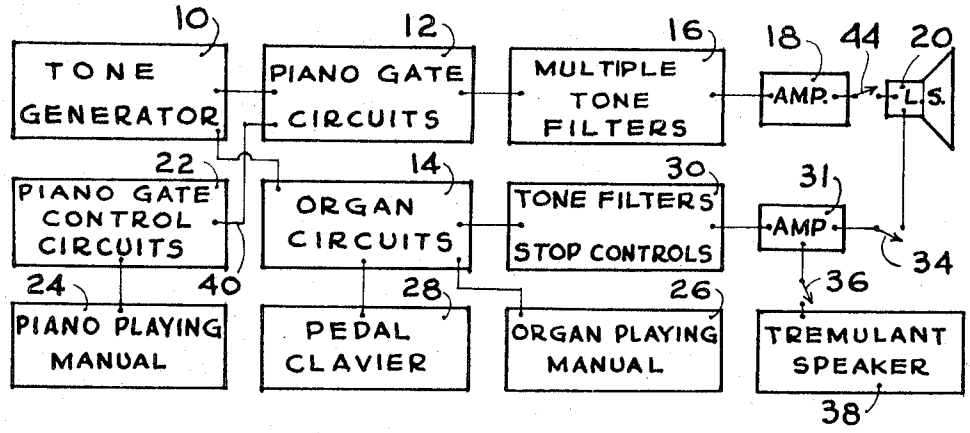
May 13, 1969 R. H PETERSON 3,444,306

ELECTRONIC MUSICAL INSTRUMENT PRODUCING PIANO EFFECTS

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FIG. 1



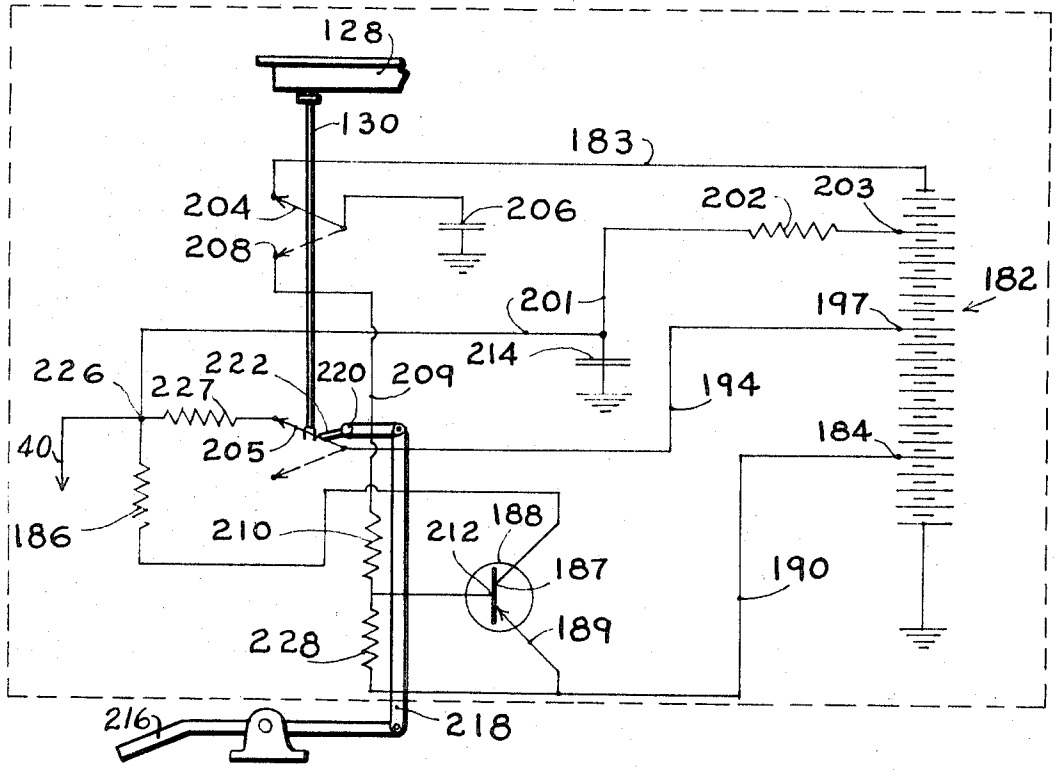




FIG.3

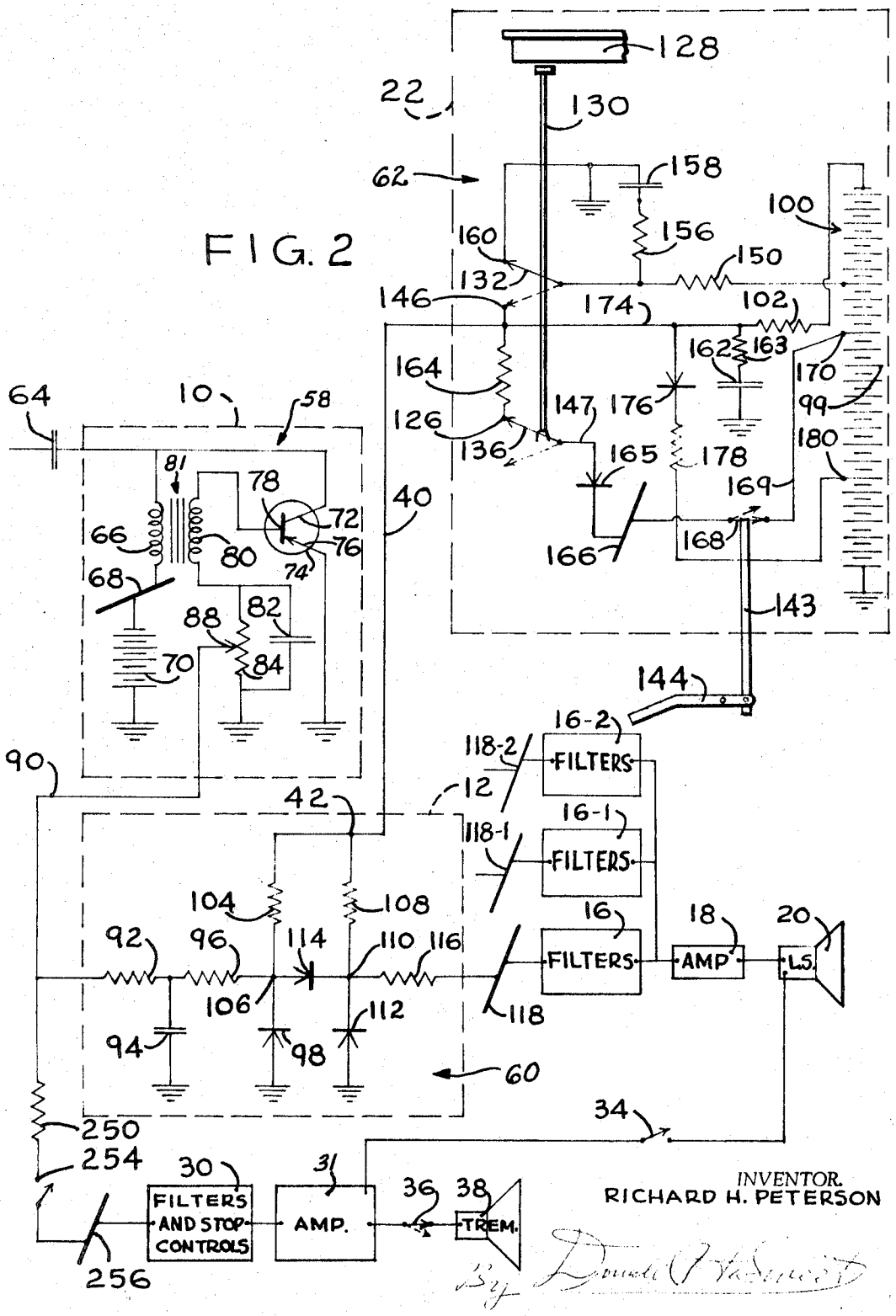
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ELECTRONIC MUSICAL INSTRUMENT PRODUCING PIANO EFFECTS

