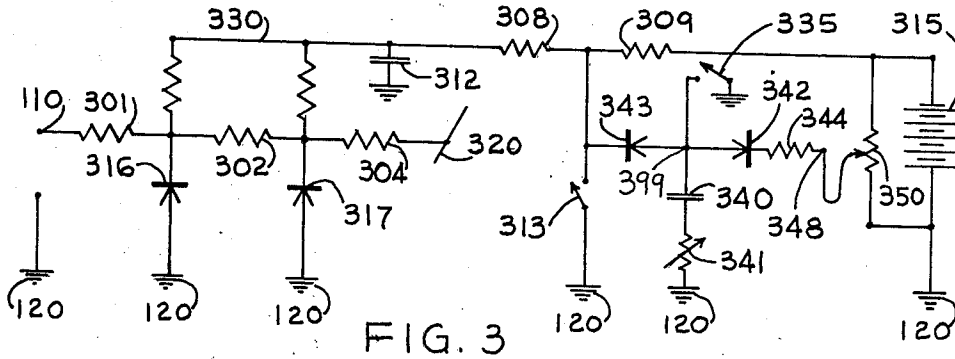
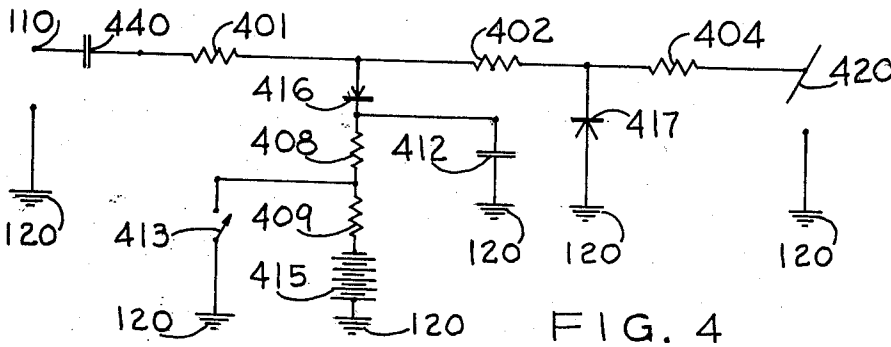
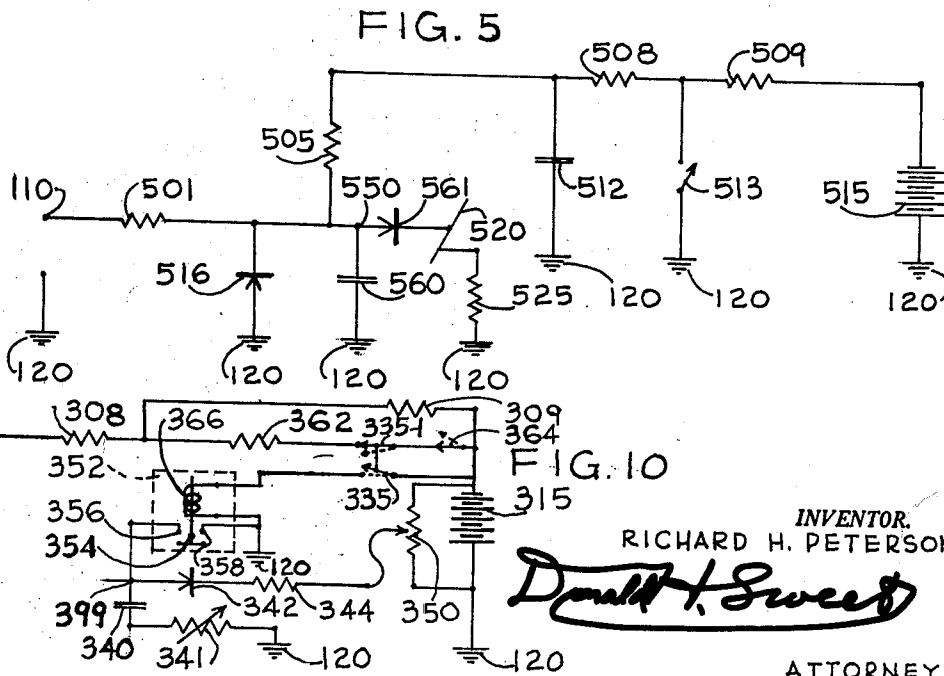
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3 Sheets-Sheet 2



