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Moog

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[54] MONOPHONIC TOUCH SENSITIVE KEYBOARD

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[73] Assignee: **Norlin Music, Inc.**, Lincolnwood, Ill.
[21] Appl. No.: **882,262**
[22] Filed: **Feb. 28, 1978**

Related U.S. Application Data

[63] Continuation of Ser. No. 591,853, Jun. 30, 1975, abandoned.

[51] **Int. Cl.**² **G10H 1/02;** G10H 5/00
[52] **U.S. Cl.** **84/1.22;** 84/1.1; 84/1.24; 84/1.27; 84/DIG. 7
[58] **Field of Search** .... 84/1.01, 1.1, 1.22, 84/1.24, 1.27, DIG. 7

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Primary Examiner—S. J. Witkowski
Attorney, Agent, or Firm—Hill, Van Santen, Steadman, Chiara & Simpson

[57] **ABSTRACT**

A keyboard for a monophonic musical instrument has a plurality of touch sensitive keys which function as variable capacitors, the capacitance depending on the force applied to the keys. The variable capacitance is detected and used to produce a variable control voltage which is used to execute one or several of various control functions, such as controlling the volume of the sound produced by The instrument, controlling the cutoff frequency of a low pass filter in the output system of the instrument, controlling the amount of vibrato or other periodic modulation introduced into the sounds produced by the instrument, controlling the frequency of the vibrato or other periodic modulation, or controlling the amount of "bend" in the pitch of a sound produced by the instrument, i.e. shifting the pitch slightly from its nominal value. The variable capacitors employ a conductive elastomer which is deformed in response to the force applied to the keys. The changes in the capacitance are converted to a DC voltage which is used to control the amplitude of an output signal.

13 Claims, 14 Drawing Figures

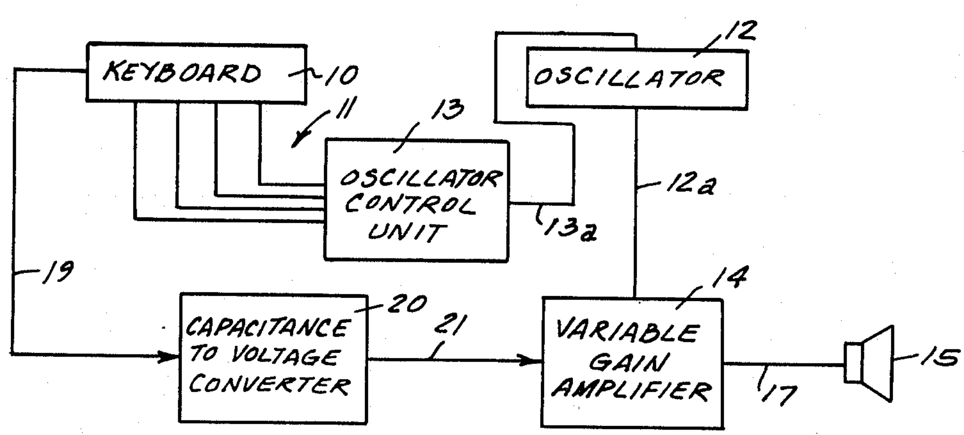
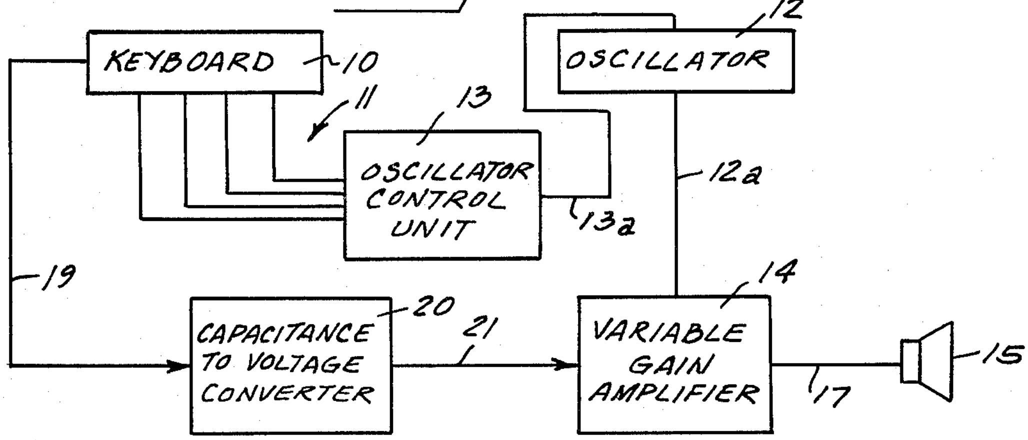


