United States Patent [19]

Studer

[11] **3,880,039**

[45] **Apr. 29, 1975**

[54] **SAMPLE AND HOLD CIRCUIT FOR AN ELECTRONIC ORGAN**

[75] Inventor: **Richard L. Studer**, Villa Hills, Ky.

[73] Assignee: **D. H. Baldwin Company**, Cincinnati, Ohio

[22] Filed: **Feb. 26, 1974**

[21] Appl. No.: **445,985**

[52] **U.S. Cl.** **84/1.01**; 84/DIG. 2; 84/DIG. 8; 84/DIG. 10; 84/DIG. 20

[51] **Int. Cl.** **G10h 1/00**; G10h 5/00

[58] **Field of Search** ..... 84/1.01, 1.03, 1.24, DIG. 2, 84/DIG. 8, DIG. 10, DIG. 20

[56] **References Cited**

UNITED STATES PATENTS

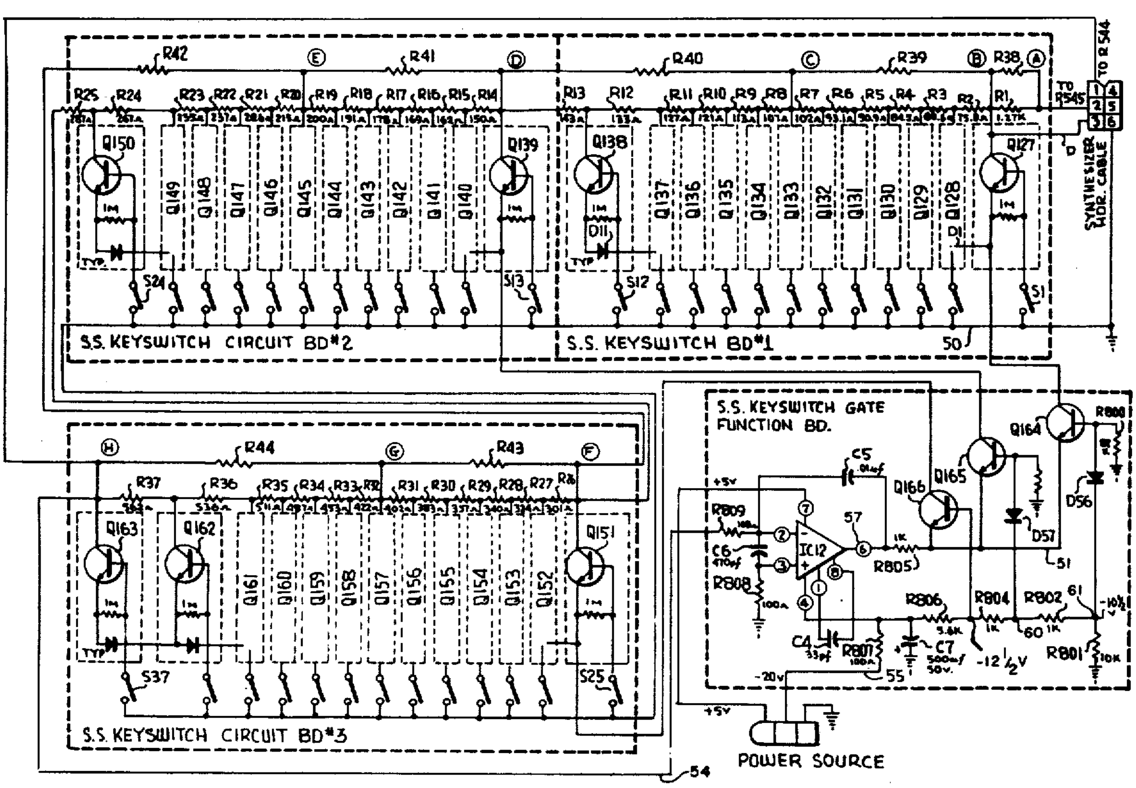
2,568,797	9/1951	Eland	84/DIG. 10
2,933,699	4/1960	Bonham	84/DIG. 20
3,288,904	11/1966	George	84/1.01
3,535,430	10/1970	Maynard	84/1.24 X
3,538,804	11/1970	George	84/1.01
3,569,603	3/1971	Kern	84/DIG. 10
3,609,201	9/1971	Adachi	84/1.01
3,609,203	9/1971	Adachi	84/1.01
3,659,031	4/1972	Adachi	84/1.01
3,733,955	5/1973	Reinagel et al.	84/1.01
3,776,087	12/1973	Ogi	84/1.24
3,786,166	1/1974	Mieda	84/1.01
R27,983	4/1974	Stearns	84/1.01

Primary Examiner—Stephen J. Tomsky
Assistant Examiner—Stanley J. Witkowski

[57] **ABSTRACT**

A sample and hold circuit for an electronic organ, in which the voltage across a cascade of resistances, selected points of which may be caused to equal ground by key switch controlled logic circuitry, is maintained at a fixed predetermined value by means of a feedback circuit, the voltage output of which is used to control the frequency of a voltage controlled tone signal oscillator, the value of the feedback voltage required being a function of the identity of the closed key switch which represents the highest note played, if plural key switches are closed. The logic circuitry selects both the highest octave containing any selected switch, and provides a virtual ground physically ungrounded at a point of the cascade of resistances corresponding with that closed switch of several which represents the highest note played.