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FIG. 2




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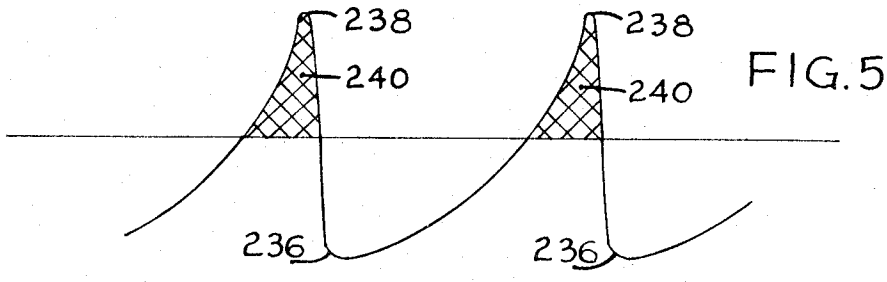



FIG. 5

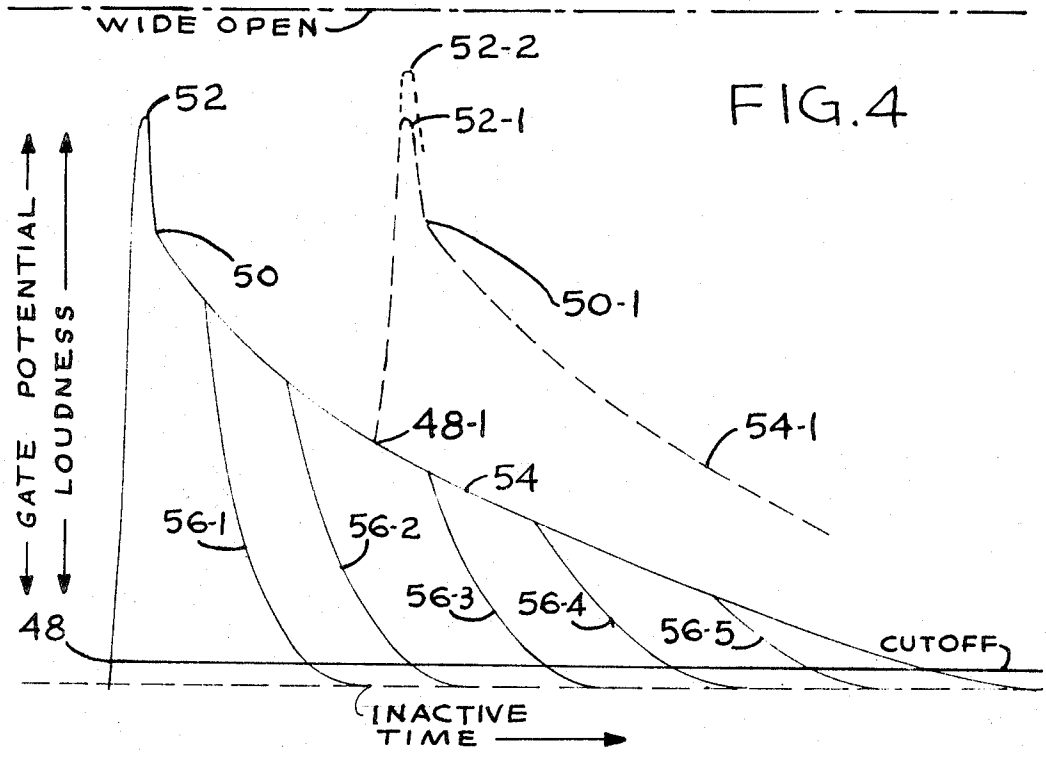
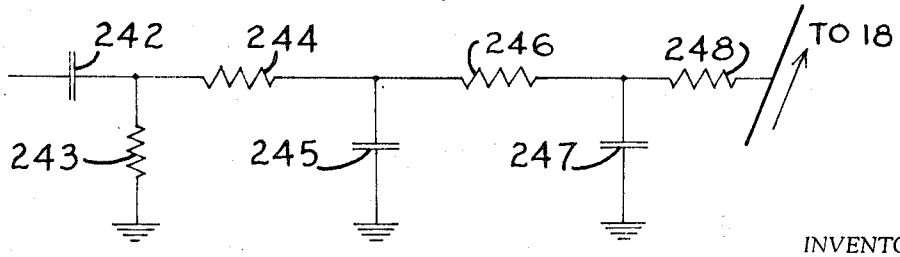



