Oct. 25, 1949. A. R. RIENSTRA 2,486,208

ELECTRONIC MUSICAL INSTRUMENT

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FIG.1.

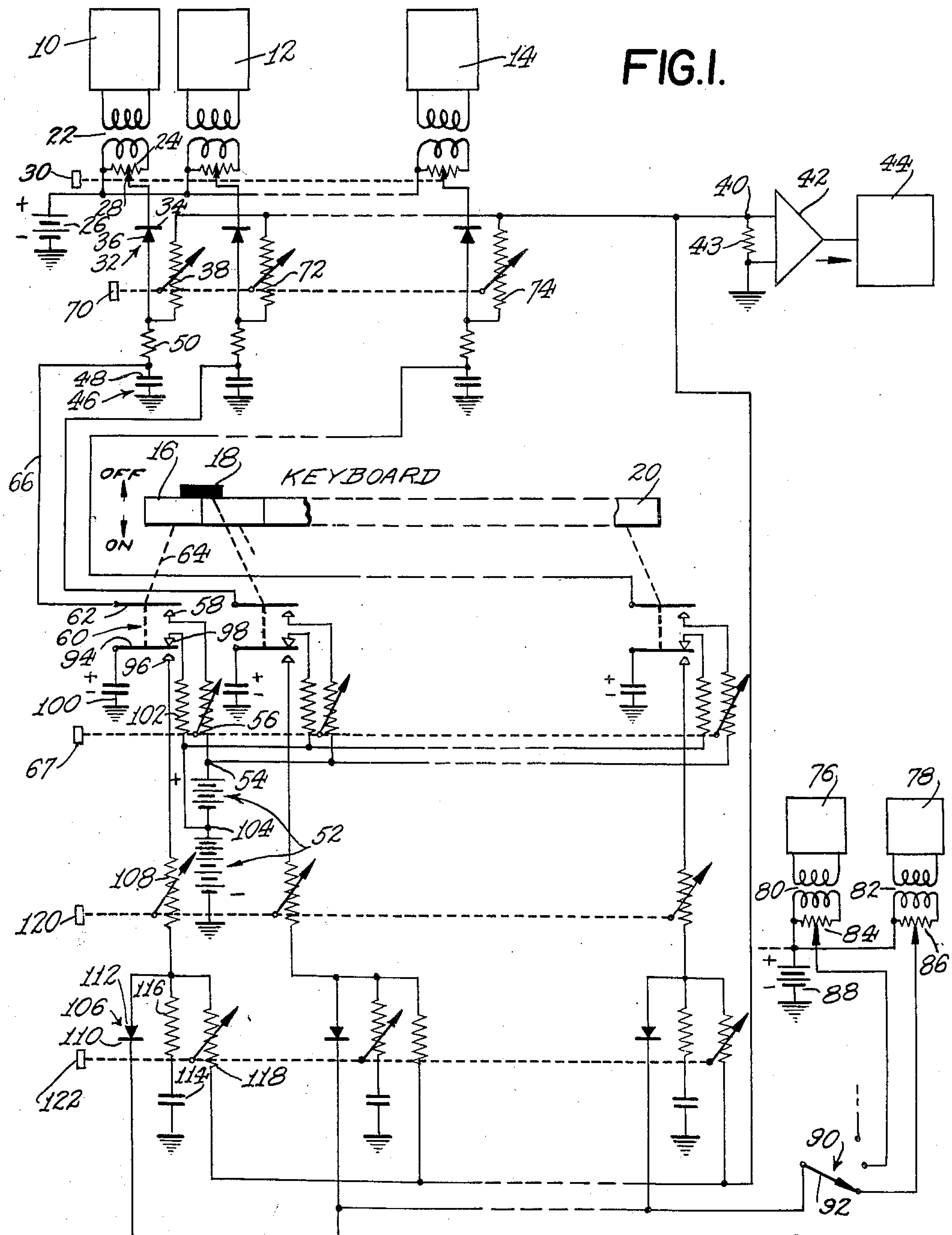

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FIG. 2.

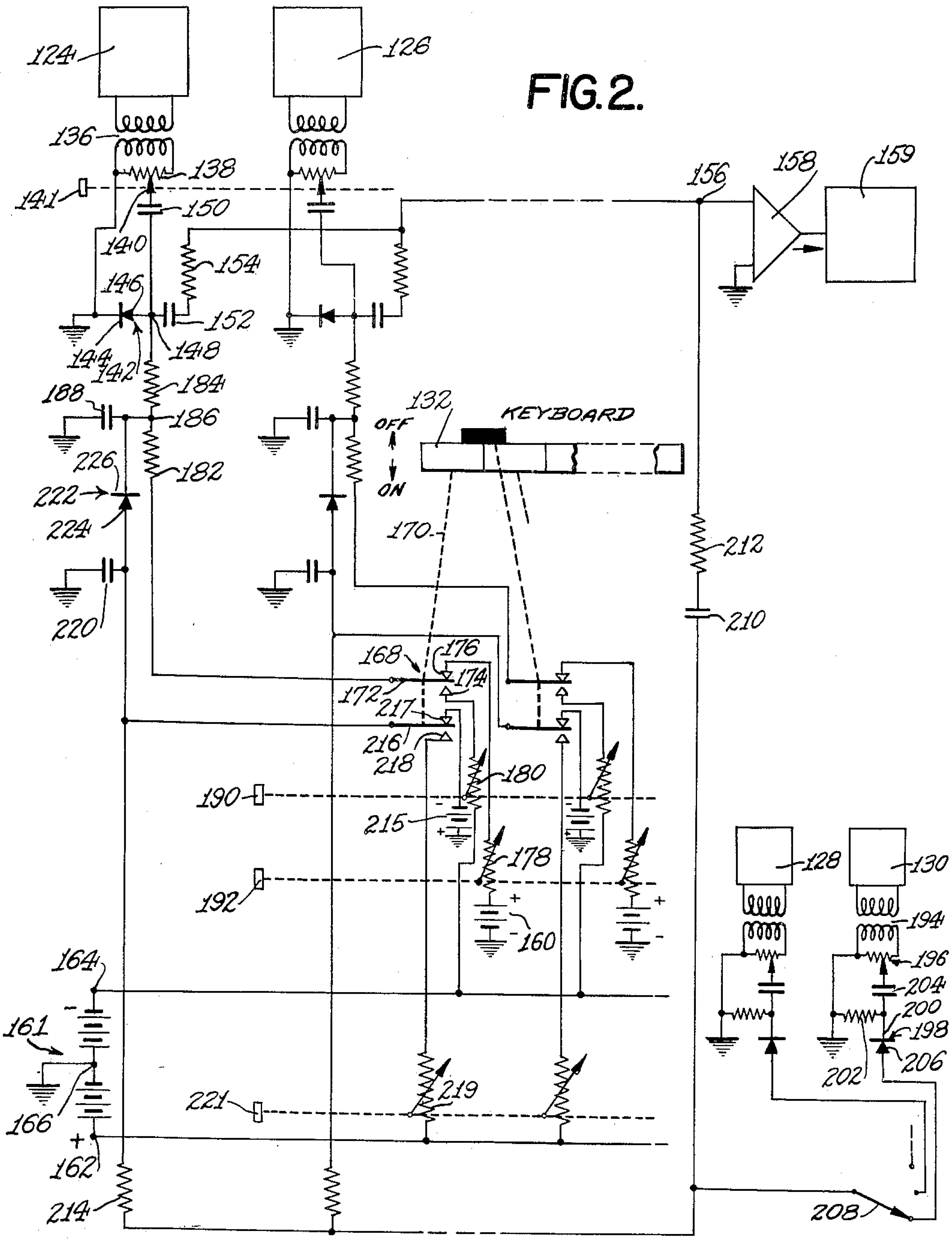

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FIG. 3.