19 Claims, 2 Drawing Figures



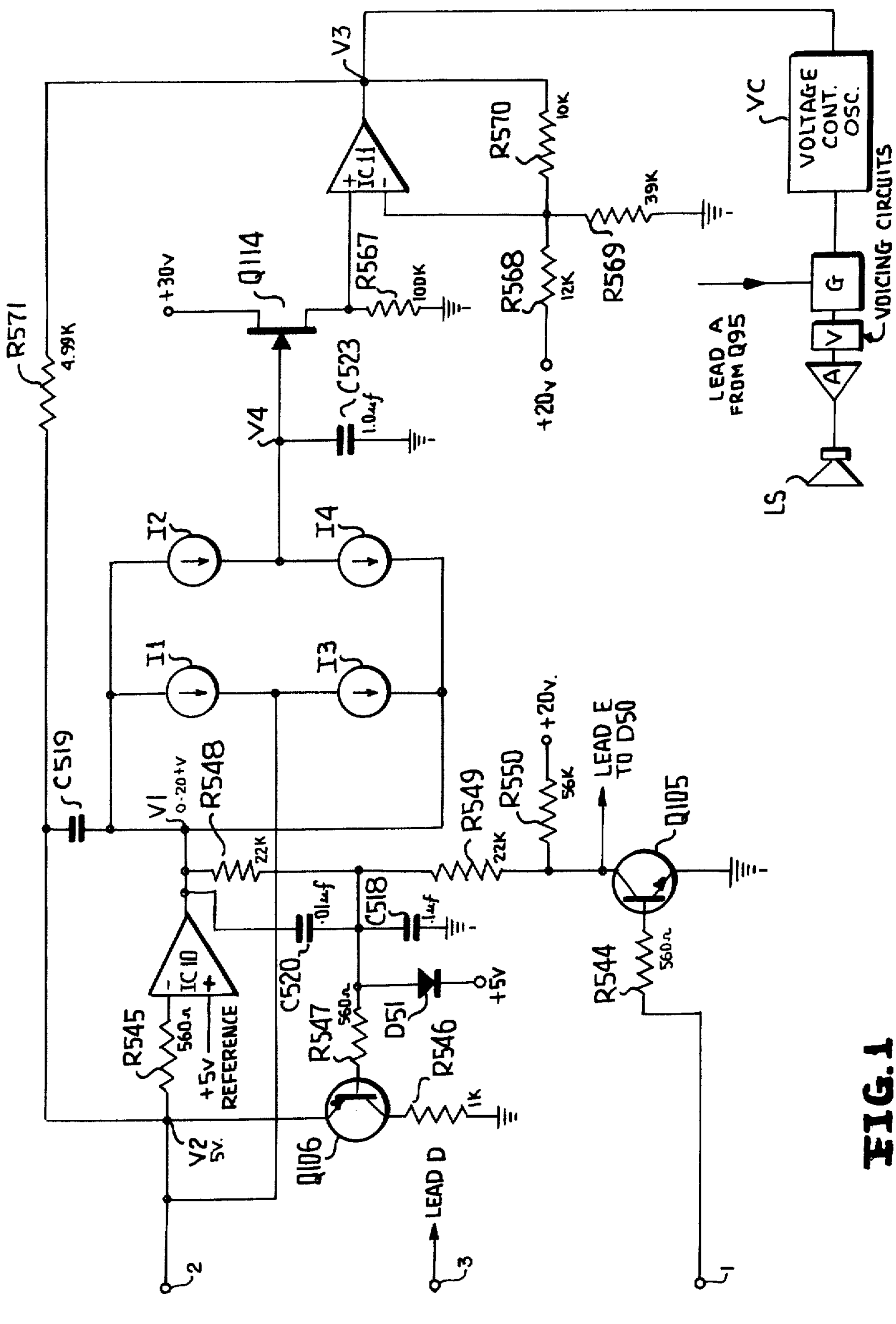

V3
VOLTAGE CONT. OSC.
VC
IC11
R570
10K
R567
100K
Q114
+30v
R568
12K
R569
39K
VOICING CIRCUITS
G
V
A
LEAD A FROM Q95
+20v
R571
4.99K
C523
1.0uf
V4
LS
I2
I4
I1
I3
C519
V1
0-20+V
R548
22K
R549
22K
R550
56K
+20V.
LEAD E TO D50
Q105
C518
.1uf
C520
.01uf
IC10
R545
560Ω
+5V
REFERENCE
R547
560Ω
D51
+5V
R546
1K
R544
560Ω
V2
5V.
Q106
LEAD D
2
3
1