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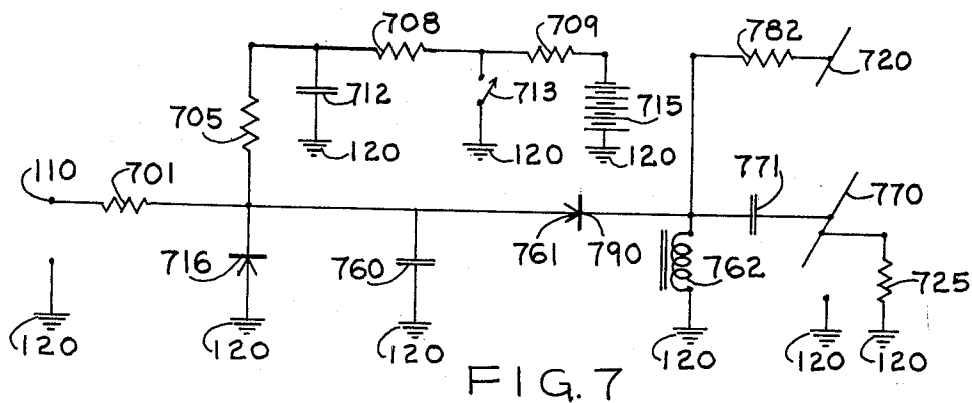
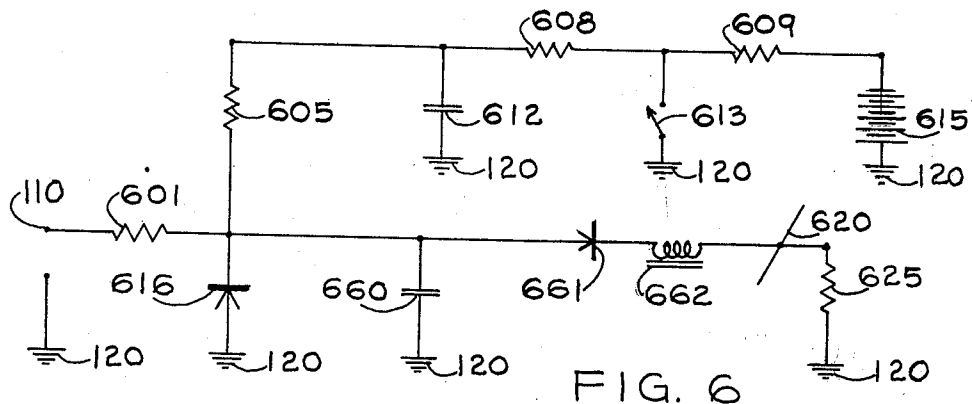
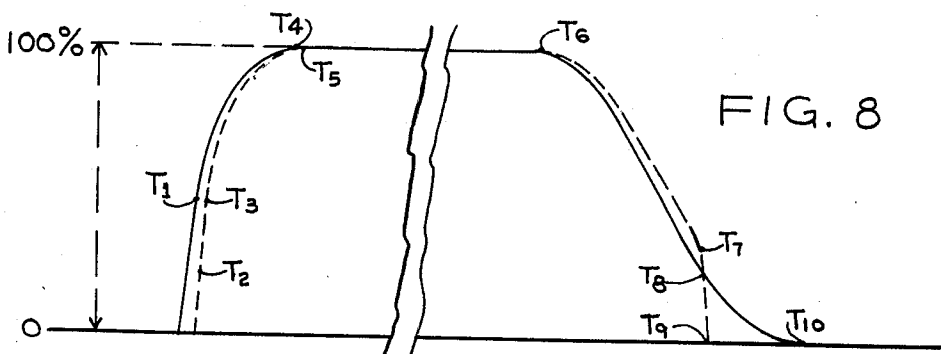
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ELECTRONIC MUSICAL INSTRUMENT

Filed May 29, 1961

3 Sheets-Sheet 3



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ELECTRONIC MUSICAL INSTRUMENT
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20 Claims. (Cl. 84-1.01)

This invention relates to electronic musical instruments. More specifically, it relates to improved envelope-controlling keying attenuators for use with organs having tone generators that are in continuous oscillation. In organs of this type, the playing keys of the instrument control the switching of signals from the oscillators into the amplification circuits. Some organs use ordinary mechanical switches for this purpose, with the result that the starting and stopping of the tone occurs in a very abrupt, unmusical manner. Mechanical switches employing variable impedance elements are known, but these are at best only partial solutions of the problem, mainly because they cannot secure accuracy in duplicating the attack and decay characteristics of acoustic devices.

The tone of an organ pipe, for example, takes a short but very significant amount of time to decay after the wind to the pipe has been cut off. The resultant lingering of the tone and the mixing of this "tail" with the notes that follow is highly desirable. Electronic switching devices, or electronic gates, in the form of vacuum tube or transistor keyers, or diode attenuators are known to have been used for the purpose of envelope control in musical instruments. All such devices known to applicant, however, fail in one or more important respects to meet all of the requirements that are desirable in such devices. For a keying gate to be completely satisfactory, it must be low in cost, since generally a great number must be used. Usually, where unification and/or octave coupling and intermanual coupling are provided, it is necessary to have several gates associated with each playing key on the organ. The gates must also have controllable attack and decay characteristics so that the attack and decay of different types of acoustic instruments can be simulated. Further, the gate must not introduce distortion of a type that would make the harmonic structure of the tone passing through it change in an unnatural manner during the attack or decay period. Also, the operation of the gating circuit must not introduce undesirable transients, such as clicks or thumps. Finally, it is essential that leakage through all the gates that are closed at any particular instant must be so small as to produce no noticeable effect.

It is therefore the object of this invention to provide improved envelope-controlling gating circuits having all the desirable characteristics enumerated. It is a further object to provide gating circuits that also distort the tone in a desirable manner such that the harmonic structure as well as the speech characteristics closely duplicate certain acoustic instruments. It is a still further object to provide gating circuits so that regular or percussion type musical instruments may be duplicated.