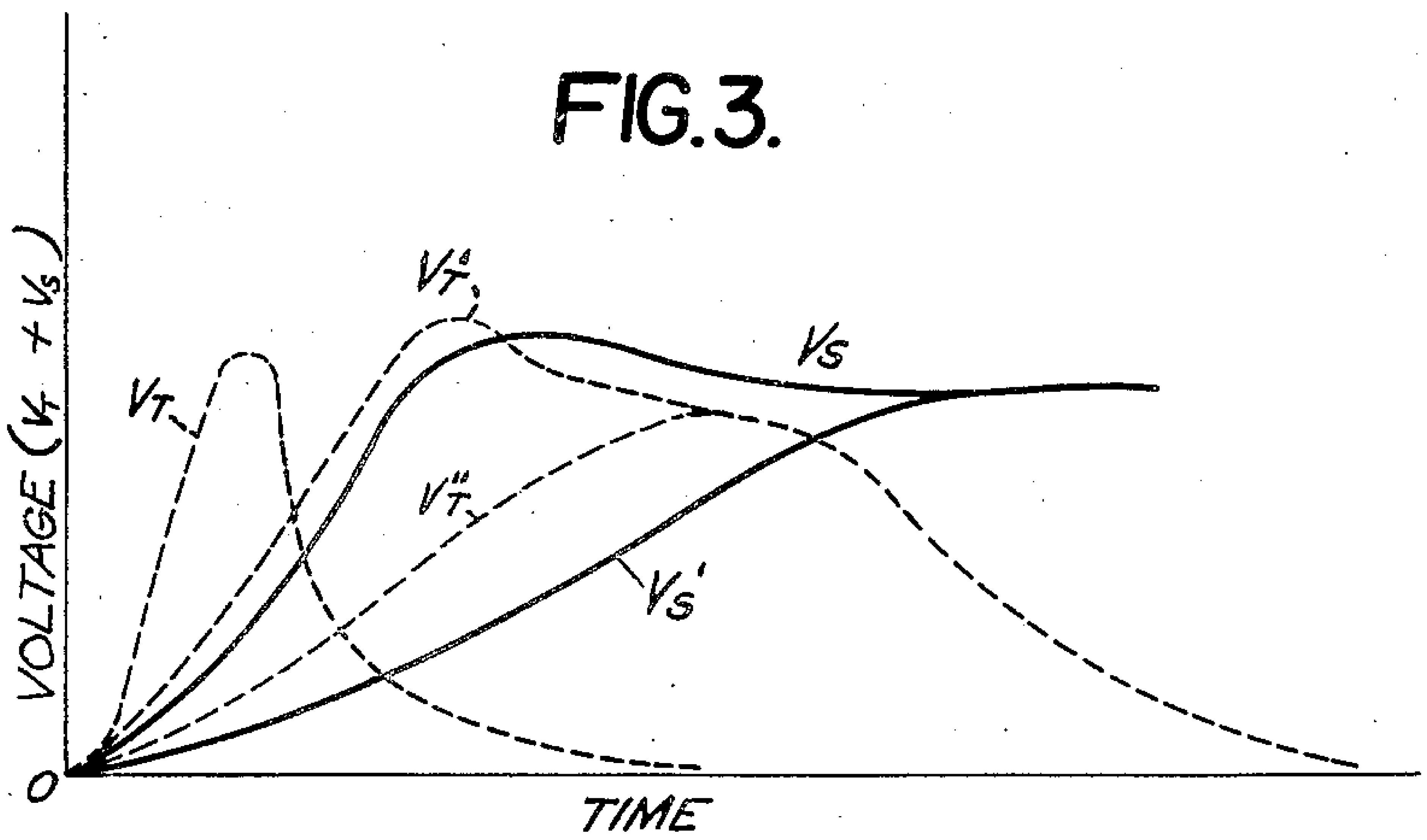

FIG. 4.

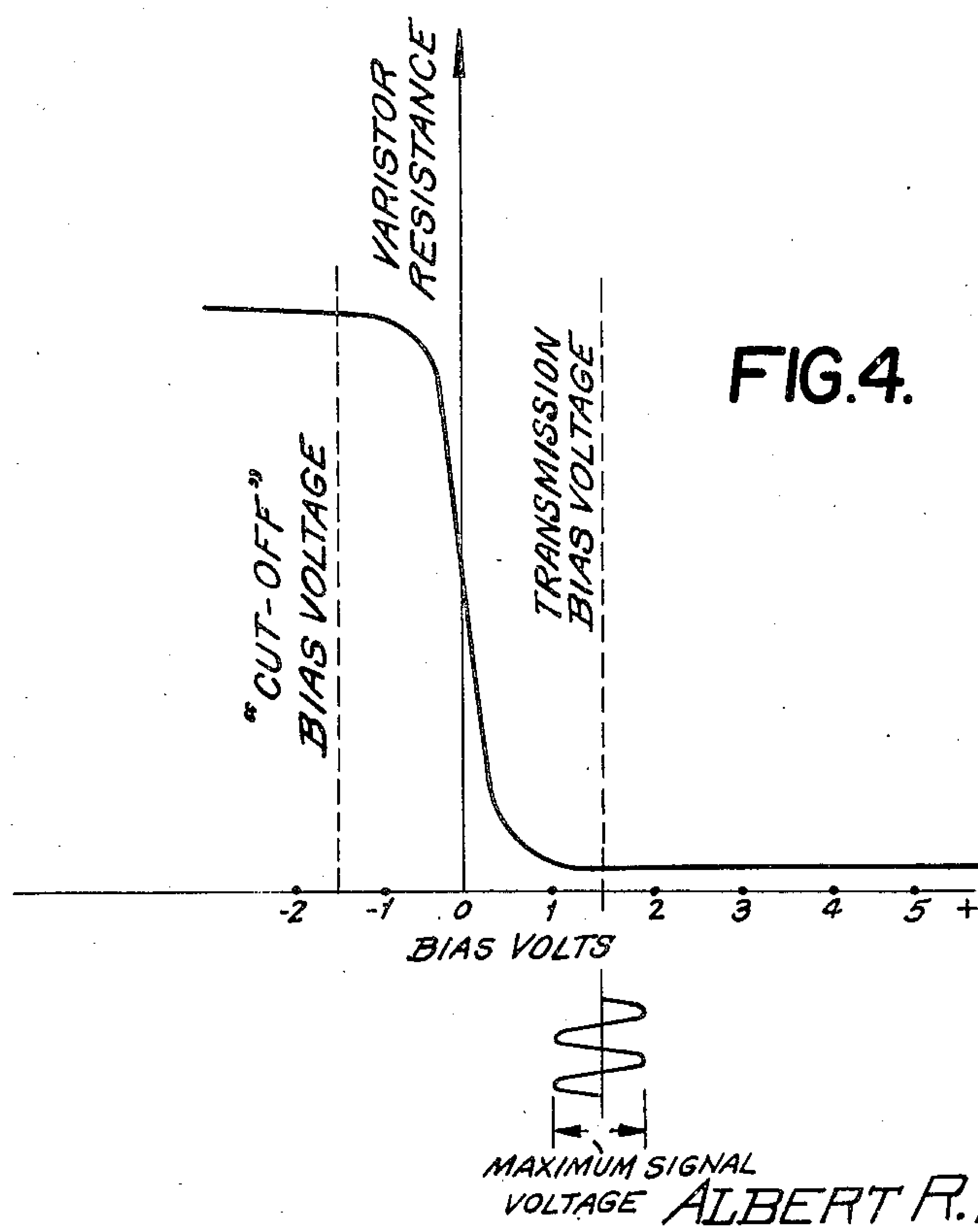

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FIG.5.