FIG.1

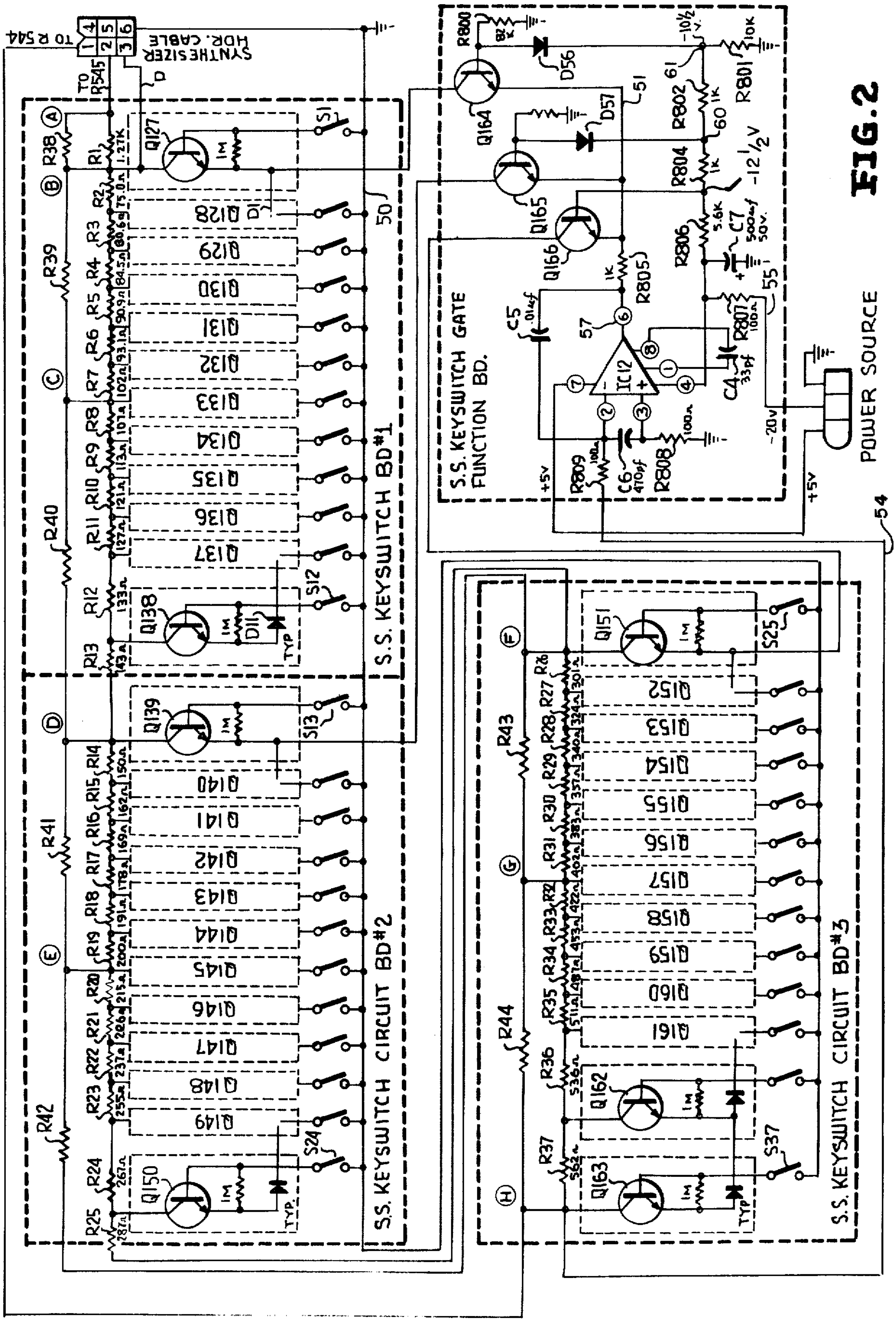

S.S. KEYSWITCH CIRCUIT BD#1
S.S. KEYSWITCH CIRCUIT BD#2
S.S. KEYSWITCH CIRCUIT BD#3
S.S. KEYSWITCH GATE FUNCTION BD.
POWER SOURCE
SYNTHESIZER HDR. CABLE
TO R544
TO R545
IC12