In the annexed drawings:

FIGURE 1 is a schematic diagram of one type of oscillator that can be used with the invention, together with a block representation of other parts of an organ system;

FIGURE 2 is a schematic diagram of a gate having a desirable linear relationship between attenuation and applied voltage;

FIGURE 3 is a schematic diagram of a gate capable of producing a wide variety of attack and decay characteristics;

FIGURE 4 is a schematic diagram of a gate requiring

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relatively lower operating current than those of FIGURES 2 and 3;

FIGURES 5, 6 and 7 are schematic diagrams of gates having three different kinds of desirable tonal characteristics;

FIGURE 8 is a graph of air pressure and tone amplitude as a function of time for a conventional organ pipe;

FIGURE 9 is a schematic diagram of a gate in which a single attenuator section utilizes two diodes; and,

FIGURE 10 is a partial schematic diagram indicating a modification of FIGURE 3.

In the embodiment selected to illustrate the invention, and referring first to FIGURE 1, transistor 100, transformer 101, and timing components 103, and 104, together with a power source 102, form an oscillatory circuit that will produce a signal at a frequency determined primarily by the constants of resistor 103 and capacitor 104. This is one form of blocking oscillator circuit and is representative of one type of oscillation generator that is suitable for use with the gating circuits of the invention. Since oscillators of this general type are known to those skilled in the art, this application is not encumbered with details of operation. In a complete organ there is generally a similar circuit provided for each semi-tone throughout the gamut of the instrument. Since these oscillators are not very stable in themselves, they are customarily synchronized in chains, or cascades, controlled by a master oscillator. Capacitors 105 and 106 are coupling capacitors for coupling synchronizing signals into and out of the oscillator 99. For example, capacitor 105 might be connected to a stable oscillator one octave above the frequency of oscillation of transistor 100, and capacitor 106 couples energy from the oscillator 99 of FIGURE 1 into a conductor 96 for activating the next cascade oscillator (not shown) operating one octave lower.

During operation, a signal voltage in the form of a sawtooth wave appears across resistor 103 and capacitor 104 and this signal is applied to the input terminal 110 of the gating circuits 107, of which only three are illustrated. Each gating circuit may be any of the gating circuits illustrated schematically in FIGURES 2, 3, 4, 5, 6 and 7. Signal, after passing through a gating circuit, is applied to conventional amplification and filtering circuits represented by the rectangle 108 and is then translated into sound by the loudspeaker 109. The gating circuits according to the invention are diode type attenuator circuits wherein the attenuation of the circuit is a function of a D.C. current which is controlled by a playing-key-operated switch, such as that represented at 111.

FIGURE 2 is a keying attenuator or gate capable of a very great attenuation ratio. In addition, the amount of attenuation is relatively independent of diode characteristics and is relate in a very linear manner to the current flowing in the circuit. This makes possible the use of this gate in circuits arranged such that the gates can be usefully employed under conditions where they are only partially open. Input to the gate is applied across terminals 110 and ground 120.

Resistor 201 and diode 216 form a signal voltage divider whereby the signal appearing at point 221 is substantially that appearing at terminal 110 multiplied by a quotient consisting of the dynamic impedance of the diode 216 divided by the sum of that same dynamic impedance plus the impedance of resistor 201. This can be written:

$$V_{221} \text{ equals } V_{110} \text{ times } \left(\frac{R_D}{R_{201} \text{ plus } R_D} \right)$$

wherein R_D is the dynamic impedance of diode 216.

The dynamic resistance of diode 216 is a function of the current through the diode such that, with no current, the diode impedance is extremely high and with typical diodes may be in the order of 10 megohms or more. If a current is caused to flow through the diode, however, its dynamic impedance will become very low, typically in the order of 50 ohms. In this circuit the D.C. current path is from the bias power source 215 through resistor 209, resistor 208, resistor 205, then through diode 216, and back to ground 120. Conductor 230 extends from resistor 208 to resistor 205, and has three lateral connections to capacitor 212 and resistors 207 and 206.

It is apparent, then, that the signal appearing across diode 216 will be greatly attenuated when a bias current is flowing. However, the ear is sensitive to an enormous range of intensity levels, the ear's sensitivity being according to a logarithmic curve. This means that the attenuation obtained in a gate employing a single diode may not be sufficient to avoid an objectionable amount of residual leakage through the closed gate. For this reason, a second attenuator section consisting of resistor 202 and diode 217 is provided, and bias current is supplied to diode 217 through the resistor 206. For very critical applications, still a third attenuator section may be provided as by resistor 203 and diode 218, receiving current through resistor 207. The output of the attenuator is connected through resistor 204 to the bus 220 which may be common to similar gates associated with other oscillators.

In this attenuator, the total attenuation is equal to the product of the attenuations afforded by each of the three sections. It should be noted that the resistances of resistors 201, 202, 203 and 204 are relatively low compared to the resistances of resistors 205, 206 and 207, and therefore do not unreasonably reduce the signal transmission through the attenuator during the times when the diode impedances are high. Switch 213 is a conventional key switch arranged to be closed by the depression of one of the playing keys of the organ. When this switch is closed, the junction between adjustable resistors 208 and 209 is shorted to ground and as a result no current can flow from the bias supply 215 through the diodes.