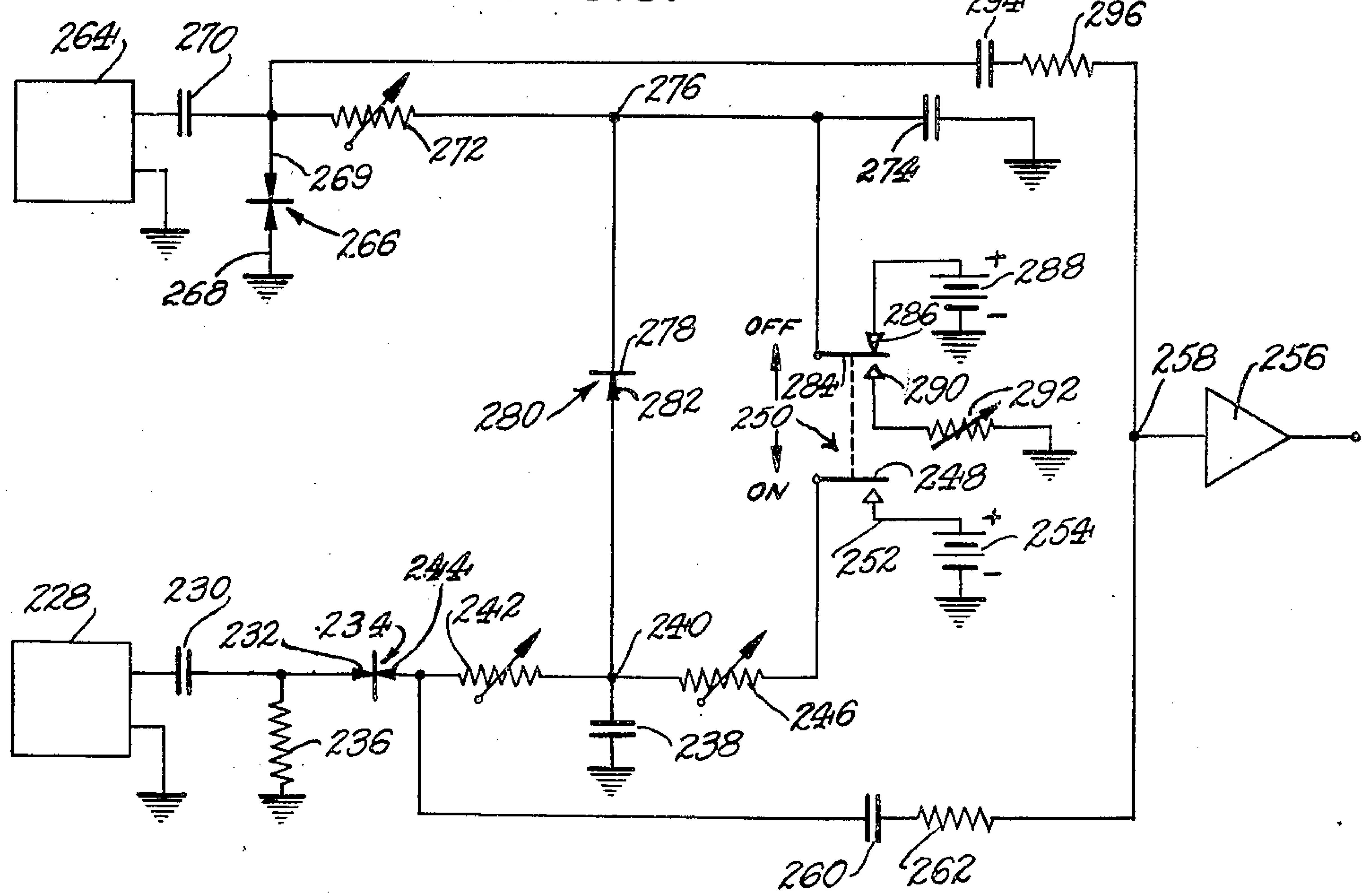
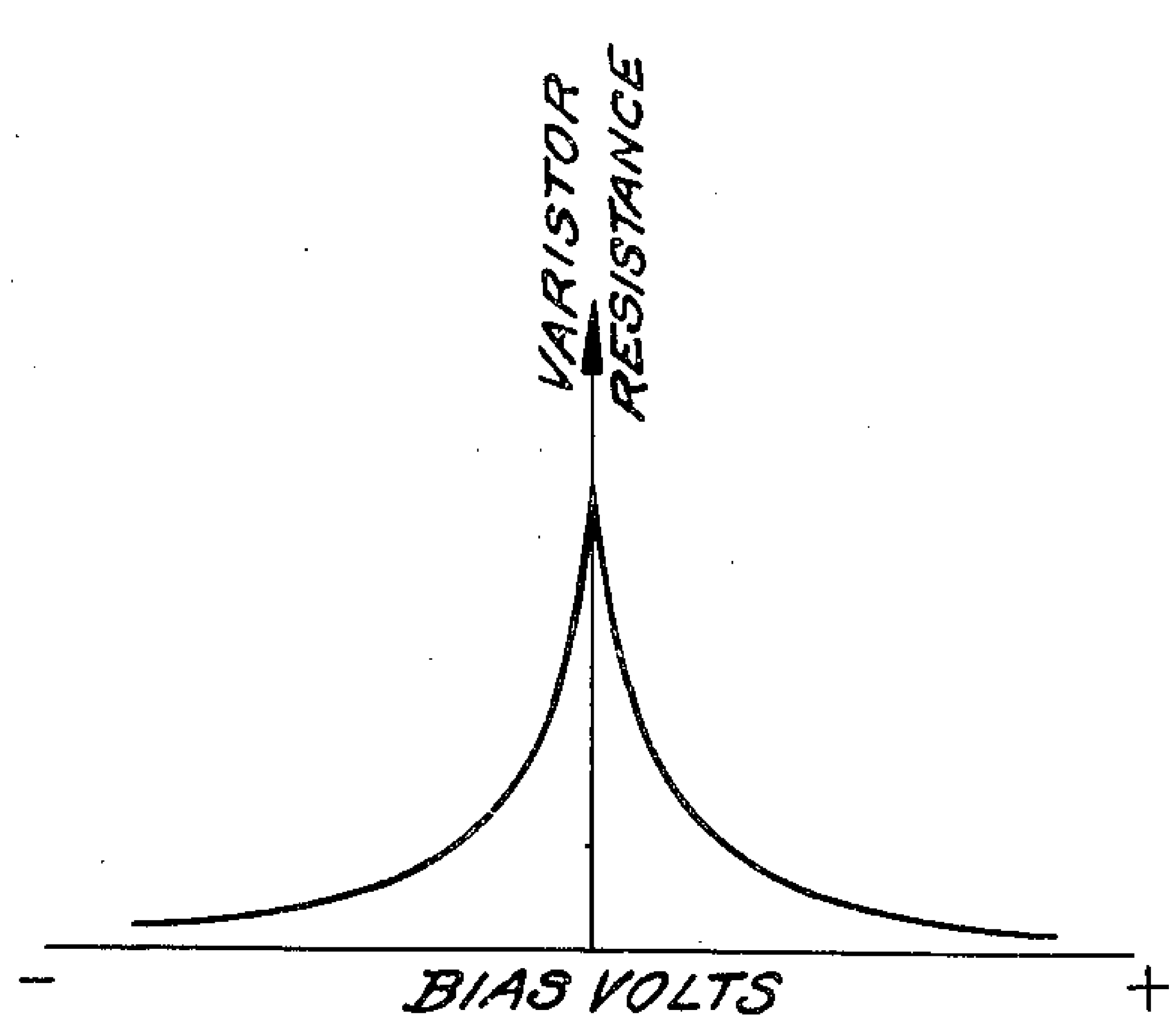


FIG.6.



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ELECTRONIC MUSICAL INSTRUMENT

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Application August 23, 1947, Serial No. 770,299

11 Claims. (Cl. 84—1.26)

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The present invention relates to electrical apparatus for producing signals in timed relationship, and is particularly applicable to electronic musical instruments.

Electronic musical instruments are frequently employed in an effort to imitate particular instruments of the ordinary type. One difficulty encountered in this connection is that although a tone may be produced which for a considerable portion of its duration simulates a tone of an imitated instrument, there are certain sounds occurring at the beginning of a tone produced by an ordinary musical instrument which are not normally present at the beginning of a tone produced by an electronic musical instrument. For example, at the beginning of a note produced by a flute, there will usually be present in considerable quantity the second harmonic of the note in question. As another example, at the beginning of a tone produced by a wind instrument, there is usually present a considerable hiss or wind noise. These noises or sounds are of considerable importance in enabling the listener to identify the tone as corresponding to that of a particular musical instrument.

An object of the present invention is to provide, in electronic musical instruments, circuit means for introducing transient effects in an electrically generated musical tone, particularly at the start of the tone, to characterize that tone so that a listener will identify it as belonging to some particular musical instrument.

Another object of the invention is to produce in timed relationship electrical signals having amplitudes which build up and decay, the decay of one signal having a predetermined relationship to the build-up of another signal.

In one embodiment of the present invention for use in an electronic musical instrument, there is provided a series of sources of electrical signals corresponding to the musical scale. These sources may for convenience be called steady state signal sources. There is also provided one or more sources of electrical signals corresponding to hiss or wind noise, for example, or signals of any other arbitrary form. These last-mentioned sources are employed for transient effects, particularly at the start of a tone, and may therefore be termed transient effect sources. The sources proper, of both types, may produce constant-amplitude signals at their own output terminals. There are provided, however, circuits including attenuating means coupling the sources of both types to an electro-acoustic output system for producing a tone, and the attenuating means

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are adapted to control as functions of time the effective amplitudes of the steady state and transient signals so that when a key is depressed and held down, the steady state signal has little initial effective amplitude and builds up gradually, and the transient signal is introduced for only a brief initial interval, and then decays and disappears, whereby toward the beginning of the tone, the transient effect of arbitrary wave form predominates, and thereafter during the major portion of the tone, the signal corresponding to a steady state tone predominates. The overall effect is to improve considerably the degree to which the electronic musical instrument simulates the imitated instrument.