FIG. 2

SAMPLE AND HOLD CIRCUIT FOR AN ELECTRONIC ORGAN

BACKGROUND

In a previous application for U.S. patent, Ser. No. 263,649, filed June 16, 1972, in the name of David Bunger, assigned to the assignee of the present invention, there is disclosed a monophonic organ having provision for sounding only the highest note played, and for controlling the frequency of a single tone signal source in response to a voltage which is determined by that highest note played. The Bunger system includes a sample and hold circuit which is interposed between the source of control voltage which ultimately controls the tone signal source, and the voltage control terminal directly applied to that source for effecting frequency control. That sample and hold circuit must be precise, i.e., its output voltage must equal its input voltage. However, various diode drops occur in the sample and hold circuit, which must be compensated for. The diode drops, i.e., the voltage between base and emitter for a transistor, or the voltage across a diode, are temperature sensitive, and there occurs a failure of precise tracking as a function of temperature, which in turn results in imprecision of tuning.

In a prior application for U.S. patent, filed in the name of Munch, Uetrecht and Studer, Ser. No. 370,283, filed June 15, 1973, and entitled "Sample and Hold Circuit," which is assigned to the assignee of the present application, a set of mechanical switches is employed to ground points of a resistance divider chain when keys of an organ manual were actuated. It has been found that such switches are not of essentially zero resistance when closed, and that their resistances are in fact unpredictable. This property upsets the voltage relations present, and consequently leads to incorrect tuning of the voltage controlled oscillator of the Munch, et al., system. The present system, as well as the Munch, et al., system, employs three octaves of keys plus one or thirty-seven switches. The disclosure of the Munch et al application is incorporated herein by reference.

The sample and hold system of the Munch, et al., application represents a solution to the problem of temperature dependence, and also eliminates inaccuracies of tuning which may result from variations of supply voltages, and of imprecision of amplifier gains, in that output voltage of the system, representing a desired tone frequency, is controlled by a negative feedgack loop extending around the entire sample and hold circuit, and in that the feedback loop is reference to one fixed voltage. The present invention additionally solves the problem of variation of switch contact resistance.

SUMMARY OF THE INVENTION

A sample and hold circuit in a monophonic electric organ, in which organ keys set a zero voltage point along an array of resistances, and in which a negative feedback circuit extends from the output of the sample and hold circuit to the array of resistances and serves to maintain a predetermined point of the array of resistances at constant voltage regardless of the resistance to ground to the array when any of the keys is operated.

Three octaves of organ keys are hence of resistances are involved and these are in circuit on a per octave basis and the junctions of the resistances are placed at effective ground values via transistor switches instead of via mechanical switches which connect to actual ground.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit diagram of a system as disclosed in Munch, et al., Ser. No. 370,283, filed June 15, 1973 assigned to the assignee of the present invention.

FIG. 2 is a circuit diagram of the system of the present, invention, connected to the system of FIG. 1.

DETAILED DESCRIPTION

The system can be divided into three sections. The first is called the sample and hold section, and provides a voltage that corresponds to the highest note key being played, or, if no keys are presently being played, to the last highest not key that was played. This section is illustrated and described in Munch, supra.

FIG. 1 contains integrated circuits **IC10** and **IC11** which are operational amplifiers. The current sources **I1** through **I4,** which are constructed with transistors and resistors, are described in Munch Ser. No. 370,283. The current sources are under the control of the voltage **V1.** When the voltage V1 is below 5 volts, current sources **I3** and **I4** are turned on. When the voltage **V1** is between 5 volts and 20 volts, all four current sources are essentially turned off (open circuit). When the voltage **V1** is above 20 volts, current sources **I1** and **I2** are turned on. In addition to providing an On - Off control, the voltage **V1** determines the magnitude of these current sources. The ratio of **I2** to **I1** when these current sources are turned on is equal to the ratio of **I4** to **I3** when the latter current sources are turned on.

The operation of the sample and hold under various conditions is as follows. With any switch **SI-S37** closed, transistor **Q105** is turned off which allows diode **D51** to become forward biased through **R549** and **R550** if **V1** does not fall below 0.8 volt. This condition on V1 is always satisfied. Transistor **Q106** is off because its emitter is held at 5 volts and its base is a diode drop above that voltage. These two transistors are now essentially out of the circuit.