However, upon closure of switch 213, bias current through the diodes does not cease instantly because of the energy that has been stored in capacitor 212, which, prior to the closure of switch 213, was connected across bias source 215 through resistors 208 and 209. Upon the operation of switch 213, capacitor 212 discharges through resistors 205, 206, and 207 in parallel, but each in series with its respective diode 216, 217, and 218. It can also discharge through the resistor 208 and switch 213. Since resistor 208 is ordinarily of a much smaller value than the resistors 205, 206 and 207, the discharge time of capacitor 212 is primarily determined by the resistance of resistor 208. The values of resistor 208 and capacitor 212 therefore control the abruptness with which the bias current ceases to flow, and the rate of attack of the tone signal transmitted through the gate.

Upon opening key switch 213, bias current is again allowed to flow through the diodes but this current will not build up instantly because of capacitor 212. The build-up of voltage at point 225 is determined by the time constant of capacitor 212 and the combined resistance of resistors 208 and 209. Since resistor 209 is ordinarily many times greater in resistance than resistor 208, the resistance of resistor 209 substantially determines the build-up of current and therefore the decay rate of the signal through the attenuator.

At 214 I have illustrated an additional key switch which may typically be controlled by a different playing key than that which controls switch 213. This second playing key may be one of the playing keys on a separate playing manual or it may be related by an octave or other musical interval to switch 213 on the same keyboard.

One terminal of switch 214 is connected to the junction between resistors 208 and 209 as before, while the other terminal is connected to a resistor 211 which resistor is connected to the slide contact on the potentiometer 210, connected across the power source 215, to avoid a short circuit of part of the source 215 if both switches 213 and 214 happen to be closed at the same time. If the slide on resistor 210 is connected in the position illustrated by the dotted line, operation of the switch 214 will be substantially as that of switch 213. However, if a connection to resistor 210 is made as shown by the full line arrow, the junction of resistors 208 and 209 will be connected to a D.C. voltage when switch 214 is open. This results in partial attenuation of the signal through the gate, the degree of attenuation being determined by the position of the slide on the potentiometer 210.

Thus it is possible to control the same gate from two different keyboards, and have one keyboard cause the signal to be transmitted with substantially no attenuation while the other keyboard will cause a transmission of a partially attenuated signal. Typically, potentiometer 210 is common to a great many key switches such as that shown in 214 and a corresponding number of separate attenuators corresponding to the different notes of the scale, with the result that the adjustable potentiometer 210 is, in effect, a balancer that can balance the loudness of all the signals controlled by switches 213 and all the signals controlled by switches 214. All the keys 213 secure full loudness, but all the keys 214 secure partial loudness, and the signal potentiometer may be adjusted during play by the player, to change the relative loudness for all the notes controlled.

In FIGURE 3 I have shown a gate circuit similar to that of FIGURE 2, but with only two diode attenuator sections instead of three. Whether two sections or three are employed in any instance depends primarily on the attenuation ratio desired and on the desired shape of decay curve with respect to time. In FIGURE 3, the attenuation of the gate will be a function of the square of the current in resistor 308, while in the case of the attenuator shown in FIGURE 2, the attenuator will be a function of the cube of the current in the corresponding resistor 208. The functioning of the attenuator sections shown in FIGURE 3 is the same as the corresponding parts in FIGURE 2. Key switch 313 (FIGURE 3) operates in the same manner as key switch 213 (FIGURE 2).

But key switch 335 which operates by grounding point 399, performs a function different from that of key switch 214. Associated with key switch 335 is capacitor 340, resistors 341 and 344, diodes 342 and 343, and the potentiometer 350 connected across bias power source 315. When key switches 313 and 335 are both open, a current will flow from bias power source 315, through resistors 309, 308, conductor 330, and through the parallel paths consisting of resistors 305 and 306 and the diodes 316 and 317 and back to the power source. At the same time capacitor 312 will have charged through resistors 308 and 309, and capacitor 340 will have charged through resistor 309 and diode 343. Upon closing switch 335, capacitor 312 will discharge through resistor 308 and diode 343, and capacitor 340 will discharge through resistor 341. The rate of opening the gate will thus be determined by resistors 308 and 341. Upon opening key switch 335, current in conductor 330 will again build up, but at a rate determined by the charging times of capacitors 312 and 340. Capacitor 340 also has an ancillary charging circuit including resistor 344 and diode 342. If the voltage at terminal 348 is greater than the voltage to which capacitor 340 has charged, the polarity of the voltage across diode 342 will be such as to allow capacitor 340 to draw current from the power source 315, through potentiometer 350, resistor 344 and diode 342. If the slider of potentiometer 350 is connected to the top of the resistance element, the ancillary charging path will be effective during the entire

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charging cycle of capacitor 340, while if the slider is connected to the bottom of the resistance element (ground) the ancillary path will not be effective during any part of the charging cycle. Thus we have provided a keying gate that can be operated from two different key switches wherein each switch causes the gate to open and close at a different rate with respect to time. Further the rate of opening and closing of the gate as controlled by switch 335 can be adjusted over a wide range by purely electronic means so as to duplicate the envelope characteristics of an equally wide range of instruments, from organ pipes to percussion instruments. It should be understood that the bias power source 315 and the potentiometer 350 can be common to a great many gates, such as all of those associated with the switches in the bank, or playing key board, including wye switch 335.