FIG. 1



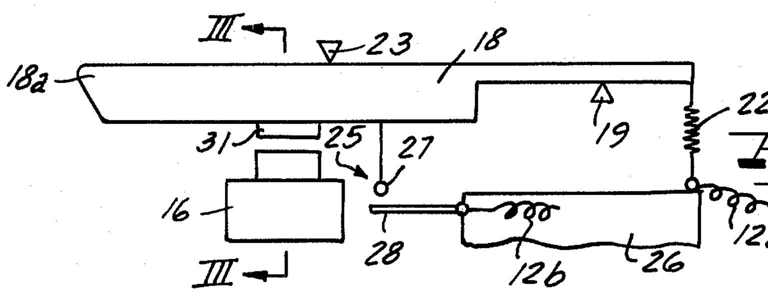


FIG. 2

FIG. 3

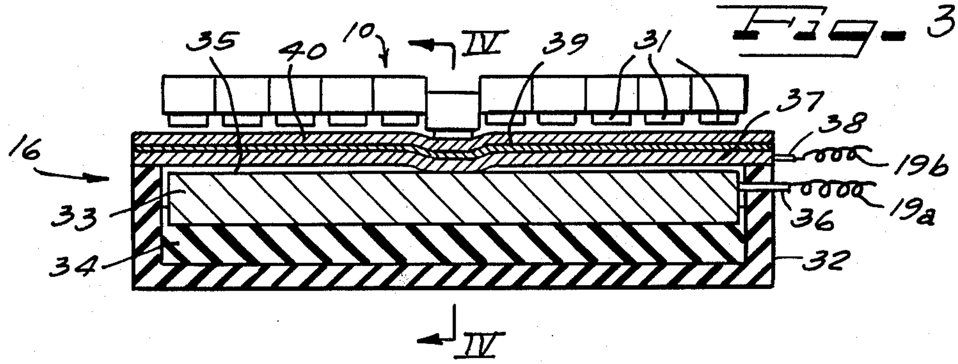


FIG. 4

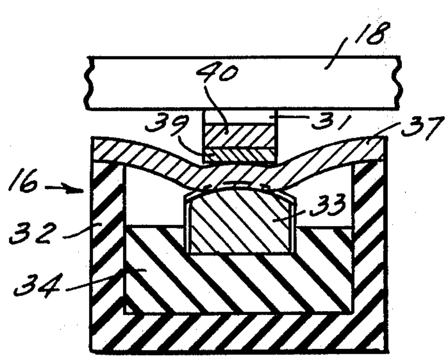


FIG. 5

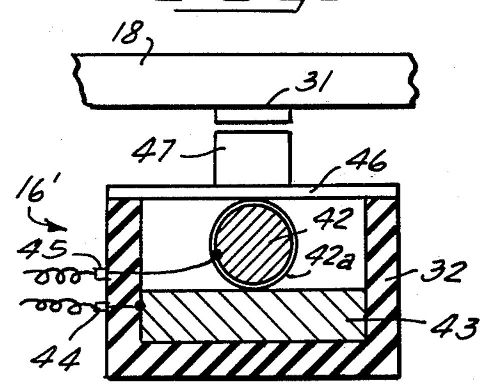


FIG. 6

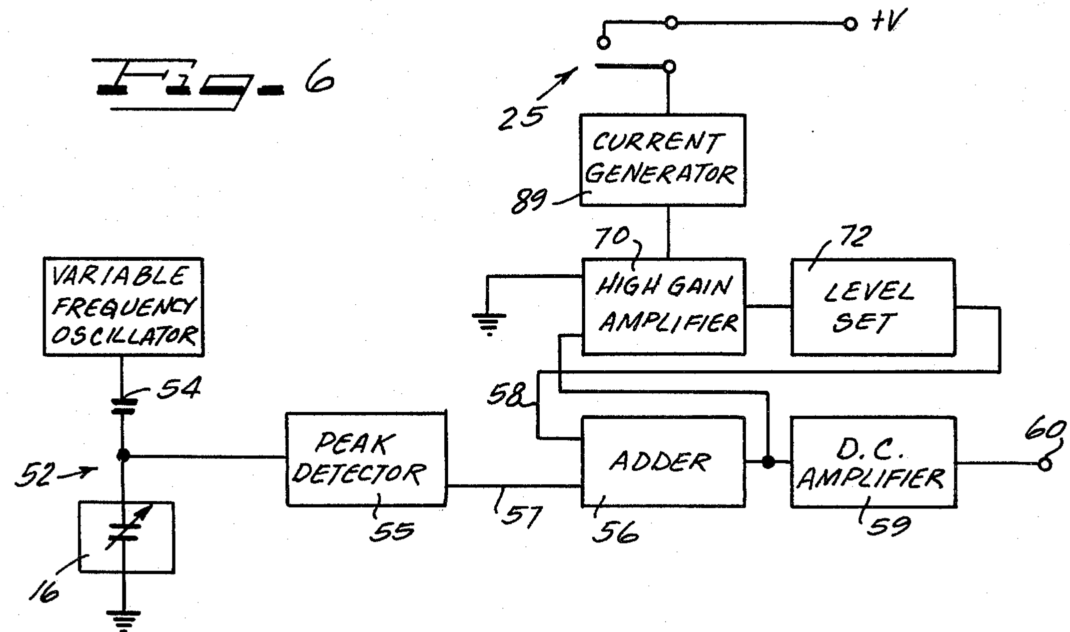
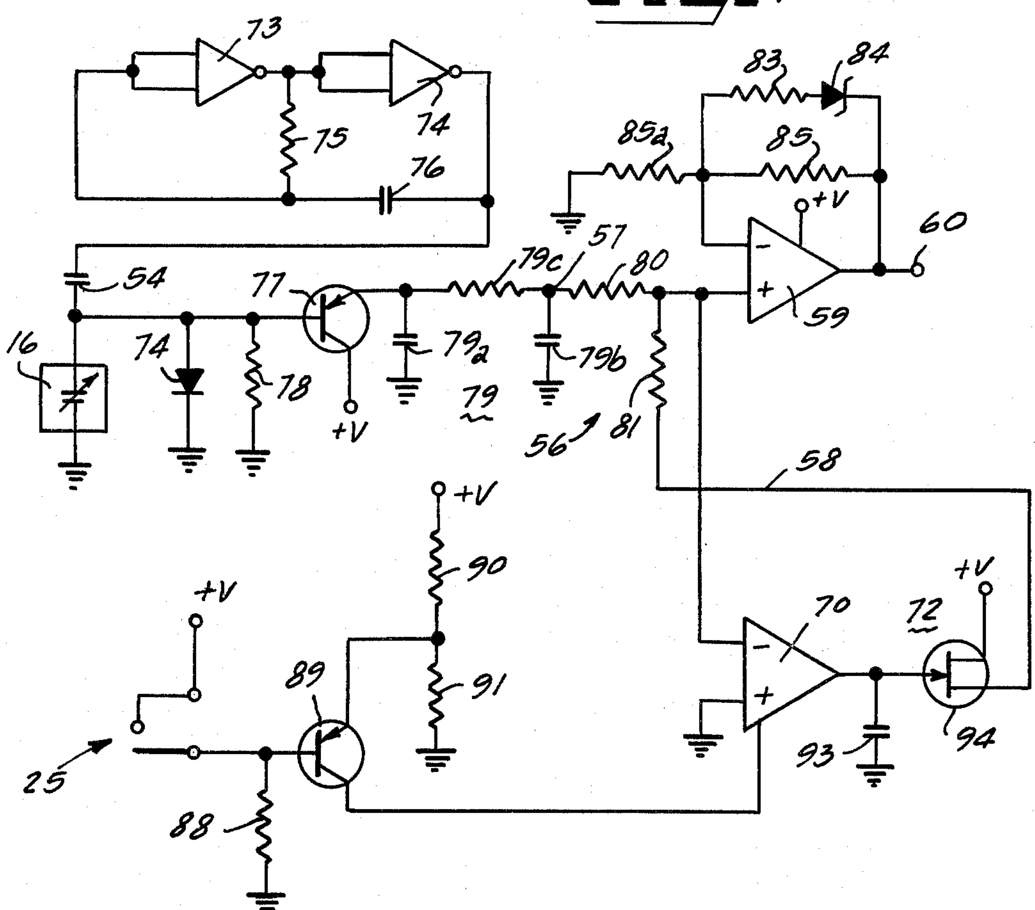