The desired output voltage **V3** with any key switch closed is the value that will cause the voltage **V2** to be 5 volts. The voltage **V2** is determined by the resistor voltage divider consising of resistance **R571** and all switch resistors from **R1** to the resistor immediately preceding the switch that is closed, and the output voltage **V3.** For example, with switch **S3** closed and **I1** through **I4** equal to zero, which occurs while **V1** is between 20 and 5 volts, the voltage **V2** will be related to the output voltage by the following expression:

$$(1)\qquad V2 = V3\left(\frac{R1 + R2 + R3}{R1 + R2 + R3 + R571}\right)$$

Since the desired value of *V3* is that which results in *V2* equal to 5 volts the following expression gives its value:

$$(2)\qquad V3\ (S3\ \text{closed}) = 5\left(\frac{R1 + R2 + R3 + R571}{R1 + R2 + R3}\right)$$

If prior to the closing of switch **S3**, the output voltage *V3* is higher than the desired value as defined by equation (2), equation (1) indicates that the voltage *V2* will be higher than 5 volts. The voltage $V2$, however, will be prevented from rising by I3. For a very small increase in $V2$, $V1$ will fall below 5 volts and turn on current source I3 which will provide a shunt path around the switch resistors to lower $V2$. This negative feedback will cause $V2$ to assume the value that will maintain the current source I3 at the proper level. The above description uses the fact that if the positive (+) and negative (−) inputs of the operational amplifier are at the same voltage, the output voltage is 15 volts. Therefore, to maintain V1 below 5 volts, the negative input of the operational amplifier must be at a higher voltage than the positive input. Since the required change in voltage from nominal at v1 is 10 volts (15-5), the voltage difference required between the positive and negative inputs must be this voltage divided by the gain of the operational amplifier. This gain is infinity in theory and in practice is typically above 100,000. This results in a required voltage difference between the operational amplifier inputs of

$$\Delta v = \frac{10 \text{ volts}}{100{,}000 \text{ volts}} = 0.0001 \text{ volt}$$

This voltage Δv is called the differential input voltage and is added to the voltage at the positive input terminal to obtain the voltage V2, i.e., V2 = 5 volts + 0.0001 volts = 5.001 volts. The small value of this differential input voltage implies that for practical purposes, the differential voltage is zero and both terminals are at the same voltage. This assumption remains true whenever negative feedback like that provided by I3 is present.

The initial value of the current souce I3 is now calculable because the value of V2 has been determined to be +5 volts. The current through R571 is known because its value is specified and the voltage across it is known. Likewise the current through the switch resistors is known and I3 must be the difference between these two.

$$I3 = \frac{V3 - V2}{R571} - \frac{V2}{R1 - R2 + R3} \quad (3)$$

Since V2 = 5 volts,

$$I3 = \frac{V3 - 5}{R571} - \frac{5}{R1 + R2 + R3} \quad (4)$$

Equations (2) and (4) show that I3 equals zero if V3 is at the desired voltage and that I3 is dependent upon the difference between the actual value of the output voltage and the desired value. Current source I4 is dependent upon I3. Its value therefore also depends upon this error voltage. Current source I4 discharges capacitor C523 whose voltage is amplified by transistor Q114 and IC11 to become the output voltage V3. The output voltage V3, therefore, begins to fall and approaches the desired value. As the voltage V3 approaches the desired value, I3 and I4 are reduced which slows the discharge of C523. When the output voltage V3 reaches the desired value, both current sources are turned off and the discharge of C523 stops. The speed with which this process takes place is determined by the ratio of current source I4 to I3. If this ratio is large, I4 is large and the output voltage converges quickly to the desired value. If, however, this ratio is small the output voltage converges slowly to the desired value. This voltage change has the same transient characteristics as a series RC combination (exponential) due to the feedback provided by I3 and I4.

If the output voltage is lower than the desired value before the switch is closed, or if a switch with a lower index number is closed after the output voltage has settled to the desired value, the system will correct itself in a similar manner. For these circumstances, however, V2 will attempt to be lower than 5 volts, which will force V1 above 20 volts thereby turning on current sources I1 and I2. Current source I1 provides the negative feedback to control IC10 and corresponds to I3 in the previous discussion. Current source I2 provides charging current for capacitor C523 to allow the output voltage to reach the desired value, and corresponds to I4 in the previous discussion.

The above description may be said to be of the transient portions of the sample mode. After the transient portion is complete, which indicates that the output voltage is at the desired value for the particular switch closed, the system continues to maintain the correct output level. Any noise, leakage currents, or other disturbances that attempt to change the output level will appear at V2 and adjust V1 to turn on the proper current source so that the proper correction can be made. Thus, while a key is being held, V1 can be at any voltage between 5 and 20 volts. Capacitor C519 provides additional negative feedback from V1 to V2 which slows the rate of voltage change at V1. This is necessary to both protect against large noise spikes and to protect against noise from the key switches during opening and closing operations.