The envelope characteristics of certain percussion instruments, such as the piano, can be even more closely duplicated if resistors 209, 309, 409 etc., are voltage-sensitive resistors, such as silicon carbide varistors. Such resistors display the characteristic of having different resistance values depending upon the amount of current flowing through them. Since the current flowing through resistor 309 varies during the charging and discharging cycles of capacitors 312 and 340 it can be seen that the shape of the charging and discharging curves with respect to time will be altered if the resistance is voltage or current sensitive. Generally, the effect on the decay characteristic of the tone passing through the gate is to cause the initial portion of the decay curve to decay more quickly than it would otherwise, and the latter portion more slowly.

In all of the gates thus far disclosed it is advantageous that the input signal to the gate be a pulse (positive with the diodes connected as shown), rather than an alternating signal having positive and negative excursions. The oscillator of FIGURE 1 delivers such a pulse. This is because a signal that causes a reversed voltage to appear across the diode (such as for example diode 216 in FIGURE 2) will cause the diode to conduct during that portion of the signal cycle and hence cause some undesired attenuation when the gate is "open."

Some diodes, particularly silicon diodes, require a certain definite forward voltage before any substantial conduction is established. With silicon diodes this voltage is usually about 0.4 volt. With such diodes it is allowable for the signal to have a negative excursion, providing the absolute magnitude of the same is less than 0.4 volt.

Where silicon (or equivalent) diodes are used, and where the signal voltage into the gate is low, it is possible to use the gate circuit shown in FIGURE 4. This is a two stage attenuator consisting of a first attenuator section comprising resistor 401 and diode 416, and a second attenuator section comprising resistor 402 and diode 417. Each of these attenuator sections is an audio-frequency voltage divider wherein the diode represents a variable impedance whose value depends upon the D.C. current through the diode. In FIGURE 4, the source of this diode current is shown at 415. With respect to this D.C. current the diodes are in series, the complete circuit including source 415, resistors 409, 408 and 402 as well as the diodes 416 and 417. With respect to signal voltages however, the diodes are in a parallel relationship because capacitor 412 is a low impedance to signal frequencies. As in the previous circuits, a key switch 413 controls the D.C. current through the diodes, and the rate of build-up and decay of this current is a function of the time constants of the resistors 408 and 409 and capacitor 412. Note that when the D.C. current is not flowing through the diodes due to switch 413 being closed, both diodes are in their high impedance condition.

A signal voltage of either polarity however will tend to cause one diode or the other to be biased in the sense to cause it to conduct and therefore attenuate the signal. For the reasons previously mentioned this will not occur

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provided that the magnitude of the signal does not exceed the forward threshold voltage that is necessary to establish conduction in the diode. With this gate it is desirable for the signal to be a true A.C. signal having both positive and negative excursions, and therefore an input coupling capacitor is shown at 440. As compared with the gates of FIGURES 2 and 3, the gate of FIGURE 4 uses a single D.C. current to control both attenuator sections, and the size of capacitor 412 is correspondingly reduced.

An important advantage of all of the keying gates thus far disclosed is that during the attack and decay period, tone signals passing through the gates are not subject to an excessive or objectionable harmonic distortion that would cause the character of the tone to change. Furthermore the tones decay in a very smooth manner down to inaudibility.

Certain acoustic instruments, particularly organ reed pipes, however, have the peculiar characteristic that their intensity envelopes are as shown in FIGURE 8. These pipes will not sound at all below wind pressures that are below a certain minimum pressure. This results in an attack that is both abrupt and somewhat percussive in character and in a rather abrupt decay. In no case however is there a transient, or an abruptness of the type associated with ordinary mechanical signal switching. Furthermore, the harmonic structure of reed pipes is generally very different from the tone signals produced by ordinary electric oscillators in that in the reed pipes a great deal of energy is concentrated in the low order harmonics of the tone. Electrical wave forms on the other hand almost always have too much fundamental as compared with the first few low order harmonics, and they generally have much too much high order harmonic energy.

In FIGURES 5, 6 and 7, I have shown keying gates that are capable of producing reed-like intensity envelopes. In addition these gates also introduce distortion of a type that is highly desirable and that results in the production of tones of unusual beauty and that could not otherwise be produced without resorting to complicated filtering systems employing many times the number of components required according to the invention.

Referring first to FIGURE 5, resistor 501 and diode 516 comprise an attenuator section of the type already described. This may be thought of as a shunt attenuator, because the diode, when conducting, shunts the signal path to ground. A second attenuator section includes diode 561 and resistor 525. This is a series attenuator because the variable impedance element (diode 561) is in series with the signal path. D.C. current for diode 516 flows in the circuit including the source 515 and resistors 505, 508 and 509. As before, a key switch (513) controls the application of the bias current and resistor 503 and 509 together with capacitor 512 control the attack and decay characteristics. When bias current is flowing a voltage will appear at point 550 that is equal to the forward voltage drop across diode 516. Since this voltage is of the opposite polarity necessary to establish conduction in diode 561, diode 561 will be "open" and no signal appears on output bus 520.

Closing key switch 513 cuts off the bias current through diode 516 and therefore removes the negative voltage from point 550. Now positive pulses of signal from the oscillator in FIGURE 1 (or equivalent), charge capacitor 560 (which is across diode 516) through resistor 501, and terminal 550 comes to a potential allowing conduction of the signal through diode 561 to the output bus 520. Because the voltage across capacitor 560 changes dynamically during each signal cycle, the impedance of diode 561 also varies dynamically, which results in distortion of the signal. This distortion prevents extremely sharp discontinuities in the wave form that appears on the output bus, and is therefore substantially equivalent to a very effective low pass filter. As a result the output tone is free from the excessive high order harmonic en-

ergy that is present in most electronically generated signals.