+V
25
CURRENT GENERATOR
89
70
72
HIGH GAIN AMPLIFIER
LEVEL SET
VARIABLE FREQUENCY OSCILLATOR
54
58
52
PEAK DETECTOR
ADDER
D.C. AMPLIFIER
60
16
55
57
56
59

FIG. 7


73
74
75
76
83
84
85a
85
+V
57
60
54
77
79c
80
16
74
78
+V
79a
79b
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+V
90
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70
72
+V
25
88
93
94

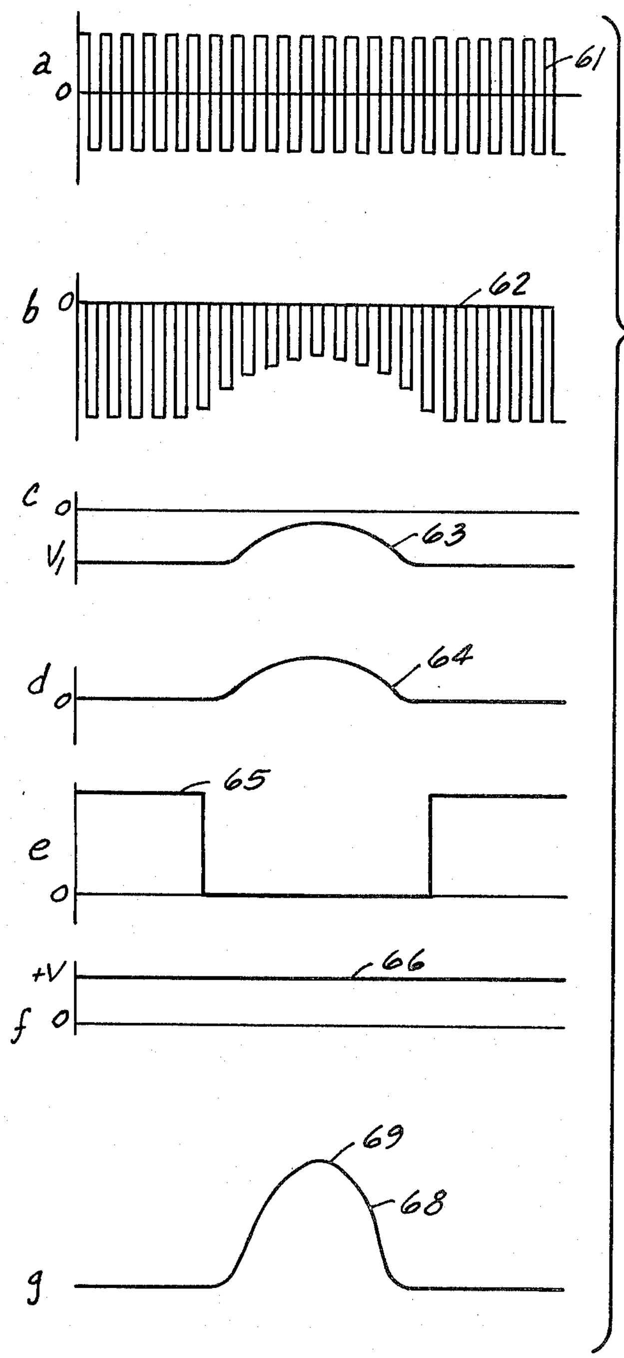
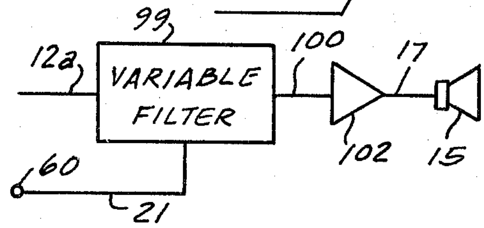


Fig-8

Fig-10



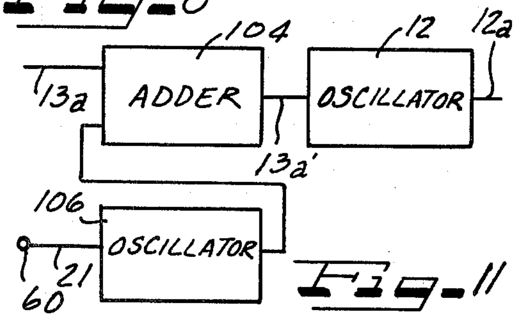
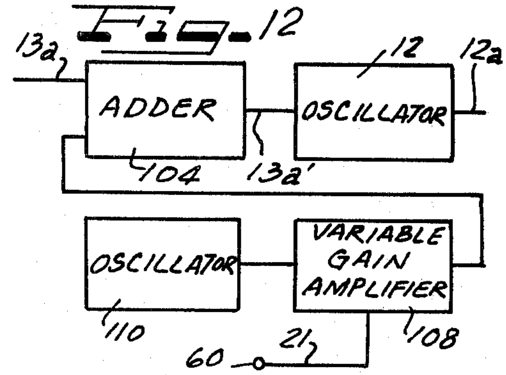