When all key switches are released it is necessary that the sample and hold circuit to transferred into the hold mode. This is accomplished by using the 5 volts at V2 through all key switch resistors connected in series to saturate Q105. With all key switches open the output voltage V3 would, unless prevented by control circuits, fall to a lower voltage than with any key switch closed. The voltage at V1 would fall and attempt to turn on I3 and I4. However, with Q105 saturated, when the voltage at V1 is equal to 10 volts, transistor Q106 turns on via R548 and provides negative feedback to V2, which will hold V1 at 10 volts. With V1 at 10 volts all current sources I1 through I4 and zero and there exists no charging or discharging current for C523. The output voltage therefore remains at the value corresponding to the last key played. The hold time is determined by the ability of capacitor C523 to hold charge, which explains the need for the buffer amplifier consisting of Q114 and IC11. This amplifier has a DC gain of 2 with respect to 15 volts which means that a voltage of 18 volts at the positive terminal of IC11 will produce an output voltage of 21 volts. This gain reduces the voltage swing required at capacitor C523 to produce a given voltage range at the output. Resistors R568 and R569 provide the resistor divider necessary to supply an effective 15 volts with a 10K impedance to the junction of R570 and the negative input of IC11, which is required to give the amplifier this gain. Resistor R567 provides bias current for transistor Q114 and resistors R545, R547, R546 and R544 are current limiting resistors, which prevent destruction of their associated active components under accidental short circuit conditions. Capacitors **C518** and **C520** provide additional noise and switch bounce protection.

The description of the operation of these current sources, **I1** – **I4** is not provided herein, because reference can be made to Munch, et al., identified supra, for such description, and because the details of the mode of operation of these current sources is not pertinent to the present improvement.

FIG. **2**, the connector plugs **1, 2, 3** are connected, respectively, to corresponding plugs in FIG. **1** and to resistance **R544**, resistance **R545**, and lead **D** of FIG. **1** respectively.

Instead of connecting the junctions of resistance **R1** – **R37** directly to a ground lead as in Munch, et al, supra, via mechanical switches **S1-S37** transistors **Q127** – **Q163** are substituted and connected to adjust the junctions to virtual ground, and these transistors have their bases connected to grounded base lead **50** via the switches **S1–S37**. When a switch, as **S1**, is closed, its associated transistor, as **Q127**, is rendered conductive, since its emitter is connected to a negative voltage point, i.e., the collector of **Q164**, which has its emitter connected to a negative lead **51**.

The emitters of transistors **Q127** to **Q138**, corresponding with one octave of notes, are interconnected via diodes as **D1** to **D11**, only **D11** being illustrated, which serve to isolate these emitters from each other and to provide certain voltage drops. **Q127** employs no diodes, and in general the highest note transistor of each octave includes no diode while all other note transistors do, the circuit of **Q150** being typical.

The operational amplifier **IC12** is supplied with + 5 volts at its terminal **7**, its terminal **2** is connected via a small resistance **R809** and lead **54** to the last resistance **R37** of the resistance chain **R1** – **R37**, and therefore has a 5 volt voltage applied thereon, if no key is operated, because the input resistance at terminal **2** of **IC12** is almost infinite. The terminal **4** is connected to lead **55**, which is held at −20 volts. The lead **55** is connected to ground via resistances **R807, R806, R804, R802, R801**. The junction of resistances **R806** and **R804** is at −12½ volts, the junction of resistances **R804** and **R802** at −11½ volts, and the junction of resistances **R802** and **R801** at −10½ volts, and these voltages are steady voltages, applied to the bases of **Q166, Q165** and **Q164**, respectively. The emitters of these transistors have variable voltages applied to them. For no keys closed, the voltage at point **57** is −20 volts.

The bases of **Q165** and **Q164**, but not of **Q166**, are connected to the points **60, 61** via diodes **D57** and **D56**, respectively, which serve to mutually isolate the bases of the transistors **Q165** and **Q164** from the −11½ and −10½ volts references.

Point A of the resistor chain R1 to R37 is held at −5 volts, as by the circuitry of FIG. **1**. If no key switch is closed, this voltage is applied through **R1-R37** to the **2** lead of **IC12**, which is referenced to zero volts. The output of **IC12** therefore approaches −20 volts, since this is the voltage applied to terminal **4** of **IC12**. These are the conditions if none of switches **S1–S37** are closed.

If any key switch is closed the base-emitter junction of the associated transistor will be forward biased, and will provide negative feedback for **IC12**. For example, if **S24** is closed the output voltage of **IC12** will fall to about −12 volts, which in turn will turn on **Q165**. The voltage at the collector of **Q165** will then fall to approximately −7.2 volts, equal to the voltages across eleven forward baised diodes, as **D1** to **D11**, and one forward biased emitter junction. The forward biased diodes are those connected to the emitters of **Q150** to **Q140**, no diode being present at **Q139**, and the emitter junction being that of **Q150**. Transistor **Q150** then turns on because it has a current path through **Q165**.

The negative feedback path from the output of **IC12** through **Q165**, eleven diodes, **Q150** and **R25** to **R37** to the input of **IC12** will cause **Q150** to conduct precisely the correct current to hold the junction of **R24** and **R25**, i.e., the collector of **Q150**, at zero volts. The result is achieved because **IC2** has extremely high input impedance and gain, so that the effect is the same as if the junction of **R24** and **R25** were directly grounded through a perfect switch.