FIG. 4

FIG. 6

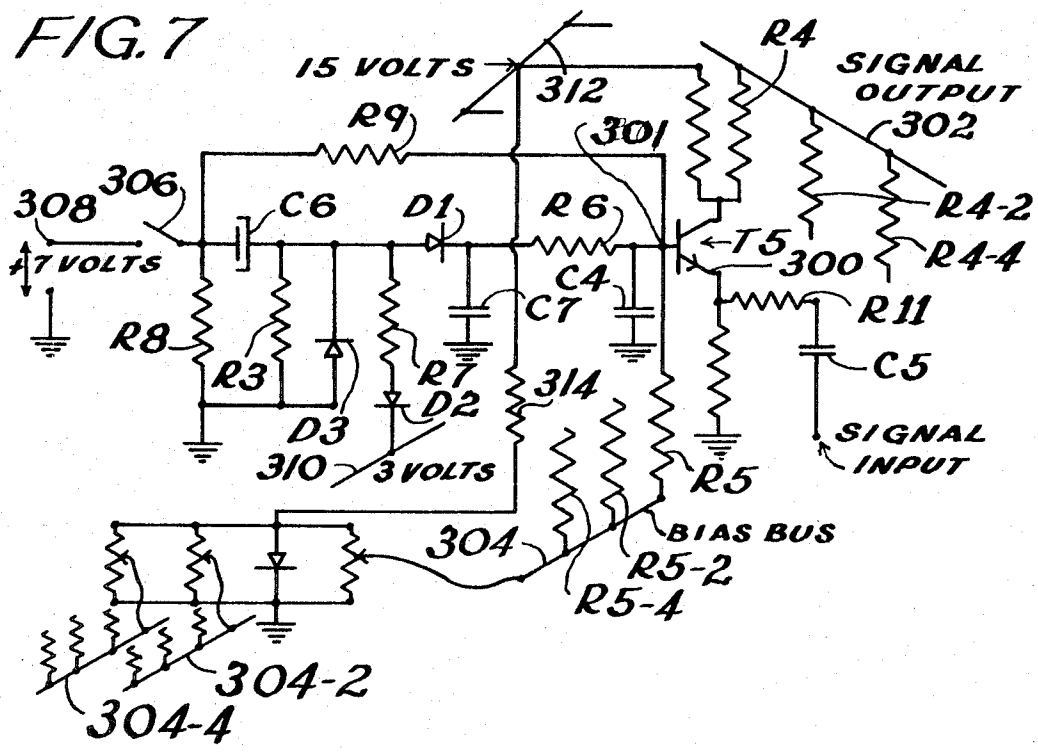



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ELECTRONIC MUSICAL INSTRUMENT PRODUCING PIANO EFFECTS

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FIG. 7




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United States Patent Office 3,444,306
Patented May 13, 1969



3,444,306

# ELECTRONIC MUSICAL INSTRUMENT PRODUCING PIANO EFFECTS

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Continuation-in-part of application Ser. No. 155,612 Nov. 29, 1961. This application Apr. 30, 1965, Ser. No. 458,806
Int. Cl. G10h 3/00, 1/02, 3/06
U.S. Cl. 84—1.13 14 Claims

## ABSTRACT OF THE DISCLOSURE

Semi-conductor gating circuits are used to selectively control, as a function of time, the delivery of electrically generated signals to a reproducing system, in a manner to simulate the envelope and harmonic charteristics of a pianoforte.

This invention is a continuation-in-part of my co-pending application Serial Number 155,612 filed November 29, 1961, now abandoned.

My invention relates to electronic musical instruments and including among its objects the production of high quality music having many of the characteristics of that emanating from a pianoforte. While a small unit capable of doing this only could be useful as a substitute for a piano, a further objective of the invention is to provide a single instrument upon which the player can produce piano tones in combination with conventional organ tones, all from the same playing manual or manuals, and wherein both types of the tone are derived from the same oscillation generating system. The combination of piano and organ is particularly popular with listeners, especially when the organ tones have a suitable tremulant, while the piano tones have their own entirely different tonal characteristics. The marked contrast between the two types of music enhances the attractiveness of both.

From the standpoint of process one specific object of the invention is to obtain, from a convenient pulse type wave, a derived signal in which the relative intensity of the fundamental has been materially reduced and the relative intensity of the very high overtones also materially reduced while the intermediate overtones are relatively emphasized.

It is also important to process the signal received by the transducer to define envelopes closely resembling, or substantially identical with, the normal envelopes of actual piano notes, including all the variations available to the player of an acoustic piano.

In terms of equipment these functions may be carried out entirely with combinations of filters and ordinary diodes. In the embodiment of FIGURE 7, one of the diode functions is performed by a transistor.

In the accompanying drawings:

FIGURE 1 is a block diagram of a complete organ system including equipment according to the invention;

FIGURE 2 indicates the circuitry for the production of one note either as a piano note or an organ note, or both;

FIGURE 3 is a schematic diagram of alternative key controls for the gating of a piano note;

FIGURE 4 is a diagram of a tone envelope;

FIGURE 5 is a wave form diagram;

FIGURE 6 is a schematic showing of a filter circuit; and

FIGURE 7 is a schematic of a complete envelope control employing a transistor.

Referring first to FIGURE 1, the embodiment of the invention selected for illustration, the tone generator **10** is adapted to deliver an electrical signal having saw tooth



wave form, for each frequency comprising the semi-tones of the musical scale throughout the scope of the range of the equipment. The individual oscillators are transistor oscillators, one for each note. Twelve master oscillators are provided for the highest frequencies produced by the instrument, or for the octave above those frequencies). These are of a highly stable type, with a plurality of slave oscillators connected in cascade to each of them, each slave oscillator having half the frequency of the oscillator immediately above it.

Signals from all of the above mentioned oscillators are delivered constantly to the piano circuits **12** and also to the organ key circuits **14**. Playing-key-selected signals leave the piano gating circuits **12** and pass through tone filters **16**, the amplifier **18** and a loud speaker **20** where they are transduced into musical sounds. What gets transmitted through the gating circuits **12** to the filter unit, **16** both with respect to the pitches selected, and to the amplitude of the signal delivered, is determined by the piano gating control unit **22**, operated by the piano playing key manual **24**.