Fig-11

Fig-12



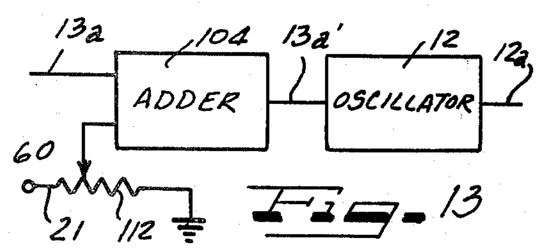


Fig-13

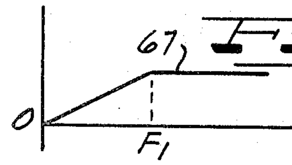


Fig-9A

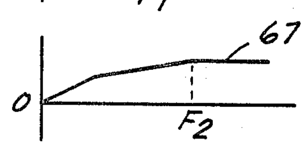


Fig-9B

MONOPHONIC TOUCH SENSITIVE KEYBOARD

This is a continuation of application Ser. No. 591,853, filed June 30, 1975, and now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to electronic musical instruments, and more particularly to a monophonic instrument with a touch sensitive keyboard for selecting tones and for controlling the amplitude with which such tones are produced.

2. The Prior Art

It is frequently desirable, in keyboard type musical instruments, to produce tones and other sounds with a variable amplitude or volume, under the control of the operator or player of the instrument. By this means, the operator can produce loud or soft sounds at will. Several arrangements have been developed in the prior art for performing such a function.

In monophonic instruments, such as electronic music synthesizers or the like, where a single tone is produced at any one time, it is desirable to provide a keyboard by which the amplitude of the sound is produced in a continuous manner, so that such a sound, produced continuously without interruption, may be continuously varied up or down in its amplitude or volume, without any interruption in the production of the sound. The apparatus which is available in the prior art does not provide means by which this may readily be done.

It is therefore desirable to provide a touch sensitive keyboard by which the volume or amplitude of a sound may be continuously varied, in response to the force applied to the keys of the keyboard, with such sound being initiated with the first touch of the key corresponding to such sound.

It is also desirable to provide a touch sensitive keyboard, having means for producing a control voltage in response to the force applied to the keys of the keyboard, which voltage can be used to control other parameters, such as the cutoff frequency of a filter, vibrato amplitude and frequency, or pitch bending.

SUMMARY OF THE INVENTION

It is a principal object of the present invention to provide a touch sensitive keyboard by which the production of sounds may be initiated and parameters affecting production of such sounds may be varied at the will of the operator or player.

It is another object of the present invention to provide such a keyboard which is simple in construction and economical to produce.

It is a further object of the present invention to provide such a keyboard by which the amplitude of sounds, or other parameters, may be varied continuously.

Another object of the present invention is to provide a variable capacitance apparatus for such a keyboard, constructed so that the capacitance varies as a function of the force applied to a key.

A further object of the present invention is to provide such a variable capacitance apparatus, with means for compensating for changes in the quiescent capacitance of the apparatus.

These and other objects and advantages of the invention will become manifest by an inspection of the following description and the accompanying drawings.

In one embodiment of the invention there is provided, in an electronic musical instrument, a touch sensitive keyboard having a deformable conductive body separated by a dielectric from another conductive body. As a key is depressed, a downwardly directed force deforms the deformable conductive body in a manner such as to increase a capacitance between the two conductive bodies. The change in capacitance is sensed by a control circuit which produces a control voltage in response to the capacitance. The control voltage is used to modify the characteristics of sounds produced by the instrument. The control circuit includes an oscillator connected to a bridge circuit including the variable capacitor of the keyboard unit. A comparator senses the voltage corresponding to the quiescent capacitance of the variable capacitor, and produces a compensated voltage which is independent of ambient changes in the quiescent capacitance of the variable capacitor.

In another embodiment the variable capacitor unit of the keyboard has a circular cylindrical conductive body resting on a bed of conductive elastomer. As a key is depressed, force is applied to the body to drive it into greater surface contact with the bed, and increase the capacitance in accordance with the force acting on the key.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made to the accompanying drawings, in which:

FIG. **1** is a functional block diagram of a monophonic musical instrument incorporating an illustrative embodiment of the present invention;

FIG. **2** is a side elevation of a touch sensitive key showing the variable capacitor in diagrammatic form;

FIG. **3** is a vertical cross-sectional view of a touch sensitive keyboard taken in the plane **3—3** of FIG. **2**;

FIG. **4** is a vertical cross-sectional view of the apparatus of FIG. **3** taken in the plane **4—4**;

FIG. **5** is a vertical cross-sectional view corresponding to FIG. **4** but illustrating an alternate embodiment of the variable capacitor unit;

FIG. **6** is a functional block diagram of the amplitude control circuit of FIG. **1**;

FIG. **7** is a schematic circuit diagram of the amplitude control circuit of FIG. **6**;

FIG. **8** is a series of graphs a-h representing waveforms present at different locations in the amplitude control circuit during operation thereof;

FIG. **9** is a series of graphs **9A** and **9B** representing two plots of the gain characteristic of the variable gain amplifier of FIG. **1**; and

FIGS. **10–13** are functional block diagrams of alternative embodiments of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1**, which shows an illustrative embodiment of the present invention, a monophonic musical instrument incorporating a touch sensitive keyboard is shown. The keyboard **10** has a plurality of output lines **11** which are all connected to an oscillator control unit **13**, each line corresponding to a separate key of the keyboard **10**. The control unit **13** produces a voltage level on a line **13***a*, which line is connected to the control input of a variable frequency oscillator **13**. The frequency of the oscillator is determined by the voltage level on the line **13***a*. The signal produced by the oscillator **12** is furnished, in the embodiment of FIG.