In one embodiment of the invention it is possible to control the rate of build-up of the transient effect, the rate of decay of the transient effect, the rate of build-up of the signal corresponding to the steady state tone, the rate of decay of this signal, and the eventual amplitude of the steady state tone, all by independent controls. A novel feature of another embodiment of the invention is that the decay of the transient effect is determined by the build-up of the signal corresponding to the steady state tone.

The above-mentioned, as well as other objects, together with the many advantages obtainable by the practice of the present invention, will be readily comprehended by persons skilled in the art by reference to the following detailed description taken in connection with the annexed drawings which respectively describe and illustrate a preferred embodiment of the invention, and wherein

Fig. 1 is a schematic diagram of a system for producing an electrical signal having the properties described herein, and for producing a corresponding tone. As a part of the control means of the system, there is illustrated in front elevation, a keyboard, by means of which music may be played.

Fig. 2 is a schematic circuit diagram of a different embodiment of the present invention. In this system the build-up of the steady state signal is employed to control the decay of the transient signal.

Fig. 3 is a graph showing the variation with time of the envelope of typical transient and steady state components of electrical output signals which may be generated by the systems disclosed herein.

Fig. 4 is a graph of the resistance-versus-bias voltage characteristic of typical copper oxide rectifiers or varistors which may be used in certain embodiments of the apparatus.

Fig. 5 is a schematic circuit diagram of still another embodiment of the present invention, featuring the use of symmetrical varistors. In this system, also, the build-up of the steady state signal is employed to control the decay of the transient signal.

Fig. 6 is a graph of the resistance-versus-bias voltage characteristic of a typical symmetrical varistor, such as one of the silicon carbide type.

Embodiment shown in Fig. 1

Reference is made to Fig. 1 which may be assumed to represent schematically an electronic organ system. There is provided one or more sources of electrical signals which may correspond to notes of the musical scale. Such sources may comprise oscillators, and are represented in Fig. 1 by a series of sources **10**, **12** and **14**. Thus the source **10** may provide an electrical signal corresponding to the lowest note on an organ keyboard, the note C. The source **12** may correspond to the sharp of this note. The source **14** may produce a signal corresponding to the highest note on an organ keyboard. A whole series of sources providing signals of intermediate pitch may be provided, in order to produce an entire musical scale. There is provided a keyboard, including the keys **16**, **18**, and **20**, which respectively control circuits associated with the sources **10**, **12** and **14**. In the keyboard, which is schematically shown in front elevation, the key **16** may be considered to represent a white key at the extreme left-hand or lower end of the scale, while the key **20** represents a white key at the extreme right-hand or upper end of the scale. The key **18** is a black key, and the note produced thereby is the sharp of the note produced by the key **16**. Thus the key **18** controls circuits associated with the source **12**.

For the sake of simplicity, the system will be described primarily in connection with the elements controlled by the key **16**, but it will be, of course, understood that a plurality of keys may be depressed simultaneously.

The signal from the source **10** is applied through a transformer **22** to a potentiometer **24**. One end of this potentiometer may be biased to a small positive potential with respect to ground by a source of direct current potential **26**. The amount of this bias may conveniently be of the order of 1.5 volts. For controlling the amplitude of the steady state signal derived from the source **10**, and thereby controlling the amplitude to which the tone derived from this source eventually builds up, the voltage across the potentiometer **24** may be tapped off at its slider **28**, the position of which may be adjusted by a control **30**, which may be termed a steady state tone source voltage control. The transformer **22**, and the potentiometer **24**, should be arranged to provide a low impedance level at the slider **28**. The impedance level at this point may, for example, be about 10 ohms. There is provided a bias controllable impedance device such as a varistor or rectifier **32**, which may, for example, be of the copper oxide type, having a terminal **34** connected to the slider **28** and a terminal **36** connected through a large variable resistor **38**, of say 50,000 ohms, to a point **40** of the input circuit of an amplifier **42**. As a part of this input circuit, a resistor **43** of, for example, 600 ohms, is connected between the point **40** and ground. The output of the amplifier **42** is applied to an electro-acoustic output system, **44**, adapted to convert electrical signals into sound. The point **40** may be considered an output point for the electrical signal generating section of the system.

The resistance-versus-bias characteristic of a varistor such as **32** is shown in Fig. 4. It may be noted that when properly biased such a varistor presents a very high resistance to current flow and when the bias is reversed, it presents a low resistance. The varistor **32** is so oriented that when its terminal **34** is biased positively with respect to its terminal **36**, it has a very high resistance. There is provided a capacitor **46**, which conveniently may be of the order of 100 microfarads, having its lower plate grounded and its upper plate **48** connected through a small resistor **50**, of, say, 20 ohms, to the terminal **36** of the varistor **32**.

There is provided a source of direct current potential such as **52**, having its negative terminal grounded and a rather strongly positive terminal **54** connected through a variable resistor **56** to a contact **58** of a switch **60**. The positive direct current potential at the point **54** may conveniently be approximately 90 volts, and the resistor **56** may be of the order of 80,000 ohms. The switch **60** is provided with a movable contact arm **62** mechanically connected to the key **16** by suitable means **64**. When the key **16** is depressed into the down or on position, the contact arm **62** is adapted to move downwardly to engage the contact **58**. When the key **16** is released, the contact arm **62** moves upwardly and is disengaged from the contact **58**. The contact arm **62** is connected by a lead **66** to the upper, ungrounded plate **48** of the capacitor **46**.

When the key **16** is in the up or off position, the lower end of the lead **66** may be considered open-circuited. Under this condition, the direct current source **26** biases the terminal **34** of the varistor **32** above the terminal **36** to such an extent that this varistor has a very high resistance and may be considered practically non-conducting. More specifically, the varistor may be considered biased to the "cut-off" condition indicated in Fig. 4, or even beyond this point, that is, to the left thereof on the graph. Since this varistor is in series with the signal from the source **10**, this signal is unable to reach the amplifier **42**, and hence the steady state tone is not produced before the keys are depressed.

When the key **16** is depressed, the switch **60** closes the contact between the elements **58** and **62**, and the direct current source **52** gradually charges the upper plate **48** of the capacitor **46**, through the resistor **56**, to an increasingly positive potential. Under this condition the bias effect of the direct current source **26** on the varistor **32** is gradually overcome; that is, the terminal **36** of the varistor **32** is raised to a positive potential with respect to that of the terminal **34**. The varistor therefore gradually moves from a bias condition corresponding to the left-hand side of the diagram shown in Fig. 4 in which its resistance is high, to a bias condition corresponding to the right-hand side of this diagram in which its resistance is low. In Fig. 4 the bias position marked "transmission bias voltage" indicates a point to which the bias may satisfactorily move. In the usually preferred mode of operation, the amplitude of signal voltage at the varistor should have a maximum value small enough so as not to swing the varistor back into the sloping portion of the characteristic, as indicated in Fig. 4. As a result of the change in bias after the key is depressed, the steady state tone signal from the source 10 may, to an increasing degree, pass through the varistor 32 and be applied, through the resistor 38, to the point 40 of the input circuit of the amplifier 42. Thus the steady state tone signal delivered to the amplifier 42 will build up until the capacitor 46 becomes charged to the full potential of the direct current source 52, after which time its amplitude will remain relatively constant. The rate of build-up of this signal is determined by the rate at which the direct current source 52 charges the capacitor 46 through the variable resistor 56, which rate in turn is determined by the time constant of this circuit. This time constant is substantially proportional to the product of the capacitance of the capacitor 46 and the resistance of the resistor 56. The rate of building up of this steady tone signal may be controlled by controlling the value of the resistor 56. Means, such as a control 67, are provided for manually adjusting the setting of this resistor. This control may be ganged to control other resistors corresponding to 56 for regulating the build-up rate of signals from other steady state tone sources such as 12 and 14.

When the key 16 is released and the contact between the elements 58 and 62 is broken, the positive potential on the plate 48 of the capacitor 46 will decrease as this capacitor discharges. In the illustrated embodiment the major discharge path will be through the resistor 50, the resistor 38 and the resistor 43 of the input circuit of the amplifier 42. For a short interval after the key 16 is released, there will also be a discharge path through the varistor 32, the potentiometer 24, and the bias source 26, to ground, but as the resistance of the varistor 32 increases, this discharge path diminishes in importance. As the capacitor 46 discharges, the varistor 32 returns to its original bias condition in which its terminal 34 is biased above its terminal 36 because of the effect of the source 26, and hence the signal from the source 10 is increasingly attenuated by the varistor 32 until effectively none of it reaches the amplifier 42. In order to control the rate of decay of the signal, the resistor 38 may be varied by means such as a tone source decay rate control 70. It will be understood that signals from other sources such as 12 and 14 may be applied by similar means to the amplifier 42 through resistors such as 72 and 74. The control 70 may be adapted to control the resistors 38, 72 and 74 simultaneously, by a ganged arrangement. On the otherhand, if desired, the apparatus may be modified to allow these resistors to be independently controlled, to allow signals from various sources such as 10, 12, and 14 to decay at different rates. The same is true with respect to control of the build-up rates for these various sources.