Varying the values of resistor 501 and capacitor 560 makes possible a wide variety of desirable sounds. Increasing the value of capacitor 560 for example, lowers the frequency at which the circuit operation begins to eliminate higher order harmonics. It is interesting that the filtering action of the diode circuit does not reduce the low order harmonics and it is this selective filtering action that results in the output signal having the highly desirable harmonic energy distribution. In addition, the voltage across capacitor 560 that is due to the signal pulses, builds up during the attack period and decays during the decay period, in a manner that causes the gate to produce keyed signals having envelope characteristics as shown in FIGURE 8.

Gates according to FIGURES 6 and 7 operate in the same manner as that in FIGURE 5, except for the inclusion of an inductor in the circuit. Signal pulses through inductor 662 (FIGURE 6) cause "ringing" or the production of damped oscillations at a resonant frequency determined by the constants of capacitor 660 and inductor 662. This resonance is usually adjusted to be an octave, or up to several octaves, higher in frequency than the frequency of the signal. This formant effect is exactly analogous to the effect that an acoustic resonator has on the tone of an organ pipe. To carry the analogy further, the basic electrical signal, as modified by the distortion of the gate as previously described, is the equivalent of the pulse of air produced by a vibrating reed, while the "ringing" of the formant circuit duplicates the function of the resonator.

FIGURE 7 operates in a similar manner except that the inductor is connected from the output terminal 790 (of diode 761) to ground, and the output signal is coupled to two output busses 720 and 770. Various methods coupling the output of the gate into the amplification circuits result in differing proportions of the basic signal and the "ringing" frequency signal, to be received by the amplifier. The basic signal in FIGURE 6 is coupled through the inductor 662, and this results in relatively less high frequency energy being received by bus 620. In FIGURE 7 one bus 770 is coupled through capacitor 771, but bus 720 is coupled through resistor 782.

In FIGURE 8 the full line curve is a graph of air pressure delivered to the slot of the organ tube, and the dotted line represents the intensity of the sound emanating from the tube. The x axis represents time. For the full line, the y axis is pressure, and for the dotted line the y axis is loudness.

At the outset the pressure rises and air flow lags only a little behind. But until a certain degree of turbulence is generated at the slit, the main air column will not start vibrating. At time T_1 vibration starts, and passes the lower level of audibility at time T_2 , reaching a volume at T_3 that would continue if the pressure did not continue to rise. At point T_4 the pressure is at its 100 percent plateau and at time T_5 the vibration is also at 100 percent.

This continues indefinitely until the player lets the key up at time T_6 . On the way down the sound volume slightly exceeds what the instantaneous pressure would sustain in a steady state. At point T_7 (which is a slightly lower intensity than at point T_3), the air flow at the slit fails to maintain any energy supply to the main column. The decrease is rapid down to inaudibility at T_8 , and at T_9 the most sensitive measuring means can no longer detect oscillations in the main tube. Finally at T_{10} the last vestige of movement of air at the slit ceases.

The foregoing outline is believed to be substantially correct, but the pragmatic fact is that with gates according to any one of FIGURES 5, 6, and 7, envelopes can be secured so closely similar to the dotted line of FIGURE 8 that even a highly cultivated musical ear can

hardly distinguish between the electronically produced and the acoustically produced music.

In FIGURE 9 the resistor 901 and diode 981 function as a first signal-voltage divider, the delivered signal from which enters a single section with current-sensitive impedances in the nature of diodes 961 and 916. For many not too exacting requirements, the mere omission of diode 981 lets the original signal go directly into the double-diode section. In either instance, the signal at terminal 982 enters the same receiving gate.

The application of control current causes the shunt diode 916 to assume a high impedance state. Current is fed to the shunt diode 916 through resistor 976. When current is flowing in this circuit, with key switch 913 open, terminal 990 will assume a potential equal to the forward voltage drop of diode 916, or about 0.4 volt. This is the cathode potential of diode 961.

The anode of diode 961 is at a considerably higher negative potential, the exact potential being determined by the values of resistors 909, 908, 905 and 901, together with the source resistance across terminals 110 and 120. Since this biases the diode 961 in reverse, its impedance is high, and substantially no signal arises at point 990.

When the control current is removed, by closing key switch 913, the polarity across both diodes 961 and 981 is reversed because the input signal is a positive pulse. Under these conditions diode 961 conducts, and diode 916 opens. The signal now passes on through conductive diode 961, to point 990, coupling resistor 977, to the output bus 920, and appears across resistor 925.

Resistors 908 and 909 and capacitor 912 control the attack and decay as described previously, in connection with resistors 208 and 209.

Either or both of the capacitors 960 or 978 can be employed to vary the tone quality, as described in connection with the gate of FIGURE 5. In addition, these capacitors, particularly 960, increase the attenuation ratio by eliminating high order harmonics that increase the peak amplitude of the signal into the two-diode attenuator.