Similarly, the signals that pass through the organ key circuits **14** are determined by the player by means of the organ playing manual **26** and the pedal clavier **28**. These signals go through conventional tone filters and stop controls **30**, and an amplifier **31**. The signal from amplifier **31** can pass over either or both of two paths to different transducers. The stop switch **34** is available to deliver the organ signal to loud speaker **20** and the stop switch **36** is available to deliver the organ signal to the organ speaker **38**. Thus the operator may deliver the amplifier signal from the unit **32** to either or both loud speakers and the same note will issue from loud speaker **20** in constant volume and pitch and simultaneously from organ speaker **38** with a variation in pitch or intensity or both at vibrato frequency. The tremulant speaker referred to, may be of the type disclosed in U.S. Reissue Patent 23,323 issued to Donald J. Leslie.

*The tone envelope*

Referring now to FIGURE 4, the characteristic intensity-versus-time envelope of the piano note is of an irregular and distinctive type. In a conventional piano, the operation of a playing key causes a hammer to momentarily strike a string and then to fall back away from the string. At the instant of impact, the intensity of the sound produced is very great and includes frequency components in addition to the regular fundamental and harmonic partials of the string. This is because the impact of the hammer causes shock excitation of the sounding board and of other strings. In addition, the force of the blow causes the tension of the string to be increased at the time of contact with the hammer and this causes the production of other transient frequencies.

Identifying the moment of impact at point **48** in FIGURE 4, the initial hump of sound intensity generated might be said to terminate at about the point **50**, having leaped up to a climax at **52** and come down rapidly to point **50**. Thereafter the sound intensity follows the much more gentle curve **54**, which approximates more and more closely a true logarithmic decrement curve as the intensity becomes less.

This will take place every time the key is struck and the curve **48**, **52**, **50** and **54** will be followed as long as the string is undamped. At any instant, by releasing the key if the sustain pedal is not depressed, or by releasing the sustain pedal after the key has been released, the player can cause a felt damper to come into contact with the string and thus terminate the sound. Whereas the curve **54** might reach the lower limit of audibility (identified on FIGURE 4 by the legend "CUTOFF"), after about 15 seconds in the case of a fairly low pitch string,

the damper will carry the sound below audibility within a time period of the order of magnitude of one fourth second. Thus the decay of the sound may leave the curve **54** and follow the steeper curves **56–1**, **56–2**, **56–3**, **56–4**, etc. The gate potential at junction point **42** in FIGURE 2 may go down to a lower level, identified as "INACTIVE" on FIGURE 4.

On the other hand, the mechanism of the piano retains the hammer in an intermediate position as long as the key is held down. Releasing the key quickly and striking it again quickly can produce a new blow. This would result in the dotted line peak at **52–1**, the new curve having left curve **54** at point **48–1**, and there will be a new decay curve **52–1**, **50–1**, **54–1**. The duplication of this envelope shape electronically is a far from simple problem.

In FIGURE 4 the horizontal axis denotes time. The vertical axis corresponds to gate potential at the point **42** and also to the loudness of the resulting tone, both of which phenomena vary together. The lower limit of audibility has been identified on FIGURE 4 as a horizontal line beginning at point **48**, which is further explained by the caption "CUTOFF." The gate potential can go below the point where audibility ceases and a lower dotted line corresponding to the lowest gate potential has been identified by the caption "INACTIVE." Similarly, the dot and dash line at the top of FIGURE 4 identified by the caption "WIDE OPEN" represents the maximum potential and the maximum loudness that the equipment would be capable of if there were no restraint by the damping action of the various circuits.

*The oscillator*

Referring to FIGURE 2, I have indicated an oscillator unit **58**, a gate circuit **60**, and a gate control circuit **62**. The unit **58** is indicated as a slave oscillator synchronized through capacitor **64**, by signal from a source oscillating at twice the frequency. Briefly, it comprises a collector-emitter circuit including a transformer winding **66** receiving potential from a bus **68** from a source indicated at **70** connected to the collector **72** of the transistor **74**, which has an emitter **76** returned to the potential source through the common ground circuit. The base-emitter circuit includes the base electrodes **78**, the secondary winding **80** and the timing components including resistor **84** and capacitor **82**.

This is a form of blocking oscillator circuit in which energy in the collector-emitter is fed back to the base emitter circuit through the transformer **81**. A pulse of current in the winding **66** causes current conduction in the base emitter circuit and the very rapid charge of capacitor **82** to a potential of approximately "*n*" times the potential of the source **70**, where "*n*" is the turns ratio of winding **80** with respect to winding **66**. This potential is sufficient to cut off further conduction of current in the collector-emitter circuit, until sufficient time has elapsed for resistor **84** to discharge capacitor **82** to a potential below cut-off. When this occurs, collector current again begins, this current building up very rapidly due to the amplification of the transistor and the regenerative phasing of the transformer winding. Thus the cycle repeats, and we have achieved an oscillator having a free-running frequency determined primarily by the constants of resistor **84** and capacitor **82**. A signal having a saw tooth wave form appears at **88** and is delivered to the gate circuit **12** through a conductor **90**. There the saw tooth wave form is somewhat modified by a first filter comprising resistor **92** and capacitor **94**. This filter rounds the sharp points at the peaks of the saw tooth and reduces the amplitude of the wave by reducing materially the high order harmonic frequencies that are undesirable musically and that interfere with efficient operation of the gate circuits to be described later.

It should be noted that it is significant in terms of proper operation of the particular gate circuit shown in FIGURES 2 and 3, that the oscillator described produces a wave form having a potential that is always positive with respect to ground. That is, the signal is not an A.C. signal, but rather a series of positive pulses. This signal is always present during use of the instrument whether the note is being played or not.