In addition to the sources of steady state tone signals, such as 10, 12, and 14, there are provided one or more sources of electrical signals of arbitrary wave form, such as 76 and 78, corresponding to wind sound, harmonics of various notes, noise, sounds such as that produced by a violin bow at the beginning of a stroke, a hiss, overtones, or any other signal which it is desired to apply to the amplifier 42 and the electro-acoustic output system 44 for a brief interval, say, one-half second, near the beginning of the tone. By way of further example, the noise thus introduced may be similar to thermal noise.

It is to be noted that with the present invention it is possible to introduce, from sources such as 76 and 78, signals other than harmonics of the steady tone signals. It is thus possible to obtain results considerably different from those which would be obtained if only harmonics of the steady tone signals could be introduced as transient effects.

The voltage outputs from the sources 76 and 78 are applied, through transformers 80 and 82, respectively, across potentiometers 84 and 86. The impedance level at the sliders of these poteniometers should be very low, for example, 10 ohms. To one end of each of these poteniometers is connected a source 88 of direct current bias potential of, for example, 1.5 volts, having its other terminal grounded. There is provided a selector switch 90 having a series of contacts to which the sliders of the poteniometers are connected, and a movable arm 92 which may be positioned to select the output voltage from any desired source of arbitrary wave form such as 76 and 78. In the present illustration it may be assumed that the arm 92 is in position to select the output voltage from the source 78. The arm 92 may be connected to circuits controlled by all of the keys of the keyboard. The present discussion, for simplicity, will be largely limited to the effect of the arbitrary wave form introduced into circuits controlled by the key 16. As part of the switch 60, there is provided a movable arm 94, ganged with the arm 62. When the key 16 is up, the arm 94 is moved upwardly, that is, into the off position. Cooperating with the arm 94 are a pair of contacts 96 and 98. The arm 94 engages the contact 98 when in the off position, and the contact 96 when in the on position. There is provided a capacitor 100, which may conveniently be of the order of 50 microfarads, having one plate grounded and its other plate connected to the arm 94. There is provided a resistor 102, which may satisfactorily be about 200 ohms, one end of which is connected to an intermediate positive potential point 104 of the direct current source 52, and the other end of which is connected to the contact 98. The potential of the point 104 may conveniently be of the order of 45 volts. The arm 92 of the selector switch 90 is connected through a bias controllable impedance device such as a varistor 106 and a variable resistor 108 to the contact 96 of the switch 60. The variable resistor 108 may satisfactorily be of the order of 6000 ohms. The terminals of the varistor 106 may be designated as 110 and 112. When the terminal 110, which is connected to the arm 92, is at a positive bias potential with respect to the potential of the terminal 112, which is connected to the resistor 108, the resistance of the varistor is very high. The resistance of the varistor is quite low when the potential of the terminal 110 is negative with respect to that of the terminal 112.

There is provided a capacitor 114 of, for example, 100 microfarads, one plate of which is grounded and the other plate of which is connected through a resistor 116 of, for example, 30 ohms, to the terminal 112 of the varistor 106. This terminal is connected through a large variable resistor 118 to the point 40 of the input circuit of the amplifier 42. The resistor 118 may satisfactorily have a value of approximately 25,000 ohms.

The action of the circuits adapted to apply the transient effect of arbitrary wave form will now be described. When the key 16 is in the up or off position, before having been depressed, the arm 94 is up, and the capacitor 100 becomes charged to the potential of the point 104 of the source 52. The potential of the terminal 112 of the varistor 106 is under this condition substantially ground, since it is disconnected at the contact 96 of the switch 60 from the capacitor 100, and since it is connected through the resistor 118 and the resistor 43 of the input circuit of the amplifier 42 to ground. It is recalled that no potential is being applied to the point 40 from the steady state section of the system, under this condition. The terminal 110 of the varistor 106 is biased to a slight positive potential by the action of the direct current source 88, and therefore the varistor has under this condition a high resistance. This high resistance in series with the source 78 prevents a signal from this source reaching the amplifier 42 before the key is depressed, as desired.

When the key 16 is depressed the arm 94 of the switch 60 is moved downwardly, thereby connecting the capacitor 100 to the contact 96. This capacitor, previous to this switching operation will have been charged to the voltage at the point 104. The capacitor 114, previous to this switching operation, bore no effective charge. After switching, the capacitor 114 will become charged through the resistors 116 and 108, from the capacitor 100. The setting of the variable resistor 108 may be used to control the rate at which the capacitor 114 becomes charged, and for adjusting this resistor there is provided a control 120 which may be termed a transient source build-up rate control.

The potential at the terminal 112 of the varistor 106 will be largely controlled by the potential at the upper plate of the capacitor 114. As this capacitor is charged by the capacitor 100 after the key 16 is depressed, the potential at terminal 112 of the varistor 110 rises rather quickly. It will, however, shortly drop, as the charge on the capacitor 114, and also the charge on the capacitor 100, leak off. One path for this leakage is through the resistors 118 and 43. During the early portion of its leakage, there will also be some discharge through the varistor 106, the potentiometer 86, and the source 88, but when the potential of the terminal 112 approaches that of the terminal 110, there is very little leakage through this path. The potential at the terminal 112 continues to drop as a result of the leakage through the resistors 118 and 43, and approaches ground. In this last stage the resistance of the varistor 106 is quite high. During the time when the potential at the terminal 112 is strongly positive, the resistance of this varistor is quite low, and the signal from the source 78 may readily pass through the varistor, thereafter passing through the resistor 118 to the point 40 of the input circuit of the amplifier 42. The circuits coupling the sources 10 and 78 to the point 40 may be viewed as an adding and attenuating network. When the potential at the terminal 112 drops sufficiently so that the resistance of the varistor again becomes high, the signal from the source 78 may no longer reach the amplifier 42. It may thus be seen that the varistor 106 comprises a bias-controllable impedance device or time-varying attenuator adapted to control the signal derived from the source 78, and that there is provided a source of transient bias, responsive to the key 16, connected to this varistor and adapted to apply thereto a bias which increases and then returns to its original value when the key is depressed and held down.

To control the rate of decay of the transient, there is provided a transient decay rate control 122, adapted to adjust the value of the variable resistor 118. This control 122 may also adjust simultaneously corresponding resistors in portions of the system responsive to different keys. In some cases the decay rate of the steady tone or the transient may be adjusted to correspond to the rate of decay of sound in a reverberant room. The various controls 30, 67, 70, 120, 122 and the selector switch 90 may be adjusted in relation to each other to obtain a desired overall effect.

The output signal at the point 40 may in general be considered to be a composite signal comprising a steady tone signal and a transient effect signal. The steady tone signal, after the key is depressed, has small initial amplitude, then increases in amplitude gradually, and is thereafter substantially constant. The transient effect signal rises steeply in amplitude after the key is depressed, and is then rather quickly attenuated and disappears. Thus toward the beginning of the note the transient effect predominates, while toward the end of the note the steady tone effect predominates. It will be understood that the steady tone signal may in many cases include various frequency components and the same is true for the transient signal.

In Fig. 3 the broken lines V_t, V_t' and V_t'', respectively, represent the variation with time, as the tone progresses, of the amplitude of the transient signal as a whole, at the point 40, for various combinations of circuit constants. In other words, the broken lines are in the nature of envelopes for the transient portion of the output signal. The solid lines V_s and V_s' have a corresponding significance for the steady tone signal. A composite output signal would be represented by the sum of one broken and one solid line.

The sound effects produced by the device disclosed may imitate a desired instrument much more closely than has heretofore been possible.

Embodiment shown in Fig. 2

In Fig. 2 there is illustrated a different embodiment of the present invention, characterized by the feature that the decay of the transient, instead of being controlled by an independent manually adjustable control, is determined by the build-up of the steady state signal.

In this embodiment there is provided one or more sources of signals corresponding to musical tones, such as 124 and 126, which may be referred to as steady state sources, and one or more transient effect sources of arbitrary wave form, such as 128 and 130. For convenience, the signals from the steady state source 124 and the transient effect source of arbitrary wave form 130, will be discussed in connection with their response to a key 132.