To complete the full duplication of the envelope characteristics the piano has when the usual sustain pedal is being used, any of the playing keys 213, 214, 313, 335, etc., may be operatively associated with the momentary impulse unit of FIGURE 1. I have indicated the key 335 connected in this way. Illustrated is a portion of FIGURE 3, modified by adding the impulse unit 352, having a jumping armature 354 adapted to overshoot and make momentary contact with terminals 356 and 358 over a very short time interval that can be adjusted with high precision.

Closure of switch 335 energizes the winding 366 and causes the armature 354 to jump into momentary contact and connect point 399 to ground, just as in FIGURE 3, but only for the predetermined short time interval, independent of how long it takes the player to get the switch 335 open again.

Later, when the switch 335 is opened by the player, it is desirable that the sound terminate with the same envelope as a piano string when engaged by its felt damper. The companion switch 335-1 is mechanically connected to switch 335 to open when switch 335 is closed and close when 335 is opened. The return of the parts to full line position restores an electronic damping action, through resistors 362 and 308. Resistor 309 has a high impedance to secure a slow, percussion decay while key 335 is still held down by the player, but resistor 362 has only a fraction of that impedance, proportioned to secure the much shorter decay characteristic of the felt-damped piano string.

To give the player a sustaining control, equivalent to a piano sustaining pedal, switch 364 is provided in series with switch 335-1. This switch is opened by the sustaining pedal to secure the sustaining action, in which case closure of switch 335-1 has no effect, and the tone continues to decay slowly. But if the player, with switch 364

open, plays a chord or a succession of notes, and lets all the key switches open again, and subsequently closes switch 364, the simultaneous rapid decay of all the notes still sounding gives a performance substantially indistinguishable from that of a piano. The electronic sustaining pedal operates a gang switch which includes a switch 364 for every note.

It will be understood that each signal source is operatively associated with a number of gates, and that player-controlled stop means to select the gates that can transmit to the amplifier and filter 103 are always provided. These are usually part of the filter system itself, but for additional clearness, they are individually indicated in FIGURE 1 at S_1 , S_2 , and S_3 .

Others may readily adapt the invention for use under various conditions of service by employing one or more of the novel features disclosed or equivalents thereof. As at present advised, with respect to the apparent scope of my invention, I desire to claim the following subject matter:

1. In an electronic organ, in combination: a source of audio-frequency electronic signal; a gating circuit; said gating circuit comprising a first attenuator section comprising a first signal-voltage divider; said divider comprising a relatively constant impedance and a current-sensitive variable impedance; said divider having an input terminal connected to receive signal from said source; a connection for receiving a first derived signal from across said variable impedance; a second attenuator section comprising a second similar signal-voltage divider connected to receive said first derived signal, and comprising a relatively constant impedance and a variable impedance; a second connection for receiving a second derived signal from across the variable impedance of said second signal-voltage divider; transducing means connected to receive said second derived signal and generate sound corresponding thereto; and direct current biasing means operatively associated with said variable impedances for changing the condition of said variable impedances from high to low and vice versa.

2. A combination according to claim 1 in combination with a third, generally similar, attenuator section, interpolated between said second signal-voltage divider and said transducing means.

3. A combination according to claim 1 in which both variable impedances are diodes; each diode having a low impedance value many times smaller and a high impedance value many times greater than the impedance of its associated relatively constant impedance.

4. A combination according to claim 3, in which said diodes are adapted to change from low to high impedance and vice versa at a predetermined potential differing substantially from zero; whereby oscillations involving excursions in both directions, but not exceeding said predetermined potential in the direction from zero to said predetermined potential, may pass through without distortion.

5. A combination according to claim 3 in combination with playing key controlled means operatively associated with said attenuators for delivering direct current potential simultaneously to the diodes of both attenuators to change the impedance of both diodes.

6. A combination according to claim 5 in which each attenuator has its own independently predetermined time-attenuation ratio curve in response to the receipt of any stated direct current potential; whereby the ultimate attack curve of the inception of signal delivered to said transducing means is a function of the time-voltage curve of the key controlled direct current, compounded with the time-ratio curves of the first attenuator for various direct current voltages, combined with the time-ratio curves of the second attenuator for various direct current voltages.

7. A combination according to claim 6, in combination with a third attenuator connected between said transducing means and one of the output connections of said second attenuator; and biasing means operatively associated

with said attenuators for biasing the diodes of all three of said attenuators to substantially confine signal to channels leading to said translating means, or to exclude signal from channels leading to said transducing means.

8. A combination according to claim 1 in which said direct current biasing means includes a player-operated key-switch; a timed momentary impulse relay activated by said key-switch; connections for delivering the timed momentary impulse from said relay to said gating circuit to establish the delivered signal; and a continuously operative restoring connection operatively associated with said gating circuit and adapted to restore the initial inoperative condition of said gating current slowly, over an extended time period corresponding to the decay period of a percussion instrument.

9. A combination according to claim 8 in combination with a second restoring circuit rendered operative by opening said key-switch and operatively associated with said gating circuit, for restoring the inoperative condition of said gating circuit more rapidly.

10. A combination according to claim 9 in combination with player-controlled means operatively associated with said second restoring circuit for effectuating a pedal sustain effect by rendering said second restoring circuit inoperative regardless of the position of said key-switch.