A gate circuit is provided for each oscillator, to enable the selective transmission of the various notes to the amplification and translation circuits. The particular gate illustrated in FIGURE 2, is of a type disclosed in my copending application Serial Number 113,289 filed May 29, 1961, now Patent 3,178,499, issued Apr. 13, 1965. It is a voltage-controlled attenuator consisting of a network of resistors and diodes wherein the diodes are variable impedance elements, their impedance being a function of a D.C. bias current. To achieve a high degree of attenuation when the gate is closed, I prefer to use a gate having cascaded sections. Still referring to FIGURE 2, resistor **96** and diode **98** form a first attenuator section in which the signal voltage appearing across diode **98** is largely determined by the impedance of the diode **98** as compared to the impedance of the resistor **96**. A second attenuator section includes diodes **114** and **112**. The proportion of the signal appearing across diode **98** that appears across diode **112** is determined primarily by the relative impedances of diode **114** and **112**. Signal appearing across diode **112** is coupled to the tone signal output bus **118** by means of resistor **116**. If a negative voltage is applied to point **42** with respect to ground, the potential will be imposed on a circuit through resistor **104** to junction point **106**, to diode **98**, to ground; and equally on a parallel circuit through resistor **108**, junction point **110**, to diode **112**, to ground. These diodes will be biased in a conductive or low impedance direction, while diode **114** will have a high impedance. If the voltage at point **42** is sufficietly high no signal will appear on bus **118** and the gate is said to be closed.

By reducing the negative voltage at point **42** to appropriate values it is possible to maintain the three diodes **98**, **112**, and **114** in a transition condition in which the gate is only partly closed. With the parts of the gating unit **60** properly proportioned there is a useful range of voltages for point **42**, over which the amount of signal delivered through the gate bears a desirable simple relationship to the voltage at point **42**. The piano gate control circuits include means for subjecting the point **42** to a time-voltage relationship corresponding to the time loudness relationship represented by FIGURE 4.

*The gate control*

It is convenient to consider three types of manipulation to which the player may resort in controlling the instrument. First: the sustain pedal may be held down, and all the notes sounded will have the slow decay of curve **54**, until releasing the pedal causes all of them to end quickly together along one of the curves **56–1**, etc. Second: with the sustain pedal not in use, the key may be struck and immediately released, and the decay will be along curve **56–1**, which produces a staccato effect. Third: with the sustain pedal not in use, one or more keys may be held down by the player's finger. This produces curve **54** for the notes held down, but other keys may be struck simultaneously or during the decay of the notes held by the player. Thus the player has an individual selection of the notes to be prolonged.

In all three cases, the curve from **48** to **52** and down again to **50** is automtically produced, and this part is conveniently identified as the "strike." The curve from **48** to **52** and an initial portion of the return to point **50** result primarily from the distribution of the charge of bucket capacitor **162** between itself and bucket capacitor **158** through resistors **163** and **156**. Considerable control over the shape of the tone envelope during the strike can be achieved in design by varying the values of capacitors **158** and **162** and their associated resistors **156** and **163**.

It is empasized that point 52 does not represent the maximum potential, nor the maximum sounds, of which the assembly is capable.

Return to the level of cutoff results from restoration of the initial potential of point 42 through various RC time circuits. Resistor 102 delivers current to rechange capacitor 162. As long as the key 128 is held down, resistor 150 delivers additional current, and both resistors 150 and 102 jointly restore both capacitors 158 and 162. If each of these circuits has the same time constant, the decay will be exactly the same, whether the key stays down and both resistors deliver current to both capacitors, or the key is released and only capacitor 162 and resistor 102 control the time curve for the potential of terminal 42.

From 52 down to 50 the decrease is due to the combined action of several circuits. There is the slow restoring circuit just described, involving the action of resistors 150 and 102 and their timing capacitors. There is a second restoring circuit which acts much more quickly, but only down to point 50. It comprises a tap 180 at the potential for point 50, a resistor 178 and a diode 176. As long as point 52 is at or beyond the potential for point 50, this circuit acts in the direction of cutoff and thus the logarithmic decrement curve down to point 50 is much steeper, coming to an end when the fast circuit from tap 180 becomes inoperative by the reversal of the potential across the diode. Beyond this point there remain only resistor 102 or resistor 102 and resistor 150, and either of these combinations produces the curve at 54.

Unless capacitor 158 has a capacitance of from ten to twenty times that of capacitor 162, an objectionable "pumping up" will occur if a playing key is operated several times in rapid succession. If, for example, capacitor 158 is of the same capacitance as capacitor 162, the first time a key is depressed the charge on capacitor 162 will drop to one-half of its key-up value. If however, the key is quickly released, capacitor 158 will be very rapidly discharged, and if the key is then depressed again, the voltage across capacitor 162 will not have returned to key-up value and will be reduced to one-half the value of that appearing across capacitor 162 at that instant. The result is that the second strike causes a greater signal amplitude than the first. Actually, I prefer to have capacitor 158 only about twice the value of capacitor 162, and I avoid the undesirable pump up by means of the circuit including conductor 174, diode 176 and low-valued resistor 178, connected to a predetermined potential at tap 180, corresponding to the level of point 50 in FIGURE 4.

This circuit begins to function as soon as the potential exceeds that of point 50, but the equalization between capacitors 162 and 158 is much faster and carries the curve up to point 52, which is a tiny fraction less than the equalization would reach if the circuit to tap 180 were not present.

But at point 52, equalization is at an end, and the return to point 50 at intermediate speed represents the restoration to potential 50 primarily by the circuit to tap 180. On the second strike, therefore, the circuit to tap 180 again become active at the level 50 and prevents the peak at 52–1 from rising materially higher than the peak at 52, whereas it might otherwise reach some such intensity as indicated at 52–2 in FIGURE 4. As previously pointed out, this is the same restoring circuit that causes the entire curve, 52 to 50, to be much steeper than the subsequent curve 54. This particular shape is a substantial duplication of the decay curve of the piano itself.

A characteristic of germanium and silicon diodes commonly used in this type of circuitry, is that the diode functions in a conductive condition with D.C. voltage drop of about ½ volt across it. The abrupt drop of D.C. potential when the key is depressed constitutes a single D.C. pulse that generates transients during most of the time from point 48 to point 50. These transients correspond to the inertial transients generated in the piano string by the tap of the hammer, and further enhance the verisimilitude of the electronic envelope.

The circuit for producing the curves 56–1, etc., includes a tap 170 on the potential source 100, a conductor 169, a closed switch 168, a bus 166, common to all the oscillators, a diode 165, and switch 136 leading to terminal 126. Actual cut-off potential is indicated on the source 100 at point 99 and tap 170 is at potential greater than cut-off. Closure of the circuit from tap 170 will bring terminal 42 to cut-off potential with a very short time factor, determined by resistor 164.