The signal from the steady state source 124 is applied through a transformer 136 across a potentiometer 138, one end of which is grounded. At the slider 140 of the potentiometer, the impedance level should be low, for example, 1000 ohms. There is provided a tone source voltage control 141 adapted to position the slider 140 for controlling the effective output derived from potentiometer 138. There is provided a varistor 142 having a terminal 144 grounded and its other terminal 146 connected to a point 148. This varistor is of the non-symmetrical type, having low resistance when the terminal 146 is at a positive potential with respect to the terminal 144, and high resistance when this bias is reversed. The point 148 is connected through a blocking capacitor 150 to the slider 140, and is connected through a blocking capacitor 152 and a resistor 154 to a point 156 of the input circuit of an amplifier 158. It may be seen that when the resistance of the varistor 142 is very low, this varistor will short-circuit the signal from the steady state source 124 to ground, preventing this signal from reaching the amplifier 158. On the other hand, if the resistance of this varistor is high, this signal is not shunted to ground, but may reach the amplifier. Connected to the output terminal of the amplifier 158 is an electroacoustic system 159.

There is provided means for controlling the bias of the varistor 142. As a part of such means there is provided a source 160 of positive direct current bias potential, conveniently of about 200 volts. There is also provided a source 161 of direct current potential, having a positive terminal 162, a negative terminal 164, and a grounded terminal 166. The potential available at the positive terminal 162 may be for example of the order of plus 90 volts, and that available at the negative terminal 164 may be somewhat greater, for example, minus 200 volts.

There is provided a switch 168 connected by suitable means such as 170 to the key 132, and adapted to be controlled thereby. This switch is provided with a movable arm 172, and a pair of contacts 174 and 176. When the key 132 is depressed, the arm 172 is moved downwardly to engage the contact 174, and when the key is released the arm 172 is moved upwardly and engages the contact 176. The contact 176 is connected through a variable resistor 178 to the positive terminal of the bias source 160, and the contact 174 is connected through a variable resistor 180 to the negative terminal 164 of the source 161. The resistor 180 may be set to have a resistance of, for example, 50,000 ohms.

The movable arm 172 is connected through resistors 182 and 184 to the point 148. The resistor 182 may have a typical value of 10,000 ohms, while 184 may be 30,000 ohms. The junction between the resistors 182 and 184, at 186, is connected to one plate of a capacitor 188, the other plate of which is grounded. A typical satisfactory value for the capacitor 188 is 20 microfarads. When such a value for this capacitor is used, the resistor 178 may be adjusted to have a value of 0.2 megohm, for example.

Before the key 132 is depressed the movable arm 172 of the switch 168 will be in the up or off position, engaging the contact 176. Assuming that the system has been in this condition long enough to reach a quiescent condition, the capacitor 188 will have become charged by the potential source 160. The positive potential consequently existing at the point 186 will serve to elevate the potential of the terminal 146 of the varistor 142, and this varistor is, as stated, so constructed and arranged that under this condition its resistance is quite low. It therefore shunts to ground the signal from the source 124 which would tend to reach the point 148.

When the key 132 is depressed the arm 172 is moved downwardly, into the on position, being disconnected from the source 160, and connected through the resistor 180 to the negative terminal 164 of the source 161. As a result, the capacitor 188 starts to discharge and to charge to opposite polarity through the resistors 182 and 180, the point 186 moving toward the negative potential available at the terminal 164. The rate of this discharge may be controlled by adjusting the value of the resistor 180. For this purpose there is provided a tone source build-up rate control 190. As the potential at the point 186 drops, the potential at the point 148 likewise drops, and moves toward a negative potential. When this effect has progressed sufficiently, the bias across the varistor 142 will reverse, and raise the resistance of this varistor to quite a high value. Under this condition, the varistor no longer short-circuits the output of the source 124, and this output may therefore reach the amplifier 158.

When the key 132 is released, the arm 172 of the switch 168 moves to the up or off position, again connecting the point 186 through the resistors 182 and 178 to the positive bias source 160. The condenser 188 will charge through the resistors 182 and 178 toward its original condition, the point 186 moving toward the positive potential available from the source 160. As a result, the bias across the varistor 142 will change so that its terminal 146 is biased positively with respect to its grounded terminal, and consequently the resistance of the varistor is again lowered. The varistor thus short-circuits the output from the steady state source 124, and the steady state tone decays. There is provided a tone source decay rate control 192 adapted to vary the value of the resistor 178, for the purpose of controlling the rate of discharge of the capacitor 188, and consequently the rate of decay of the steady state tone.

The means for applying a transient effect toward the beginning of the tone may now be considered. The output signal from the transient effect source of arbitrary wave form 130 is applied through a transformer 194 across a potentiometer 196, one end of which is grounded. There is provided a varistor 198, having a terminal 200 connected through a resistor 202, of for example 1000 ohms, to ground, and also connected through a blocking capacitor 204 to the slider of the potentiometer 196. The other terminal 206 of the varistor 198 is connected to one contact of a transient effect selector switch 208. Other transient effect sources of arbitrary wave form may be connected through similar networks to other contacts of the transient effect selector switch. The varistor 198 is of the non-symmetrical type, having low resistance when the terminal 206 is at a positive potential with respect to the terminal 200 and high resistance when this bias is reversed. It may be assumed that the selector switch is in position to select the signal from the source 130. It may be noted that the varistor 198 is in series with this signal. When the resistance of this varistor is high, so as to be virtually non-conducting, this signal may not pass through the varistor. When the resistance of the varistor 198 is low, this signal passes through it, and after passing through the switch 208, reaches the amplifier 158 through a path including a blocking capacitor 210 and a resistor 212, connected between the movable arm of the switch 208 and the point 156.

Means will now be described for controlling the bias on the varistor 198. The movable arm of the switch 208 is connected through a resistor 214 of, say 3000 ohms, to an arm 216 which is part of the switch 168, and which is ganged with the movable arm 172 thereof, being controlled in response to motion of the key 132. There is provided a source 215 of a small negative bias potential, for example of about 5 volts, having its negative terminal connected to a contact 217 of the switch 168. The arm 216 is adapted to engage the contact 217 when in the up or off position and to engage a contact 218 when in the down or on position. Connected to the arm 216 is one plate of a capacitor 220, the other plate of which is grounded. A typical value for this capacitor is 10 microfarads.

Before the key 132 is depressed, the arm 216 is connected to the source 215, and as a result, the ungrounded plate of the capacitor 220 becomes charged to the negative potential available from this source. This potential is impressed, through the resistor 214, on the terminal 206 of the varistor 198. This varistor is constructed and arranged so that under this condition its resistance is very high. As a result, signals from the source 130 do not then reach the amplifier 158.

The contact 218 is connected through a variable resistor 219, adjusted to have a value of, for example, 60,000 ohms, to the positive terminal 162 of the direct current source 161. When the key 132 is depressed, the arm 216 engages the contact 218, and as a result the ungrounded plate of the capacitor 220 charges through the resistor 219 toward the potential available at the terminal 162. An increasingly positive potential is therefore applied to the terminal 206 of the varistor 198, lowering the resistance of this varistor, and allowing the transient signal to build up at the point 156 in the input circuit of the amplifier 158.

There is provided a transient effect build-up rate control 221 adapted to adjust the setting of the variable resistor 219, thereby controlling the rate at which the capacitor 220 may charge, and hence the rate of build-up of the transient effect.

The ungrounded plate of the capacitor 220 is connected through a non-symmetrical varistor or rectifier 222 such as a copper-oxide rectifier, to the ungrounded plate of the capacitor 188. The varistor 222 is constructed and arranged so that when its terminal 224, which is connected to the capacitor 220, is biased negatively with respect to its terminal 226, which is connected to the capacitor 188, the resistance of the varistor is very high. As a result, when the switch 168 is in up or off position, or immediately after it is thrown to down or on position and before potentials on the capacitors 188 and 220 have changed substantially the varistor 222 may be considered substantially non-conducting. Consequently, when the ungrounded plate of the capacitor 220 moves rapidly toward the positive potential of the terminal 162, toward the very beginning of the tone, it does not affect the condition on the capacitor 188. Hence the build-up of the transient effect does not affect the build-up of the steady state effect.