11. A gating circuit for electronic musical instruments comprising, in combination: terminals for receiving audio-frequency signal; a plurality of diode attenuator sections connected to receive said signal serially; said attenuator sections being responsive to direct current bias current and having high attenuation when biased, and relatively insignificant attenuation when not biased; a source of direct current bias current operatively associated with said sections; a circuit from said direct current source through a first resistor, and a second resistor, to said attenuator sections; a capacitor connected into said circuit between said second resistor and said attenuator sections; a lateral connection connected into said circuit between said first and second resistors; a first playing key in said lateral connection for closing said connection to remove bias, and opening the same to permit bias to be restored; whereby the attack of the signal when said lateral connection is closed is a function of the values of said capacitor and said second resistor, and the decay of signal when said lateral connection is opened is a function of the value of said capacitor and the combined impedances of both said first and second resistors; and connections operatively associated with the last attenuator section for delivering an output signal suitable for conversion into acoustical oscillations.

12. A gating circuit for electronic musical instruments comprising, in combination: terminals for receiving audio-frequency signal; an attenuator connected to receive said signal; said attenuator comprising a signal-voltage divider having a relatively fixed impedance and a highly variable impedance sensitive to direct current bias; a source of direct current bias current; a key switch and circuit for delivering direct current bias current from said bias source to said variable impedance; said circuit comprising a connection from said source through first and second resistors in series, to said variable impedance; a first branch connection to ground from between said resistors; said key switch being in said first branch connection; a second branch connection to ground from between said divider and said second resistor; energy-storage means in the nature of a capacitor in said second branch connection; whereby said energy storage means changes its condition by current flow through said second resistor when said key switch is closed, to determine the attack envelope of the attenuated signal, and changes in the other direction by current flow through both resistors to determine a longer decay envelope for the decay of the signal; and connections operatively associated with said attenuator for receiving the attenuated signal from said attenuator and delivering it to an electronic musical instrument.

13. In an electronic musical instrument, in combination: a source of audio-frequency signal; a gating circuit connected to receive signal from said source; said gating circuit having a first, operative, or open, condition for passing signal; and a second, inoperative, or closed, condition for preventing signal from passing through; one of said conditions being identified as biased and the other as unbiased; transducing means for receiving signal from said gating means and generating corresponding acoustical oscillation; biasing means for changing said gating circuit from unbiased condition to biased condition; and player-controlled key-switch means for rendering said biasing means operative or inoperative; said biasing means comprising a source of direct current; a biasing circuit from the ungrounded terminal of said direct current source through a first resistor and a second resistor to said gating circuit; a first lateral connection from said biasing circuit between said second resistor and said gating circuit; a capacitor in said first lateral connection; and a second lateral connection from said biasing circuit between said first and second resistors; said player-controlled key-switch means being in said second lateral connection.

14. In an electronic musical instrument, in combination: a source of audio-frequency signal; a gating circuit connected to receive the signal from said source; said gating circuit including a plurality of attenuator sections, a first one of which receives the signal from said source, and each subsequent one of which receives signal from a preceding section; each attenuator section including a diode and a resistor in series to act as a signal-voltage divider; each diode having a biased condition and an unbiased condition; each diode, in one condition, having an impedance many times greater than its associated resistor, and in the other condition, having an impedance many times less than said resistor; a source of direct current bias current operatively associated with said attenuator sections; a playing key and a playing key-switch actuated by said key operatively associated with said source of direct current bias potential; electrical connections operatively associated with said direct current source and with said key switch for selectively delivering bias current simultaneously to all said diodes; transducing means; and connections operatively associated with the last of said attenuator sections for delivering signal from the last of said attenuator sections to said transducing means.

15. A combination according to claim 14 in which said diodes are all connected in parallel with respect to direct current.

16. A combination according to claim 15 in which said diodes are two in number, connected in parallel with respect to signal, but in series with respect to direct current biasing current.

17. In an electronic instrument of the type comprising constantly oscillating signal sources; a gating circuit comprising a first attenuator section having a first resistor and a first variable current-sensitive impedance in series with respect to signal; a second attenuator section connected to receive the signal across said first current-sensitive impedance; said second similar attenuator section comprising a second resistor and a second variable current-sensitive impedance; transducer means; connections for delivering the signal across said second current-sensitive impedance to said transducer means; and connections for delivering direct current biasing current through said first and second variable impedances in series.

18. A gating circuit for electronic musical instruments comprising, in combination: a first, shunt, signal-voltage divider comprising a first resistor and a first diode; a second, series signal-voltage divider comprising a second diode and a second resistor connected in series; said second divider being connected to receive the signal across said first diode; connections for delivering the signal across said second resistor; direct current bias means operatively associated with said first and second diodes for keeping said first diode of low impedance and said second diode of high impedance, whereby no signal is delivered; player-controlled key-switch means operatively associated with said direct current bias means for rendering said direct current bias means inoperative, to permit said gating circuit to deliver signal; and connections operatively associated with said second, series signal-voltage divider for receiving the attenuated signal from said divider and delivering it as an output signal.

19. A combination according to claim 18 in which the signal across said second resistor is subjected to formant means in the nature of a tuned circuit adapted to produce damped oscillations at a frequency other than the frequency of the original signal.

20. A combination according to claim 18, in combination with energy-storage means in the nature of a capacitor receiving the potential coming to said second diode; whereby sharp discontinuities corresponding to undesirably high overtones are eliminated by dynamic changes in the stored energy and in the dynamic impedance of said second diode.

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