There are two places where this circuit can be interrupted to prevent the damped termination of the tone. Switch 136 may be held open by keeping key 128 depressed to sustain one individual note. Switch 168 may be opened by depressing pedal 144 to raise pitman 143 and open the switch 168 mechanically. This secures the sustain effect on all the notes. Conductors 147 connect each individual note to a bus 166, and with switch 168 closed, point 42 for each note is quickly brought to cut-off potential. When switch 168 is open, bus 166 should have no potential, and each conductor 147 has a diode 165 inserted in it to prevent the inactive notes from delivering potential to the bus.

It will be obvious that pedal 144 could be mechanically connected to each switch 136 instead, or that the individual diodes 165 could be replaced by a gang of individual switches mechanically operated by the pedal 144.

Summarizing the functioning of the unit 22, there are four different circuits affecting the potential of terminal 42 and the amplitude of the signal delivered to the transducing means. The permanent slow speed restoring circuit through resistor 102 may have an impedance approximately equal to the impedance between said point 42 and ground through resistors 104 and 108 connected in parallel, and it receives a little more than twice cutoff potential so that it will be effective to produce a little more than cutoff potential at terminal 42. The circuit through resistor 150 has a lower impedance and is connected to a lower voltage but still high enough to arrive at a final equilibrium potential in excess of cutoff. Finally, the circuit for damped termination passes through resistor 164 only and requires only a little more than cutoff potential to operate with great rapidity and produce the desired termination curve. The fourth circuit is intermediate in speed of action but it is connected to an intermediate potential corresponding to the level of point 50 on FIGURE 4, and is cancelled out by diode 176 whenever the potential is less than that value.

*Transistorized control unit*

Referring now to FIGURE 3, I have illustrated an alternate, transistorized gate control circuit 22. Source 182 corresponds to source 100 in FIGURE 2.

The same conductor 40 is connected at point 226 to one end of a resistor 186 and this resistor determines the strike and corresponds to resistor 164 in FIGURE 2. When key 128 is depressed the same rod 130 opens both switch 204 and switch 205. The opening of switch 205 disconnects the damped termination circuit through resistor 227, switch 205 and conductor 194 to a tap 197 on the source 182, which is in excess of cut-off potential.

In the position illustrated, with the key 128 released, switch 204 receives current through a conductor 183 to charge a capacitor 206. When the switch 204 is moved down it engages contact 208 and a conductor 209 delivers current from the capacitor 206 through a resistor 210 to the base terminal 212 of a transistor 188. This provides the potential at point 212 necessary to render the transistor conductive and completes a circuit from terminal 226 including resistor 186, the collector 187 of transistor 188 to the emitter 189, conductor 190 and tap 184 which is at a potential corresponding to point 52 in FIGURE 4. At the time point 52 is reached, the capacitor 206 has

been discharged and the transistor is no longer conductive. The shunt resistor **228** from the base **212** to the emitter **189** assures that the transistor will resume its nonconductive condition promptly as soon as capacitor **206** is discharged.

Immediate recharging begins through a circuit including tap **203**, resistor **202**, and conductor **201**. This timed restoration will bring terminal **42** back to cut-off potential according to a logarithmic decrement curve that will give a slow decay as long as key **128** is depressed to keep switch **205** open. The player may also depress pedal **216** to lift a pitman **218** and rotate a shaft **220** carrying a radially projecting leaf **222** to hold all the switches **205** open. Thus, holding down the key sustains an individual note and holding down the pedal sustains all the notes and the manual and pedal controls for the player respond in the same identical way as in FIGURE 2.

*Tonal considerations*

Thus far I have disclosed means for electronically creating tone signal envelope characteristics corresponding to those of the piano. Also important is the problem of achieving signals having the correct timbre. The harmonic structure of a typical mid-frequency piano note includes the fundamental and first few low order harmonics in more or less equal amplitude, while the higher order harmonics are very weak. Furthermore, in general, the brightness of the piano notes increases with decreasing pitch and decreases with increasing pitch. In other words, a low pitched piano note will have a longer harmonic series, and a relatively weaker fundamental than a higher pitched note. At the extreme high pitched end of the piano the notes are quite fundamental. In addition, the unpitched transient sound becomes increasingly important as a distinguishing characteristic of the piano as you ascend the scale.

No oscillation generating system known to me approaches the harmonic structure required without extensive modification. Specifically, the pulse produced by the generating system disclosed is, for the most part, much too rich in high order harmonics and at the same time deficient in low order harmonic amplitude relative to the fundamental. According to the embodiment of the described invention, the necessary wave form modification takes place in three ways. First, there is the filtering action previously disclosed, due to resistor **92** and capacitor **94** in FIGURE 2. This is a low pass filter designed to eliminate harmonics above about the 8th. It is understood that there is a different filter for each note, and that filter is proportioned to suit the frequency of the signal to be filtered.

Second, there is the wave form modification due to the fact that the gate circuit is allowed to open only partially. As shown in FIGURE 5, this results in the wave, form being changed from the full saw tooth wave, with its low points at **236** and its peaks at **238** to a series of spaced pulses represented by the cross hatched areas **240**. These spaced pulses have much less fundamental and very low order harmonic energy than the original wave, and therefore the modified wave now has the fundamental and low order harmonics in substantially the correct proportions. Third, further attenuation of the high order harmonics is desired and this is provided by the filters **16** indicated in FIGURE 2 and shown schematically in FIGURE 6.

Resistors **244**, **246** and **248**, together with capacitors **245** and **247** form a two-section low pass filter that will give a **12** decibels per octave attenuation above a selected cut-off frequency, which may be in the order of 1000 cycles per second. This filter, if common to all of the notes, results in the desired decreasing brightness of the higher notes relative to the lower ones. Capacitor **242** and resistor **243** form a high pass filter that serves mainly to suppress the very low order components of the transient generated due to the gate operation, which might otherwise result in the intitial transient sounding more like a "thump" than the "knock" associated with a hammer striking a piano string.

Under some conditions it is dsirable to have two or more separate filters **16**, each filtering a portion of the entire pitch range and proportioned to get the best results over the frequency range delivered to the filter. This is indicated in FIGURE 2, where the sectional buses **118–1** and **118–2**, each collect from about one-third of the signal sources, and deliver to individual filters **16**, **16–1** and **16–2**.