1, over a line **12***a* to a variable gain amplifier **14**, the output of which is connected via a line **17** to a sound transducer, such as a loudspeaker **15**. A variable capacitor located in the touch sensitive keyboard **10** is connected by a line **19** to the input of a capacitance-to-voltage converter **20**, which produces a DC control voltage on an output line **21** in accordance with the capacitance changes. The control voltage is connected via line **21** to the control input of the variable gain amplifier **14**.

The oscillator control unit **13**, the variable frequency oscillator **12**, and the variable gain amplifier **14** are well known in electronic music synthesizers, and therefore need not be described in detail. In general, the control unit incorporates apparatus for converting the signals developed on one of the lines **11** (in response to operation of individual keys of the keyboard **10**) into a voltage proportional to the pitch associated with the depressed key. Typically, such apparatus takes the form of a voltage divider having a plurality of taps, with the voltage present on one tap being directly or indirectly connected to the output line **13***a*, which is connected via one of the lines **11** to the oscillator **12**. Typically, means is provided either in the keyboard unit **10** or in the control unit **13** for producing a gating signal when any key is depressed, and this gating signal either energizes the oscillator **12** or enables a gate connected to its output, so that there is no signal on the line **12***a* except when a key of the keyboard has been depressed. The details of the oscillator control unit **13**, the oscillator **12**, and the variable gain amplifier **14** form no part of the present invention.

In FIG. **2**, which shows a side view of one key **18**, a variable capacitor unit **16** is shown beneath an intermediate part of the key **18**. A switch **25** is arranged adjacent the variable capacitor unit **16**. Both the variable capacitor unit **16** and the switch **25** are actuated when the key **18** is depressed.

The key is supported by a fulcrum **19**, and is urged to rotate in a clockwise direction by a spring **22**, connected between the key and a support **26**. A stop **23** maintains the key in the position shown when it is unoperated. When the key **18** is to be operated, its upper surface near the free end **18***a* is depressed, and the key rotates counterclockwise about the fulcrum **19**.

The switch **25** has an upper contact **27** rigidly supported by and depending from the bottom surface of the key **18**. A lower contact **28** is supported by the support **26**. In the unoperated, or key-up, position of the key **18**, a slight gap separates the contacts **27** and **28**. The lower contact **28** is formed of resilient material so that, when the key **18** is depressed and the switch **25** is closed, the lower contact **28** is bent downwardly as the key **18** continues its downward motion. The upper end of the spring **22** is electrically connected to the upper contact **27**. A pair of wires **12***a* and **12***b* are connected to the spring **22** and the contact **28**, to connect the switch **25** to the selector **13**.

The variable capacitor unit **16** is located directly below a pad **31** connected to and supported by the bottom surface of the key **18**. In the key-up position, a slight gap exists between the unit **16** and the pad **31**, which slightly exceeds the gap between the contacts of the switch **25**, so that the switch **25** closes just prior to contact between the pad **31** and the variable capacitor unit **16**.

FIGS. **3** and **4** illustrate the internal construction of the variable capacitor unit **16**. A channel shaped member **32** extends the entire length of the keyboard **10**. A layer **34** of insulating material overlies the bottom of the channel, and a conductive body **33** having a rounded or convex top surface **35** and elongated design is received in a recess in the top surface of the layer **33** and is supported thereby (FIG. **4**). The conductive body **33** extends the entire length of the keyboard **10**, as shown in FIG. **3**. A terminal **36** is electrically connected with the member **33** and extends through an aperture in the supporting channel **32**. A wire **19***a* is connected to the terminal **36**.

A deformable conductive member **37**, in the shape of a ribbon, overlies the layer **34** and the member **33** throughout the entire length of the channel **32**. A terminal **38** is electrically connected to the conductive ribbon **37**, and a wire **19***b* is connected thereto. The deformable conductive ribbon **37** is preferably formed of a conductive elastomer. It normally occupies a horizontal plane spaced above the conductive member **33**. To this end, the side edges of the ribbon **37** are supported by the upper ends of the sides of the channel **32**, to which its side edges are attached. The ribbon **37** is deformable downwardly toward the member **33** upon actuation of a key, by means which will now be described.

A flexible spring strip **39** is positioned directly above the conductive body **33**, and is supported by the ribbon **37**. An elongated cushion **40** having a length similar to the spring strip **39** is mounted directly above the strip **39**. The pad **31**, which is mounted to the bottom of each key **18**, contacts the cushion **40** when the key **18** is depressed, and the deformable member **37** is forced downwardly to assume a new position in which the deformable member conforms to the outside shape of the conductive body **33**. If the key is depressed with only slight force, only a minor portion of the member **37** conforms to the shape of the member **33**. If the force is increased, a larger and larger area of the member **37** conforms to the shape of the member **33**.

The member **33** is preferably formed of aluminum, and its outer surface is formed by a thin skin of insulating aluminum oxide. Thus, when the body **37** contacts the body **33**, there is no direct electrical contact established between the wires **19***a* and **19***b*, but the capacitance effectively connected between these two wires varies with the size of the area of the body **37** which conforms to the shape of the body **33**. The greater is this area, the greater the capacitance between the wires **19***a* and **19***b*. This is because the bodies **37** and **33** form a capacitor having the insulating skin of the body **33** as its dielectric and an effective plate area corresponding to the area of the body **37** which conforms to the body **33**, as nearly all of the remainder of the body **37** is spaced much further away from the body **33** and thus contributes little to the total capacitance between the wires **19***a* and **19***b*.

The shape of the curved upper surface **35** of the body **33** determines the relationship between downward movement of the key **18** and the increase in capacitance of the variable capacitor. If the radius of curvature of this surface is large, a relatively great increase in capacitance accompanies depression of the key **18** for a short distance. Making the radius of curvature shorter gives less increase in capacitance per unit distance of key depression.