Operation of the device will now be considered as the tone progresses, and it will be explained how the build-up of the steady state signal controls the decay of the transient signal. It has already been described how after the key 132 is depressed, the point 186 moves toward the negative potential of the terminal 164. When the potential of the point 186 drops sufficiently, then the terminal 226 of the varistor 222 moves toward a bias which is negative relative to that of the terminal 224 of this varistor. A moment soon arrives when the bias on the varistor 222 is reversed, and its resistance becomes low, instead of high. When the bias on the varistor 222 is thus reversed, it may be said that the build-up of the steady state source signal begins to control the decay of the transient effect signal. This is true because the potential at the point 186 begins to control, through the varistor 222, the potential on the capacitor 220, and through the resistor 214 the bias potential on the varistor 198. Thus the potential at the terminal 206 of the varistor 198 is caused to drop. As it approaches ground and moves below ground, the resistance of the varistor 198 becomes very high, and the signal from the transient effect source 130 may no longer pass through the varistor 198 and hence may not reach the amplifier 158.

By way of recapitulation, before the key 132 is depressed, the varistor 198 is biased to have high resistance and the varistor 142 is biased to have low resistance. At the very beginning of the tone, soon after the key 132 is depressed, the varistor 198 is biased to have low resistance, and hence an electrical signal corresponding to a transient effect, of wind noise, or the like, appears at the amplifier 158 and a corresponding sound appears at the output of the electro-acoustic system 195. The bias on the varistor 142 cannot change quickly, but changes gradually, to increase the resistance of this varistor. As a result, the steady state tone builds up gradually. Toward the beginning of the tone the steady state section of the system may not affect the transient effect section because the varistor 222 through which they are connected, is biased to have high resistance. As the tone progresses, and the steady state signal builds up, the bias on the varistor 222 is reversed, and the steady state section of the system reacts on the transient effect section of the system, to alter the bias of the varistor 198, thereby causing it to have high resistance, and causing the transient effect to decay, as desired.

Embodiment shown in Fig. 5

Another modification of the present invention is illustrated in Fig. 5, featuring the use of symmetrical varistors, such as those of the silicon carbide type. The resistance-versus-bias characteristic of such a varistor is illustrated by a graph in Fig. 6. It will be noted that when no bias is applied to the varistor, its resistance is high, while when a bias is applied in either direction, its resistance is low. This characteristic is to be contrasted with that illustrated in Fig. 4 for a non-symmetrical or rectifying type of varistor, wherein the polarity of the bias determines whether the resistance is high or low.

The system of Fig. 5 is, for convenience, shown in simplified form, but it will be understood that it may serve as the basis for a complete electronic organ employing a whole series of signal sources corresponding to the musical scale, and a complete keyboard.

In Fig. 5 there is shown a source 228 of electrical signals corresponding to a musical tone, coupled through a blocking capacitor 230 to a terminal 232 of an impedance device such as a symmetrical varistor 234, which may be of the silicon carbide type. A resistor 236 is connected from the terminal 232 to ground. There is provided a capacitor 238 having one plate grounded and having its other plate connected to a point 240 and thence through a variable resistor 242 to the other terminal 244 of the varistor 234. The point 240 is connected through a variable resistor 246 to a movable arm 248 of a switch 250, adapted to engage, when in the down position, a contact 252 connected to the positive terminal of a source of potential 254, the other terminal of which may be considered grounded. Assuming this system to be part of an electronic musical instrument, when the key of the instrument is depressed, the switch arm **248** will be in the down position, and when the key is released, the switch returns to the up position. Before the key is depressed, there will be zero bias potential applied to the varistor **234**, and hence the resistance of this varistor will be high. Since this varistor is connected in series with the source **228**, no signal from this source will reach the terminal **244** of this varistor. When the switch arm **248** is depressed, current from the positive terminal of the potential source **254** will charge the capacitor **238** through the resistor **246** so that point **240** rises to a positive potential. As a result, a bias is applied across the varistor **234**, and its resistance is lowered, so that signals from the source **228** may reach the terminal **244**. There is provided an amplifier **256**, and signals from the terminal **244** are applied to a point **258** of the input circuit of this amplifier through a blocking or coupling capacitor **260** and a resistor **262**.

The build-up of the steady tone signal is substantially determined by the time constant of the resistor **246** and capacitor **238**, and may be controlled by varying the value of this resistor.

There is provided a source **264** of a signal of arbitrary wave form, which may correspond to noise or the like. It may be assumed, as heretofore, that it is desired to introduce a transient signal from this source during a short interval following depression of a key on the instrument. There is provided a bias-controllable impedance device, such as a symmetrical varistor **266**, which may conveniently be of the silicon carbide type, having a terminal **268** grounded, and a terminal **269** connected through a blocking capacitor **270** to the source **264**. The varistor **266** may thus be considered to be in shunt with the source **264**. Connected to the terminal **269** of the varistor **266** through a variable resistor **272** is a capacitor **274**, having one plate grounded. The junction between the resistor **272** and the connection to the ungrounded plate of the capacitor **274** may be designated as a point **276**. The point **276** is connected to a terminal **278** of a rectifying or non-symmetrical bias controllable impedance device **280**, which may conveniently be a copper-oxide type of varistor. The other terminal **282**, of this device, is connected to the point **240**. The purpose of the varistor **280** is to provide means whereby the build-up of the steady state signal may control the decay of the transient signal. The non-symmetrical varistor **280** is arranged so that when its terminal **278** is biased to a positive potential with respect to its terminal **282**, it has high resistance, while when the terminal **282** is at a positive potential with respect to the terminal **278**, the varistor has low resistance. Means are provided whereby the capacitor **274** may be charged, in order to supply the bias to the varistor **266**, and may be discharged. As a part of such means there is provided a switch arm **284**, which may be ganged with the switch arm **248**. The switch arm **284** is connected to the point **276**. When this arm is in the up position, it is adapted to engage a contact **286** connected to the positive terminal of a source **288** of direct current potential. When it is in the down position it is adapted to engage a contact **290**, connected through a variable resistor **292** to ground. The terminal **269** of the varistor **266** is connected to the point **258** through a blocking or coupling capacitor **294** and a resistor **296**.

The build-up of the steady signal when the key is depressed has already been described. The operation of the transient section of the system may now be considered. Before the key is depressed, the switch arm **284** is in the up position, and the ungrounded plate of the capacitor **274** will be charged to the full positive potential available from the source **288**. Under this condition, there will be applied across the varistor **266**, through the resistor **272**, a biasing potential, thereby rendering the resistance of this varistor low. As a result, signals from the source **264** are shunted to ground, and may not reach the point **258**. Since, before the key is depressed, the point **240** is at ground potential, and since the point **276** is at a positive potential, the varistor **280** will serve to isolate these two points.

When the key of the instrument is depressed, and the switch arms **284** and **248** are thrown into the down position, the capacitor **274** discharges through the variable resistors **272** and **292**. The values of this capacitor and these resistors are chosen to have a lower time constant than that of the capacitor **238** and the resistor **246**, so that the transient signal builds up more rapidly than does the steady state signal.

It will be observed that as the key is held down, the point **240** will rise in potential while the point **276** will tend to fall in potential. When the point **240** reaches a potential above that of the point **276**, the varistor **280** will have a low resistance, and thereafter, the rise in potential at the point **240** will cause the capacitor **274** to become charged again, thereby again impressing a bias across the varistor **266**. This effect again causes the signal from the source **264** to be shunted to ground, and hence the transient signal decays, the rate of decay being determined chiefly by the build-up of the steady state signal.

When the key is released the switch arms **248** and **284** will move into the up position, and the charge on the capacitor **238** will leak off through various paths. The principal path will be through the resistor **242**, the varistor **234**, and the resistor **236** to ground. The bias is thus removed from the varistor **234**, and it again has high resistance. In this way the steady state signal is caused to decay, as desired.

The transient signal will presumably have decayed before release of the key. If the key is operated very rapidly, and the capacitor **274** has not become charged to any great extent through the varistor **280** prior to release of the key, it will be noted that it will, immediately upon release of the key, become charged to the full positive potential available from the source **288**. Therefore the system will be in condition to generate the transient again if the key is depressed shortly thereafter. Hence the transient is always available, no matter how fast the key is operated. The circuit of Fig. 2 also has this advantage.

Typical circuit constants which may be employed in the circuit of Fig. 5 are: resistor **236**, 10,000 ohms; resistor **246**, 10,000 ohms; resistor **242**, 30,000 ohms; resistor **272**, 10,000 ohms; resistor **292**, 100,000 ohms; capacitor **238**, 100 microfarads; and capacitor **274**, 5 microfarads.

It will be understood that the values of circuit constants mentioned herein in connection with the various embodiments of the invention are merely in the nature of examples, and a wide variety of values may be employed, depending upon the results desired.