For the most desirable results it may be advantageous to use separate filters for relatively small groups of notes, as for example one filter for each six notes.

The organ playing manual **26**, pedal clavier **28**, organ circuits **14** and organ tone filters and stop controls **30**, as well as amplifier **31** may all be conventional. Except for their relationships with the other units indicated in FIGURE 1 they form no part of the present invention. It is noted that they use signals from the same oscillators. Conductor **90** in FIGURE 2 extends to resistor **250** and key switch **254** on the organ manual **26** and the signals are collected on bus **256** and delivered to filters **30**.

It is noted that resistor **102** in FIGURES 2, and capacitor **162** might be proportioned to give a long decay of, say nine seconds, and resistor **150** and capacitor **158** so that they would recharge by themselves in, say four seconds, although they never function except jointly with the other time circuit. Under these circumstances holding the key down would give a combined decay period of about 5½ seconds, but using the sustain pedal alone would give 9 seconds. This is a distinctive selective control that does not exist in a piano, and may or may not be desired by players.

With the types of diodes and transistors at present on the market, a desirable cutoff potential for terminal **48** is about 8 volts, and in the quiescent condition, terminal **42** is at about 8.5 or 9 volts. The potential corresponding to point **50** in FIGURE 4 is about 3 or 3½ volts and point **52** corresponds to about 2 volts. The signal intensity passing the gate continues to increase up to about 0.5 volt, corresponding to a volume of sound materially greater than that indacated at point **52**. All the voltages named are of negative potential.

Referring now to the modification of FIGURE 7, each gating circuit includes a gating transistor, T–5, connected as a common base amplifier, having a base terminal **301**. In a grounded base, or common base amplifier, the input signal is applied to the emitter circuit **300**, in this case through the capacitor C–5 and the input resistor R–11. The base of the transistor is grounded for audio frequencies by virtue of capacitor C–4. If the base of the transistor has a suitable D.C. bias, the transistor will amplify and an output signal will appear across the output load resistor R–10 and will be connected to the audio output bus **302** through resistor R–4. Ordinarily, however, the transistor is biased beyond the cutoff point by means of bias resistor R–5 and the bias adjustment potentiometer **304** common to a number of gate circuits, R–5, R–5–2, R–5–4, etc.

Upon closing the key switch **306**, the transistor T–5 becomes conductive, and effective as an amplifier because of base current "on" bias supplied from the plus 7 volt keying supply **308** through the key switch **206**, electrolytic capacitor C–6, isolating diode D–1 and resistor R–6. The bias current, however, can only flow until capacitor C–6 is fully charged. As capacitor C–6 is charging, the bias current, and therefore, the amplification of the transistor, will be maximum at the outset and then gradually diminish.

The rate of capacitor C–6's charging is determined in part by the amount of current flowing in the base-emitter circuit of the transistor T–5, but is also dependent upon, and is controlled primarily by, the resistance of resistor R–3. Almost immediately upon closing the key switch, ca-

pacitor C–7 becomes fully charged because its capacitance is much smaller than the capacitance C–6. As capacitor C–6 gradually charges, capacitor C–7 will gradually discharge until eventually capacitor C–6 will be fully charged and capacitor C–7 will be fully discharged.

If, however, the key switch 306 is released or opened before capacitor C–6 has become fully charged, capacitor C–7 will now discharge through resistor R–6 and the base-emitter circuit of the transistor and therefore continue the amplification of the transistor, which decreases quickly but not instantaneously. Because of the proportions of C–7 and R–6, the actual decay will be equivalent to the decay of a piano string damped by a felt damper. Diode D–1 is provided for the purpose of preventing C–7 from being quickly discharged by resistor R–3 and by a circuit through R–7 and D–2.

If the key switch is released and then quickly closed again, it is necessary that the tone immediately restrike at its full intensity. In order to accompish this it is necessary that C–6 be instantly discharged whenever the key switch is opened. For this purpose, a discharge path including diode D–3 and resistor R–8 is provided.

Resistor R–7 and diode D–2 form a "snubbing" circuit for the purpose of shaping the decay envelope to make it conform to the decay envelope of a real piano string. If the snubbing bus is connected to a fixed voltage such as plus 3 volts, the initial charging of capacitor C–6 upon the closing of the key switch will be accelerated due to current from the plus 3 volt supply bus 310 through diode D–2 and resistor R–7. However, when capacitor C–6 becomes a little less than one-half charged, the voltage across the diode D–2 will be of such polarity that this diode will open circuit, and the rest of the charging current for C–6 must come through the transistor emitter-base circuit, and through R–3. By carefully adjusting the proportions of R–3 and R–6, and the snubbing voltage of bus 310, it is possible to reproduce faithfully the sudden strike, rapid initial and slower later decay of the sound that is typical of the piano.

Finally, the vernier resistor R–9 is for the purpose of shifting the threshold bias of the gate in the direction toward delivery of signal when switch is closed, and providing a smoother decay characteristic, and at the same time allowing the open-key bias to be adjusted to a more positive cut-off of the gate when the key switch is open.

Audio output bus 302, potentiometer bus 304, and snubbing bus 310 may be sectionalized to serve a group of notes, for convenience in connection with their cooperation with other components.

The 15 volt supply bus 212 need not be sectionalized.

The closure of switch 306 generates a strong electronic transient, which would be objectionable if it appeared in the signal output. It is reduced and modified materially by resistor R–6 and capacitor C–4, and its energy distribution is further modified by the filters 16.

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 a sound control circuit for an electrical musical instrument, the combination comprising: a source of direct current potential; a reference point of ground potential; first and second normally closed switches connected in series with a first diode, a first resistance, and a charge storage element, said series connection being connected from said source of potential to said reference point, and said second switch being operable by a playing key of said instrument and said first switch being operable by a sustain pedal of said instrument; and an output coupled through a resistance to a junction between said first charge storage element and said first resistance.