The number of diode drops involved is only that required to assure that **Q165** will turn on. Once it is on the feedback path takes over to control voltage and the high impedance of **IC12** prevents current flow beyond the point where a conducting transistor, of **Q139-Q150**, exists.

If **S23** were now closed, **Q149** would be turned on and the collector voltage of **Q165** would rise by one diode drop, since then only ten diodes and the base-emitter junction of **Q149** would be forward biased. This removes the forward bias from **Q150**, and holds the junction of **R23, R24**, at zero volts, and this junction now represents the highest note played.

Each of the three octaves is connected to the output of **IC12** through a separate transistor, i.e., **Q166, Q165** and **Q164**. These three transistors provide highest octave preference due to the diverse voltages applied to their bases. The highest note played will always force its associated one of transistors **Q164, Q165** and **Q166** to turn on, which will prevent a lower octave from turning on.

There are, accordingly, two preference actions in the present system, - one is per octave and the other per note within an octave. Once a zero voltage point has been established along **R1-R37**, any lower note is inoperative, because the associated lower octave transistor or transistors of **Q164, Q165, Q166**, if any exist, cannot become conductive, and because lower note transistors within an octave cannot become conductive.

Resistances **R38** to **R44** are to provide precision of resistance values for the resistances **R1** to **R37**. The latter are 1.% resistances and are connected in groups of six across resistances **R38** to **R44**. It can then be the case, absent **R38–R44**, that a 6.% error of resistance will exist. The resistances **R38–R44** are selected to provide precisely the required resistance for the six resistor group. **R38** merely parallels **R1**, and these can be considered a single precise resistance, i.e., **R38** compensates for error in **R1** only.

What is claimed is:

1. An electric organ, comprising an array of keys of said organ, a resistance having points corresponding respectively with said keys, means responsive to actuation of any selected key of said array of keys for providing a physically undgrounded point of zero voltage at a point of said resistance corresponding with the selected key, said resistance having an invariable point of reference potential, means including a feedback loop for maintaining the voltage of said invariable point of reference potential constant where any of said keys is actuated by feeding back current through said resistance in amplitude sufficient to maintain constant said voltage of said invariable point of reference potential, said feedback loop including a storage capacity, a voltage controlled tone signal oscillator responsive to the voltage of a point of said feedback loop, and means for acoustically transducing said tone signal.

2. The combination according to claim **1**, wherein is included, a further high gain high input resistance feedback loop, means responsive to closure of any selected one of said key switches for controlling the voltage drops along said array of series connected resistances to provide said zero voltage at a junction of said array corresponding with the selected one of said key switches in response to the feedback action of said further feedback loop.

3. The combination according to claim **1**, wherein is included a further high gain high input resistance feedback loop, means responsive to closure of any selected plurality of said key switches for controlling the voltage drops along said array of series connected resistances to provide said zero voltage point at a junction of said array corresponding with that one of said key switches corresponding with the highest note represented by said selected plurality of said key switches in response to the action of said further feedback loop.

4. The combination according to claim **1**, wherein said means responsive to any selected key of said array of keys includes a voltage divider having points each corresponding with one of said first mentioned points, normally open electronic switches closable in response to actuations of said keys and each connecting one of said points of said resistance with one of said points of said voltage divider, and a further feedback loop between said voltage divider and said resistance.

5. An electric organ, comprising an array of key switches, a resistance, means responsive to operation of any combination of said key switches for adjusting the value of said resistance by providing one physically undergrounded point of zero voltage at any of plural preselected discrete points of said resistance corresponding with only one of said key switches, circuit means including a voltage comparator extending from an invariable point of said resistance to an output point, a resistive feedback loop extending from said output point to said further invariable point, a source of reference voltage, means for developing an input error signal for said voltage comparator as the difference of said reference voltage and the voltage of said invariable point, a voltage controlled tone signal source connected to said output point, and means for acoustically transducing the signal output of said tone signal source.

6. The combination according to claim **5**, wherein is provided a storage capacitor coupled to the output circuit of said amplifier to store the output voltage of said voltage comparator, and means responsive to said error signal for supplying charge to and abstracting charge from said storage capacitor as a function of the voltage of said invariable point.

7. The combination according to claim **5**, wherein said resistance includes plural arrays of series connected resistances, said arrays being connected in series, said arrays having junctions corresponding one-for-one with said key switches, further feedback loops, each including one of said arrays and all including a common high gain high input resistance operational amplifier, means responsive to closure of any selected plurality of said key switches concurrently for completing only that one of said feedback loops corresponding with that one of said arrays containing a junction corresponding with the highest pitched one of said key switches, and means further responsive to said closure of said selected plurality of said key switches to provide said undergrounded point of zero voltage at the last mentioned junction in response to the action of said further feedback loop.