The convex surface **35** is not necessarily circular in cross section, but may instead be parabolic or hyperbolic or elipsoidal, all of which give different characteristics of the rate of change of capacitance in response to the position of an operated key.

The spring strip **39** is effective to maintain about the same characteristic of capacitance versus key depression irrespective of which of the keys of the keyboard is depressed.

The variable capacitor unit **16'** illustrated in FIG. **5** is an alternative embodiment. The deformable conductive member 37 of the embodiment of FIGS. **1-4** tends to stretch and deform permanently with repeated operations. As a result, the dynamic capacitance range decreases with use. In the unit **16'**, a conductive member **42**, having an insulating skin **42a**, is supported on a layer **43** of deformable conductive material supported in the channel 32. The layer **43** is connected to a terminal **44**. The member **42**, shaped as an elongate rod, rests upon the conductive layer **44**, and is electrically connected to a terminal **45**. A non-conductive elastomer sheet member **46** is secured to and closes the top of the channel 32, and provides a mounting surface for an elongate cushion **47**, extending the entire length of the channel **32**. The spring member **39** of the embodiment of FIGS. **3** and **4** is not needed, since the rod-shaped body **42** supports the non-conductive sheet **46** and the cushion **47**.

Referring to FIG. **6**, a high frequency oscillator **53** with a preferred operating frequency near 100 kHz drives a capacitive voltage divider **52**, including a fixed capacitor **54** and the variable capacitor unit **16**, connected in series between the oscillator **53** and ground. The input voltage to the voltage divider **52** is illustrated in FIG. *8a* as waveform **61**, and the junction point between the capacitors is illustrated in FIG. *8b* as waveform **62**. The magnitudes of the two waveforms **61** and **62** differ in respect to the depression of a key, which causes the capacitance of the unit **16** to vary, giving the voltage available at the junction between the capacitors a low frequency modulation, in response to depression and release of a key.

A peak detector unit **55**, connected to this junction, detects the input waveform **62** to provide an output voltage waveform **63** of magnitude −V1, as shown in FIG. *8c*. The hump in the waveform **63** indicates the change in capacitance resulting from the depression and release of a key **18**. The output voltage from the peak detector **55** is connected to one input of an adder unit **56** over a line **57**. Another input of the adder unit **56** receives a correction signal over the line **58**, having a waveform **66**, as shown in FIG. *8f*. The output of the adder is represented by voltage waveform **64**, shown in FIG. *8d*. This output is connected to an input of a DC amplifier **59**. The waveform **64** is similar in shape to the waveform **63**, but has its DC level shifted so that during the key-up state, before the pad **31** engages the ribbon **37**, the output voltage from the adder **56** is at or near zero. Hence, the output of the DC amplifier **59** is also at or near zero. The output of the DC amplifier **59** is connected to an output terminal **60**. The waveform **68**, illustrated in FIG. *8g*, illustrates the output voltage waveform of the DC amplifier **59**.

The correction voltage waveform **66** is developed by a high gain amplifier **70** and a level set unit **72**. During the key-up condition the switch **25** is open. During this time, the amplifier **70** is controlled by a gating current produced by a current generator **89** (waveform **65** in FIG. *8e*). The output of the amplifier **70** corresponds to the difference between ground potential and the output of the adder **56**, to which the two input (inverting and noninverting) terminals of the amplifier are connected. The output of the amplifier **70** is a DC voltage level corresponding to the output of the adder **56**, but having the opposite sign. This is connected to the input of the level set unit **72**, which functions as a sample-and-hold unit to charge a capacitor in accordance with the input signal, and to manifest the voltage level across the capacitor at an output terminal connected to the adder **56** by the line **58**. The effect is to produce a voltage on the line **58** which is equal and opposite to the quiescent voltage on the line **57**, so as to compensate for the quiescent capacitance of the variable capacitor **16** and any changes therein.

As the key **18** is depressed, the contacts of the switch **25** apply a voltage +V to the current generator **89**, which then discontinues supplying gating current to the amplifier **70**, causing it to disconnect itself from the level set unit **72**. The gating current furnished by the current generator **89** is shown in FIG. *8e*. The level set unit **72** continues to manifest the same voltage level which is then present at its output, until the switch **25** is again opened. Subsequently, the voltage level of the output of the level set unit **72** is constant, and the voltage produced at the output terminal **60** follows the voltage changes on the line **57**, as a result of changes in the capacitance of the variable capacitor **16**.

A schematic circuit diagram of the apparatus of FIG. **6** is shown in FIG. **7**. The high frequency oscillator **53** is composed of inverters **73** and **74**, connected in series, with an RC time constant circuit including a resistor **75** and a capacitor **76**. The resistor **75** is connected between the input and the output of the gate **75**, and the capacitor **76** is connected between the output of the gate **74** and the input of the gate **73**.

The output voltage from inverter **74** is connected through the capacitor **54** to the variable capacitor unit **16**. The base of a PNP transistor **77** is connected to the junction of capacitor **54** and the variable capacitor unit **16**. A resistor **78** is connected between the base of transistor **76** and ground, and a diode **79** is also connected between the base of transistor **77** and ground, to clamp the positive-going portion of the waveform **62** to ground. The collector of the transistor **77** is connected to the supply voltage +V, and the emitter drives a low pass filter network **79** comprising shunt capacitors **79a** and **79b** and series resistor **79c**. The transistor **77** functions as a rectifier and the low pass filter **79** smooths the rectified voltage. Together they make up the peak detector **55**.

Resistors **80** and **81** make up the adder unit **56**. Resistor **80** connects the line **57**, from the output of the low pass filter network **79**, to the noninverting input of the DC amplifier **59**. Resistor **81** couples the line **58** to the same input of the amplifier **59**.