Reference is again made to Figs. 1 and 4. As previously indicated, the maximum signal voltage at the varistor 32 should usually be small enough so that after the key is depressed and the varistor has moved from its high-resistance bias condition to its final low-resistance bias condition the varistor will operate entirely in the horizontal portion of the characteristic on the right-hand side of the graph, and not swing back into the sloping portion of the characteristic. In case, however, it is desired to generate harmonics of the signal derived from the source 10, the control 30 may be adjusted to produce a larger signal voltage amplitude at the varistor, and the potential source 52 may be adjusted to supply at the terminal 54 a relatively small positive potential, that is, a potential only slightly larger than the biasing potential of the source 26. As a result, after the key 16 is depressed, the varistor 32 moves to a bias condition corresponding to a point just to the right of the zero-bias point in Fig. 4, for example, to the plus one volt point of the illustrative characteristic, and the signal will, for a portion of the cycle, swing the varistor partly or completely into the high-resistance condition. The signal derived from the source 10 reaching the point 40 will thus tend to be clipped or distorted somewhat and will contain harmonics of the signal from the source 10.

In the present application, it may be understood that where non-symmetrical bias controllable impedance devices have been specified, rectifiers of the diode type could be used, although varistors such as those of the copper-oxide type are preferred for the sake of economy. Also, instead of using diodes, the circuits could be modified to employ triodes or other multi-electrode tubes.

While the embodiment shown in Fig. 1 has been described as using varistors of the rectifying or non-symmetrical type, this circuit may be modified to employ symmetrical varistors by eliminating the bias sources 26 and 88 and grounding the ends of the potentiometers such as 24 and 86 which are shown connected to these respective sources.

While a single transient effect source may be employed in connection with all the notes of the keyboard, it will be understood that other arrangements may be used. Thus it may be desired to use differently pitched transients for different notes. In order to accomplish this in a system of the general type shown in Fig. 1, instead of connecting a single transient effect source such as 78 to the varistor 106 and to the other corresponding varistors, there may be provided a plurality of transient effect sources connected to these respective varistors, so that each key of the keyboard would control a different transient effect source. Other embodiments of the invention disclosed herein may be similarly modified to have this feature.

In conclusion, it may be seen that means have been provided for increasing the fidelity with which an electronic musical instrument may imitate an ordinary instrument. Transient effects near the beginning of the tone, which aid the listener to identify the instrument being imitated may be effectively introduced, and shortly thereafter caused to decay, as the steady state tone builds up. In one embodiment described, the decay of the transient effect is independent of the build-up of the steady tone. In other embodiments, the decay of the transient effect is controlled by the build-up of the steady tone.

While an illustrative form of the invention has been disclosed in considerable detail, it will be understood that various changes may be made in the construction and arrangement of the several parts without departing from the general principles and scope of the invention as defined by the appended claims.

What is claimed is:

1. An electronic musical instrument comprising a plurality of sources of alternating signals, an adding and attenuating network having a branch coupled to each of said sources, said network having an output point and including a bias controllable impedance device in each said branch for controlling the amplitude of signals from said respective sources reaching said point, switch means, a circuit responsive to said switch means adapted to apply a transient bias voltage to one of said devices, and a circuit responsive to said switch means adapted to apply to another of said devices a bias which changes gradually and is thereafter substantially constant at a new value.

2. An electronic musical instrument comprising a source of eelctrical signals corresponding to a musical tone, a source of electrical signals corresponding to an arbitrary sound, an adding network coupled to said sources including a bias-controllable impedance device adapted to control the signal derived from said last-mentioned source, a key, and a source of a transient bias responsive to said key connected to said device and adapted to apply thereto a bias which increases and then returns to its original value, when said key is depressed and held down.

3. An electronic musical instrument comprising a source of electrical signals corresponding to a musical tone, a source of electrical signals corresponding to sound produced by an ordinary musical instrument at the beginning of a tone, said last-mentioned signals including frequency components other than harmonics of said first-mentioned signals, and a bias-controllable attenuating and adding network connected to said sources.

4. An electronic musical instrument comprising a key, a first source of electrical signals corresponding to a musical tone, a second source of electrical signals corresponding to an arbitrary sound, an adding and attenuating network connected to said sources comprising a first and a second varistor respectively connected in series with said sources, normally biased to high impedance, and means responsive to said key for gradually biasing said first varistor to low impedance and for quickly and temporarily biasing said second varistor to low impedance.

5. An electronic musical instrument comprising a key, a first source of electrical signals corresponding to a musical tone, a second source of electrical signals corresponding to an arbitrary sound, an adding and attenuating network connected to said source comprising a first and a second varistor respectively connected in series with said sources, normally biased with a polarity to provide high impedance, means responsive to said key connected to said first varistor for gradually applying thereto a bias of opposite polarity to lower its impedance, said means comprising a resistor, a capacitor, and connections for a current source adapted to be connected in series, and means for applying to said second varistor a transient bias of opposite polarity to lower its impedance briefly, said last-mentioned means comprising a capacitor, connections for normally charging same, and a switch responsive to said key for connecting said charged capacitor to said second varistor.

6. An electronic musical instrument comprising a signal generating system having an output point, and an electro-acoustic output system connected to said output point, said signal generating system comprising a source of a first signal, a source of a second signal, a key, a network controlled by said key coupling said sources to said output point, said network comprising a time-varying attenuator adapted to apply at said output point said first signal with gradually increasing and then substantially constant amplitude after operation of said key, and a time-varying attenuator adapted to apply at said output point said second signal only briefly after operation of said keying means.

7. An electronic musical instrument comprising keying means, a source of steady state signals, a source of transient effect signals, an amplifier having an input circuit, attenuating circuits coupling said sources to the input circuit of said amplifier, said attenuating circuits having a first section adapted to apply to said input circuit said steady state signals with low initial but gradually increasing and then constant amplitude after operation of said keying means, and a second section adapted to apply said transient effect signals strongly to said input circuit for only a brief interval after operation of said keying means, and a bias-controllable impedance device constructed and arranged to couple said first and second sections together when said steady state signal increases to a predetermined extent, and to cause said transient signal to decay in response to further increases in said steady state signal.

8. An electronic musical instrument comprising a first source of electrical signals corresponding to a tone, a second source of electrical signals corresponding to an arbitrary sound, an adding and attenuating network including a first varistor, normally biased to low impedance, connected in shunt with said first source, and a second varistor, normally biased to high impedance, connected in series with said second source, a key, circuit means responsive to said key including resistance and reactance means adapted to apply a slowly-changing bias of a first polarity to said first varistor to increase its impedance and to apply a quickly-changing bias potential of opposite polarity to said second varistor to decrease its impedance when said key is operated, and a third varistor connected between said first and second varistors adapted to apply to said second varistor a bias potential of said first polarity, when that being applied to said first varistor increases beyond a critical value, thereby attentuating the signal from said second source.

9. An electronic musical instrument comprising a signal generating system having an output point, said system comprising a key, a source of electrical signals corresponding to a musical tone, an attentuating network coupling said source to said output terminal and comprising a varistor connected effectively in shunt with said source, normally biased to low impedance, means responsive to said key for gradually biasing said varistor to high impedance, a second source of electrical signals corresponding to an arbitrary sound, an attenuating network coupling said last-mentioned source to said output point and comprising a second varistor in series with said second source, normally biased to high impedance, means responsive to said key adapted to bias said second varistor to low impedance, and a circuit including a third varistor coupling said first and second varistors together and adapted to cause the impedance of said varistor again to increase as the bias controlling said first varistor increases beyond a critical value.

10. An electronic musical instrument comprising switch means, a first source of electrical signals corresponding to a musical tone, a second source of electrical signals corresponding to an arbitrary sound, an adding and attenuating network comprising a first, symmetrical, bias-controllable impedance device connected effectively in series with said first source, normally at high impedance, a second, symmetrical, bias-controllable impedance device connected effectively in shunt with said second source, normally biased to low impedance, said switch means being adapted, when operated, to quickly decrease the bias on said second device to increase its impedance, means responsive to said switch means adapted to apply to said first device a gradually increasing bias to decrease its impedance, and a non-symmetrical bias-controllable impedance device adapted to again increase the bias on said second device to lower its impedance as the bias on said first device increases beyond a critical value.

11. An electronic musical instrument comprising a source of electrical signals corresponding to a musical tone, a source of electrical signals corresponding to wind noise produced by a wind musical instrument at the beginning of a tone, a key, means controlled by depression of said key for causing signals from said first source to produce a corresponding musical tone for a duration determined by the period of depression of said key, and means brought into action by depression of said key for causing signals from said second source to produce a corresponding wind sound for a duration terminating independently of the period of depression of said key.

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