8. The combination according to claim **5**, wherein said means responsive to operation of said key switches includes a separate normally open solid state switch operatively associated with each of said key switches, means responsive to closure of each of said key switches for rendering conductive the solid state switch associated with that key switch, a diode voltage divider chain interconnecting first corresponding terminals of said solid state switches to discrete points of said diode divider chain, said diode divider chain including identically poled diodes in series, a load circuit terminating said diode divider chain, a voltage comparator device including a source of reference potential and an input terminal for applying voltage for comparison with said reference potential by said voltage comparator device, and means responsive to the output of said comparison device for controlling the potential at said variable load circuit terminating said diode voltage divider chain, and means supplying voltage from one end of said resistance to said input terminal of said comparison device, said voltage comparison device providing a negative feedback loop extending from said one end of said resistance to said variable load circuit, said voltage comparison device being arranged to draw substantially zero current from said resistance via said input terminal, and means connecting second terminals of said solid state switches to said discrete points of said resistance, said variable load circuit being a voltage responsive device responsive to control voltage to provide a variable load as a function of magnitude of said control voltage.

9. The combination according to claim **6**, wherein said means responsive to actuation of any selected key of said array of keys includes a separate normally open solid state switch connected to be closed in response to operation of each of said keys, an amplifier, and a further feedback circuit extending through any closed ones of said solid state switches to the output of said amplifier and via said resistance to the input of said amplifier.

10. In an organ system, a chain of equal series connected resistances extending from a first point to a second point, a chain of equal impedances providing equal voltage drops thereacross extending from a third point to a fourth point, an amplifier having an input and an output, means applying a voltage to said first point, means connecting said second point to said input, means connecting any selected junctions of said resistances to selected ones of junctions of said impedances, means connecting said fourth point to said output, said third point floating, wherein is provided means for maintaining said first point at a fixed voltage, a voltage controlled tone signal oscillator, means responsive to said last means for controlling the frequency of said voltage controlled oscillator, and means for transducing the tone signal output of said oscillator.

11. An electric organ, comprising an array of normally open key switches, an array of electronic switches, each of said key switches when closed rendering conductive one of said electronic switches, a series resistance chain having junctions corresponding one for one and each connected to one terminal of one of said electronic switches, a diode chain including series connected correspondingly poled diodes, means connecting the remaining terminals of said electronic switches one for one with corresponding electrodes of said diodes, a source of control voltage, means applying said control voltage to one end of said resistance chain, an amplifier having an input terminal and an output terminal, means connecting the other end of said resistance chain to said input terminal, means connecting one end of said diode chain to the output terminal of said amplifier, said resistance chain, diode chain and electronic switches being arranged and interconnected to provide a circuit from said source of control voltage through resistances of said resistance chain and via closed ones of said electronic switches and via said diode chain to said output terminal, and said resistance chain alone providing a circuit from said source of control voltage to said input terminal.

12. An electric organ, comprising a series connected array of resistances having a reference point, means including key switches for bringing any selected junction of said array of resistances to a physically ungrounded zero potential, said junction being a function of the operated key switches, a comparison circuit responsive to the voltage of said reference point and to a fixed reference voltage for generating an error signal, a storage capacitor, current source and drain means responsive to said error signal for controlling the charge of said capacitor, an output terminal, means amplifying the voltage across said storage capacitor to provide an amplified version of said voltage across said capacitor to said output terminal, a resistive feedback circuit extending from said output terminal to said reference point, a voltage controlled tone signal oscillator connected to said output terminal and responsive to the voltage of said output terminal to generate tone frequency signals of variable frequency, and means for asoustically transducing said tone frequency signals.

13. The combination according to claim **12,** wherein is included means responsive to opening of all said key switches for disabling said current source and drain means for controlling said charge on said capacitor.

14. The combination according to claim **12,** wherein said means including key switches for bringing any selected junction of said array of resistances to a physically ungrounded zero potential includes a voltage divider chain, solid sate switches responsive to closure of said key switches for connecting said selected junctions one for one with points of said voltage divider, and a further feedback circuit connecting an end point of said voltage divider with and end point of said array of resistances.

15. The combination according to claim **14,** wherein said voltage divider is a series array of diodes each providing a fixed voltage drop.

16. The combination according to claim **15,** wherein said switch means are solid state switch means.

17. The combination according to claim **16,** wherein said impedances are diodes.

18. The combination according to claim **17,** wherein said amplifier is a comparator, said voltage of said first point is positive, and the output of said comparator is negative.

19. The combination according to claim **18,** wherein said chain of series connected resistances encompasses a resistance for each note of plural octaves of notes.

* * * * *