The DC amplifier **59** has a resistor **85** connected between its output terminal and the inverting input, and a resistor **85a** connected between the inverting input and ground, to establish the gain of the amplifier. A series circuit including a zener diode **84** and a resistor **83** is connected in parallel with the resistor **85**, to give a nonlinear gain characteristic. Without the diode **84** and the resistor **83**, the gain of the amplifier **59** would be constant for all input voltage levels. It is desirable, however, to provide a nonlinear characteristic to prevent the amplifier **59** from saturating, for if the amplifier were permitted to saturate, increased downward force on the key **18** would produce no change in output voltage of the amplifier **59**, producing a flat topped output signal (**69** in FIG. *8g*). Saturation could be prevented by simply limiting the gain of the amplifier, but it is desirable to have a steeper characteristic for low key forces, so that there is a dramatic change in amplitude to differentiate a moderate from a light touch on the keys of the keyboard. The curve **67** of FIG. 9A, which is a graph of the output of amplifier **59** as a function of the force of key depression, shows that when the gain is constant, saturation occurs at force F_1. Curve **67'** of FIG. **9B** shows that with the nonlinear gain characteristic, the same slope is provided for low forces, but saturation is avoided until the higher force F_2.

The switch **25** is connected between the supply voltage +V and the base of the current generator **89**, which comprises a PNP transistor. The base is also connected to ground through a resistor **88**. The emitter of the transistor **89** is connected to the junction of a pair of resistors **90** and **91**, which resistors serve as a voltage divider between the supply voltage +V and ground. The collector is connected to the gating terminal of the amplifier **70**.

The inverting input of the gated high gain amplifier **70** is connected to the output of the adder unit **56**, and its noninverting input is grounded; its output is connected to one terminal of a capacitor **93**, the other terminal of which is grounded. The amplifier **92** functions as a means to charge and discharge the capacitor **93**, in accordance with the difference in voltage applied to its inputs, as long as it receives gating current from the transistor **89**.

The output of the amplifier **70** is also connected to the gate of an FET **94**, which has its drain and source terminals connected in series between a voltage source +V and the line **58**. The FET **94** functions as a source follower, and its high input impedance permits the voltage level capacitor **93** to remain constant for long periods of time. The capacitor **93** and its associated circuitry thus function as a sample-and-hold circuit.

In operation, the capacitor **93** is charged by the amplifier **70** to the value necessary to bring the output of the adder unit **56** to zero, which permits the amplifier **70** to cease charging or discharging the capacitor **93**, which thereafter has a constant voltage impressed across it. If the quiescent capacitance of the variable capacitor **16** changes, the change in the voltage level on the line **57** causes the amplifier **92** to charge or discharge the capacitor **93** in such a way as to compensate for the change, and bring the output of the adder unit **56** back to zero.

When a key **18** of the keyboard is depressed, the switch **25** is closed, and a high voltage is connected to the base of the transistor **89**. This cuts off the transistor and turns off the gating current for the amplifier **70**, so that it becomes ineffective to charge or discharge the capacitor **93**, irrespective of its input. The subsequent change in the capacitance of the variable capacitor **16**, therefore, as a key **18** is depressed further, changes the level on the line **57** with no corresponding change in the voltage level present on the line **58**, since the voltage across the capacitor **93** remains constant.

As the key **18** is released by the operator or player, the capacitance of the variable capacitor **16** returns to its quiescent value before the switch **25** is reopened. Thereafter, any intervening or subsequent change in quiescent capacitance is compensated for in the manner described.

Although the present invention has been described particularly in relation to the control of the volume of sound produced via a variable gain amplifier **14**, it finds utility in other control operations as well. Four additional arrangements are shown in FIGS. **10–13**, illustrating four additional modes of use of the present invention.

In FIG. **10**, a filter **99** having a variable cutoff frequency is shown, and the signal produced by the oscillator is conducted over the line **12a** to the signal input of the filter, the filtered output being connected over a line **100** to the input of an amplifier **102**, the output of which is connected to the loudspeaker **15** over the line **17**. The terminal **60** of the capacitance-to-voltage converter **20** is connected via the line **21** to the control input of the filter **99**. Variation in the voltage level on the line **21** affects the cutoff frequency of the filter **99**, which causes a dramatic change in the sound produced by the loudspeaker **15**. In FIGS. **11–13**, the control signal furnished over the line **13a** is modified by operation of an adder unit **104**, producing a modified signal which is connected over the line **13a'** to the control input of the oscillator **12**. The adder **104** receives, in each case, one input from the line **13a**, but the second input is different. In FIG. **11**, the output of another oscillator **106** is connected to the second input of the adder **104**, the frequency of which is controlled by the voltage level present at the terminal **20**. The signal from the oscillator **106**, when added to the signal on the line **13a**, causes a vibrato effect, the frequency of which is controlled by the potential on the line **21**.

In FIG. **12**, the second input of the adder **104** is supplied from the output of a variable gain amplifier **108**, which has its signal input connected to the output of a fixed frequency oscillator **110**. The gain of the amplifier **108** is controlled by the voltage level on the line **21**, so that a variable amount of the signal from the oscillator **110** is mixed with the signal on the line **13a**. As the oscillator **110** operates at a relatively low frequency, the effect on the sound produced is a vibrato, with a vibrato frequency equal to the frequency of the oscillator **110**, and with the amount or amplitude of vibrato determined by the voltage level on the line **21**.

In FIG. **13**, the second input of the adder unit **104** is connected directly to the line **21**, through a variable voltage divider **112**, so that variation of the voltage level on the line **21** affects the pitch of the oscillator **21**. The amount of the pitch change, in relation to the change in the voltage, is controlled by adjustment of the variable resistor **112**. The operator or player of the instrument can slightly change or "bend" the pitch of the oscillator **12** in accordance with the force used on the keys.

It will be understood by those skilled in the art that while the arrangements shown in FIGS. **1** and **10–13** all use the control voltage on the line **21** for an individual purpose, the control voltage may be simultaneously used to perform two or more of the several functions described. By the use of suitable switches, the control voltage may be selectively supplied to one or several destinations, so that the operator or player can select the desired effect at any given time.