2. In an electronic musical instrument, in combination: a source of complex pulsed signal of constant frequency; a gate adapted to receive said signal; said gate having a control terminal and being adapted to pass a variable portion of the received signal, depending on the potential of said control terminal; said gate being adapted to pass all of each excursion of said signal in excess of a minimum determined as a function of the potential of said control terminal; a source of D.C. control potential; a main line circuit from said source of D.C. potential to said gate control terminal; said main line circuit having a playing key switch for connecting and disconnecting it to said potential source; then a primary decay timing capacitor; then an isolating diode; then a strike and timing resistor for timing the strike and damping; and then said control terminal; a branch circuit comprising a strike capacitor connected from line to ground between said strike and damping resistor and said control terminal; a branch circuit comprising a damping capacitor connected from line to ground between said isolating diode and said strike and damping resistor; a snubbing branch circuit between said primary capacitor and said isolating diode; a snubbing bus kept at constant D.C. potential intermediate between ground and supply potential; said snubbing circuit including a resistor and a diode in series and being connected to said snubbing bus; said diode being oriented to permit flow in the direction to reduce line potential, but not to increase it; and a high speed repeater branch circuit in shunt around said primary timing capacitor; said repeater circuit comprising a repeat resistor connecting one plate of said primary timing capacitor to ground; a return conductor connecting the grounded end of said repeat resistor to the other plate of said timing capacitor, and an isolating diode in said return conductor to permit charging of said primary capacitor and prevent grounding of said main line.

3. In an electronic musical instrument, equipment for generating a musical note having substantially the harmonic structure and tonal characteristics of a pianoforte, comprising, in combination: generating means for producing a signal of recurrent pulses; transducer means for receiving a signal and translating it into sound; a signal transmission channel connected from said generator means to said transducer means; gating means interpolated in said channel between said generator means and said transducer means; means operatively associated with said channel for generating an electronic transient at the inception of a note; and filter means associated with said channel for modifying the transient signal energy distribution, and to increase the relative prominence of the second, third, fourth, fifth and sixth harmonics.

4. An electronic musical instrument comprising, in combination: a multiplicity of signal sources, one for each of a multiplicity of consecutive semi-tones; said sources each delivering a wave of complex shape; a gate for each source consisting of resistors and semi-conductors; each gate having a control terminal and being adapted to deliver a signal received from its associated source with amplitude determined by the potential of said control terminal; transducing means adapted to receive said signals from a plurality of said sources and generate acoustic oscillations corresponding to the composite signal received from said sources; and a control unit for each gate; each control unit including a playing key; a first means rendered operative by depressing said key, for changing the terminal potential to render said gate conductive and transmit said signal; a second means for gradually restoring the potential at which said gate is nonconductive, identified as cut-off potential; and a third means, rendered operative by releasing said key, for restoring cut-off potential quickly, in the approximate time interval corresponding to the decay of a damped piano string of the same pitch.

5. A combination according to claim 4 in combination with an additional restoring circuit operatively associated with said gate, and having a short time constant for quickly changing the potential in the direction of cut-off, whenever the potential rises above a predetermined value.

6. A combination according to claim 4 in which said control unit first means comprises a strike circuit connected

to the potential for rendering said gate conductive; and automatic means activated by movement of said key to depressed condition for rendering said strike circuit momentarily operative.

7. A combination according to claim 6 in which said strike circuit includes a transistor having its emitter and collector connected into said strike circuit; a capacitor; a ciruit for disharging said capacitor to the base of said transistor to render said transistor conductive only until the capacitor charge is spent; a key switch in said last mentioned circuit for rendering it operative or inoperative; and means activated by releasing said key for restoring the capacitor charge.

8. A combination according to claim 4, in combination with player-controlled means for rendering said third restoring means for all said sources inoperative, regardless of the condition of said keys; said last mentioned means comprising a sustain foot pedal; said third restoring means being an electric circuit; and means actuated by said foot pedal for rendering said third restoring circuits of all said sources inoperative, independently of said keys.

9. A combination according to claim 4 in which said gate is an amplifying transistor connected as a common base amplifier; said control terminal being electrically connected to said transistor; said transistor being adapted to amplify the signal in a variable ratio determined by the potential of its control terminal.

10. A combination according to claim 9; in combination with an independent source of D.C. potential intermediate between maximum and cut-off values; and a fourth, snubbing circuit, operatively connected to said intermediate source and adapted to change potential in the direction of cut-off more rapidly than said third restoring circuit, only as long as the potential of said gate terminal is at greater value than said intermediate source.

11. A combination according to claim 10 in which said fourth, snubbing circuit includes a diode adapted to prevent reverse current flow when said transistor terminal is at potentials nearer cut-off than said intermediate D.C. potential source.

12. A combination according to claim 10; in combination with a fifth, cut-off biasing circuit adapted, in the absence of potential from said closed-key circuit, to maintain said transistor biased close to or beyond cut-off potential.

13. A combination according to claim 12; in combination with a sixth, playing-key activated vernier biasing circuit, adapted to shift the bias of said terminal from its open-key bias value in the direction for opening the gate.

14. A combination according to claim 4, in combination with means adapted, in the absence of potential from said key circuit when closed, to maintain said gate beyond cut-off potential; and a vernier biasing means rendered operative by closing said key circuit, for shifting the threshold bias of said gate in the direction toward the delivery of signal while said switch is closed; thereby providing a smoother decay characteristic, and at the same time allowing the open-key bias to be adjusted to a more positive cut-off of the gate when the key switch is open.

No references cited.

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U.S. Cl. X.R.

84—1.17, 1.26

# UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,444,306 May 13, 1969

Richard H. Peterson

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

Column 1, line 25, "including" should read -- includes --; line 33, "of the tone" should read -- of tone --; line 69, "Figure 1, the embodiment" should read -- Figure 1, in the embodiment --. Column 2, line 6, before "or" insert an opening parenthesis; line 17, "filter unit, 16" should read -- filter unit 16, --; line 64, after "50" insert a comma. Column 4, line 36, "sufficietly" should read -- sufficiently --; line 67, "automtically" should read -- automatically --. Column 5, line 61, "become" should read -- becomes --. Column 7, line 55, "wave, form" should read -- wave form --. Column 8, line 4, "dsirable" should read -- desirable --; line 25, "Figures" should read -- Figure --; line 64, "206" should read -- 306 --. Column 9, line 49, "212" should read -- 312 --.

Signed and sealed this 27th day of October 1970.

(SEAL)
Attest:

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