The several arrangements shown in FIGS. **1** and **10–13** are merely illustrative of ways in which the control voltage may be used, and other uses will be apparent to those skilled in the art.

From the foregoing, it is apparent that the present invention is effective to permit the continuous control of characteristics of a sound or tone selected by a key of the keyboard, as long as the key remains depressed, in accordance with the force with which it is depressed, and compensates completely for any changes in quiescent capacitance.

Although the invention has been described in connecton with a monophonic musical instrument, it is obvious that an individual variable capacitor may be provided for each key, to permit the simultaneous control of the amplitudes of more than one sound. Other modifications and additions may be made without departing from the essential features of the invention, which are intended to be defined and secured by the appended claims.

What is claimed is:

1. In an electronic musical instrument having a keyboard with a plurality of keys, a tone signal generator for producing a tone signal, means for controlling said tone signal generator is response to operation of said keys and an output system for receiving said tone signal and converting the same into sound waves, the combination comprising:

(a) sensing means underlying all of the keys of said keyboard and responsive to a plurality of said keys for sensing the force with which said keys are operated and for producing a signal having a level corresponding to the sum of said forces, and

(b) amplifier means connected to said sensing means and to said output system for controlling the amplitude of said sound waves in response to said signal, in accordance with the sum of the forces of the operated keys.

2. Apparatus according to claim **1**, wherein said sensing means comprises a variable capacitor unit having first and second conductors and a dielectric therebetween, said first conductor being mechanically connected to said key for changing its position relative to said second conductor to cause the capacitance of said capacitor to vary in response to a force applied to said key, and voltage producing means connected to said variable capacitor for producing a DC voltage in response to the capacitance of said variable capacitor.

3. A variable capacitance unit for the keyboard of an electronic musical instrument for producing a signal responsive to the sum of the forces with which the keys of said keyboard is operated, comprising:

(a) a first conductor disposed below said keyboard and extending along the entire length thereof,

(b) a second conductor supported above said first conductor and adapted to be moved downwardly in response to operation of one of said keys,

(c) a dielectric layer interposed between said first and second conductors for maintaining them electrically insulated from each other, and

(d) electrical conductor means secured to said first and second conductors for manifesting an electrical signal in response to the capacitance between said first and second conductors, whereby said electrical signal responds to the sum of the forces of the operated keys.

4. Apparatus according to claim **3**, wherein said first conductor comprises an elongate conductive body and said second conductive body comprises a conductive elastomer supported in a plane above said first conductor and adapted to be deformed downwardly in response to key operation.

5. Apparatus according to claim **4**, wherein the upper surface of said first conductor is a convex curved cylindrical surface.

6. Apparatus according to claim **5**, including resilient means interposed between said key and said second conductor whereby said second conductor is forced downwardly over an area exceeding the area of contact between said key and said resilient means, a portion of said second conductor being adapted to be pushed downwardly sufficiently as to conform to the upper surface of said first conductor, the area of said conforming portion depending on the force with which said key is operated.

7. Apparatus according to claim **4**, including spring means supported above said second conductor and adapted to be stretched downwardly in response to operation of said key, thereby to force said second conductor downwardly toward said first conductor.

8. Apparatus according to claim **3**, wherein said first conductor comprises a conductive elastomer and said second conductor comprises an elongate cylindrical body supported on said elastomer, and including means interposed between said key and said second conductor for engaging said second conductor and forcing it downwardly so as to displace a portion of said first conductor.

9. Apparatus according to claim **8**, including resilient means interposed between said key and said second conductor.

10. Apparatus according to claim **8**, wherein said second conductor comprises a round conductive bar with a thin coating of insulating material.

11. In an electronic musical instrument having a keyboard with a plurality of keys, a tone signal generator for producing a tone signal, means for controlling said tone signal generator in response to operation of said keys and an output system for receiving said tone signal and converting the same into sound waves, the combination comprising:

(a) sensing means juxtaposed with said keyboard and responsive to a plurality of said keys for sensing the force with which said keys are operated and for producing a signal having a level corresponding to said force,

(b) amplifier means connected to said sensing means and to said output system for controlling the amplitude of said sound waves in response to said signal, and

(c) means connected with said sensing means for compensating said sensing means against changes in ambient conditions.

12. In an electronic musical instrument having a keyboard with a plurality of keys, a tone signal generator for producing a tone signal, means for controlling said tone signal generator in response to operation of said keys and an output system for receiving said tone signal and converting the same into sound waves, the combination comprising:

(a) sensing means juxtaposed with said keyboard and responsive to a plurality of said keys for sensing the force with which said keys are operated and for producing a signal having a level corresponding to said force,

(b) amplifier means connected to said sensing means and to said output system for controlling the amplitude of said sound waves in response to said signal,

(c) said sensing means comprising a variable capacitor unit having first and second conductors and a dielectric therebetween, said first conductor being mechanically connected to said key for changing its position relative to said second conductor to cause the capacitance of said capacitor to vary in response to a force applied to said key, and voltage producing means connected to said variable capacitor for producing a DC voltage in response to the capacitance of said variable capacitor, and

(d) said voltage producing means including an adder unit and means for generating a correction voltage which is equal and opposite to said DC voltage for the quiescent capacitance of said variable capacitor.

13. A variable capacitance unit for the keyboard of an electronic musical instrument for producing a signal responsive to the force with which a key of said keyboard is operated, comprising:

(a) a first conductor disposed below said keyboard and extending along the length thereof,

(b) a second conductor supported above said first conductor and adapted to be moved downwardly in response to operation of one of said keys,

(c) a dielectric layer interposed between said first and second conductors for maintaining them electrically insulated from each other,

(d) electrical conductor means secured to said first and second conductors for manifesting an electrical DC signal in response to the capacitance between said first and second conductors, and

(e) detection means for sensing the quiescent capacitance of said variable capacitor and for producing a signal responsive thereto, and means connected to said variable capacitor and to said detection means for producing an output signal which is compensated for quiescent capacitance.

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