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Selected US specifications from IPC sub-class G10H

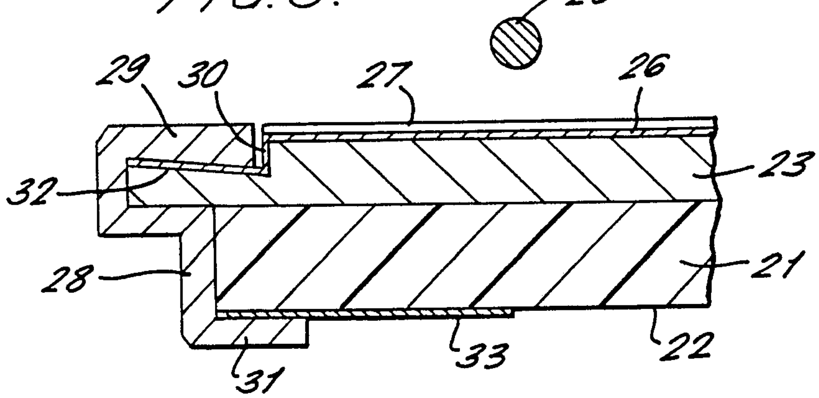
(54) Electronic musical instrument

(57) A guitar synthesiser has electrically conductive frets and strings (28). Electronic circuitry connected to the frets and strings identifies any electrical contacts between strings and frets during playing of the instrument and controls synthesiser circuits to generate tones accordingly. Each fret has contact resistance with a string (28) which is high relative to the longitudinal resistance of the fret from end to end. The fret can comprise an insulating substrate 23, a first conductive layer (26) providing a relatively low resistance from end to end of the fret, and a second surface layer (27) providing a relatively high resistance between the under layer (26) and any string (28) in contact with the surface layer (27).

This design of fret permits individual string/fret contacts to be identified in all circumstances, and also permits note "bending" to be measured.

Capacitive sensors may be used to detect the amplitude of string movement or vibration.

FIG. 3.



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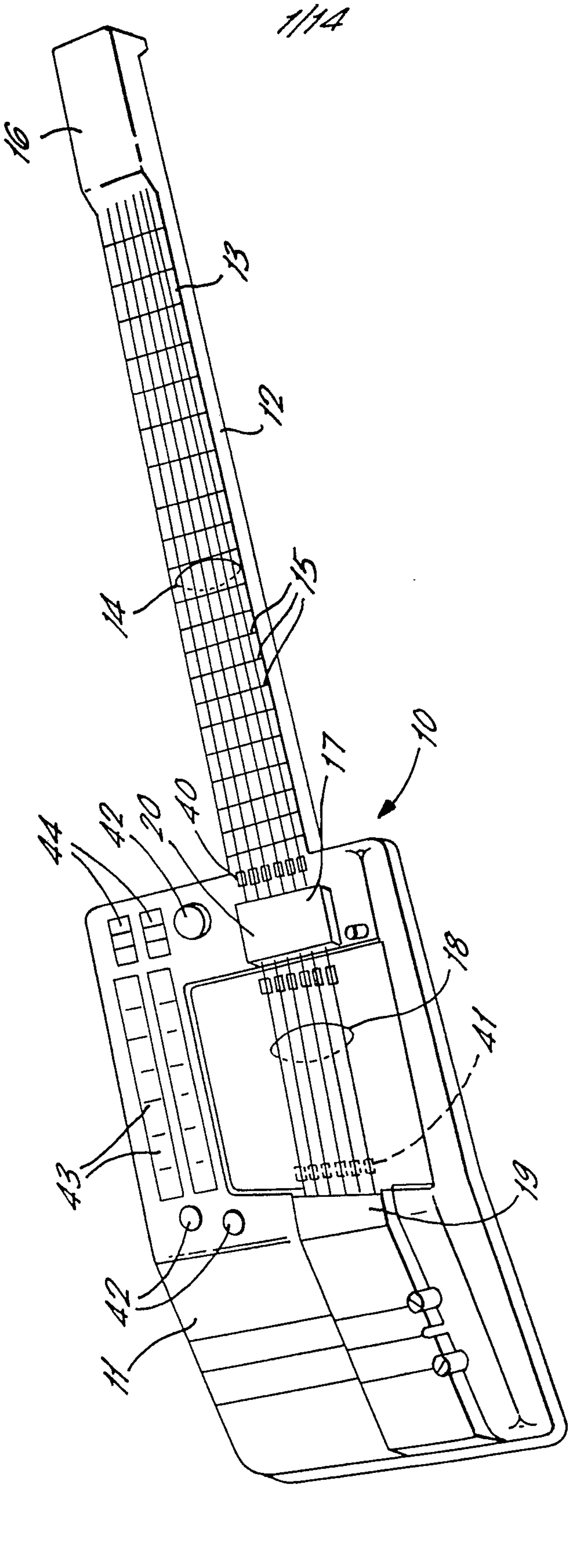


FIG. 1.

FIG. 2.

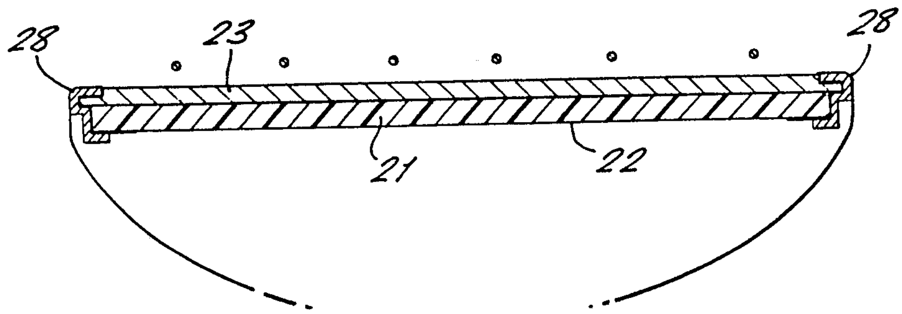


FIG. 3.

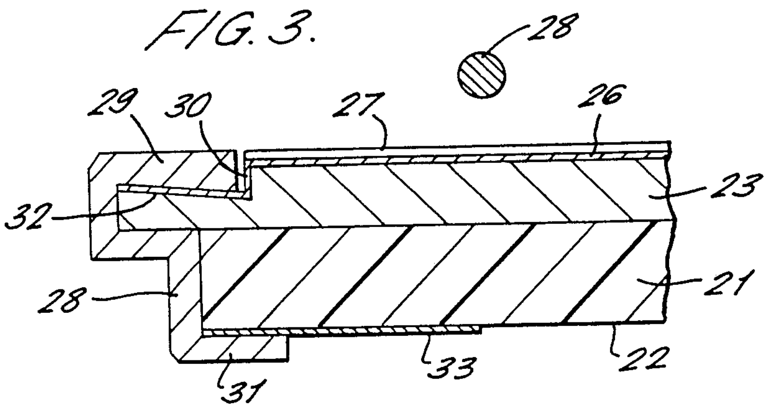


FIG. 4.

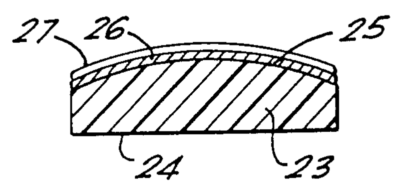
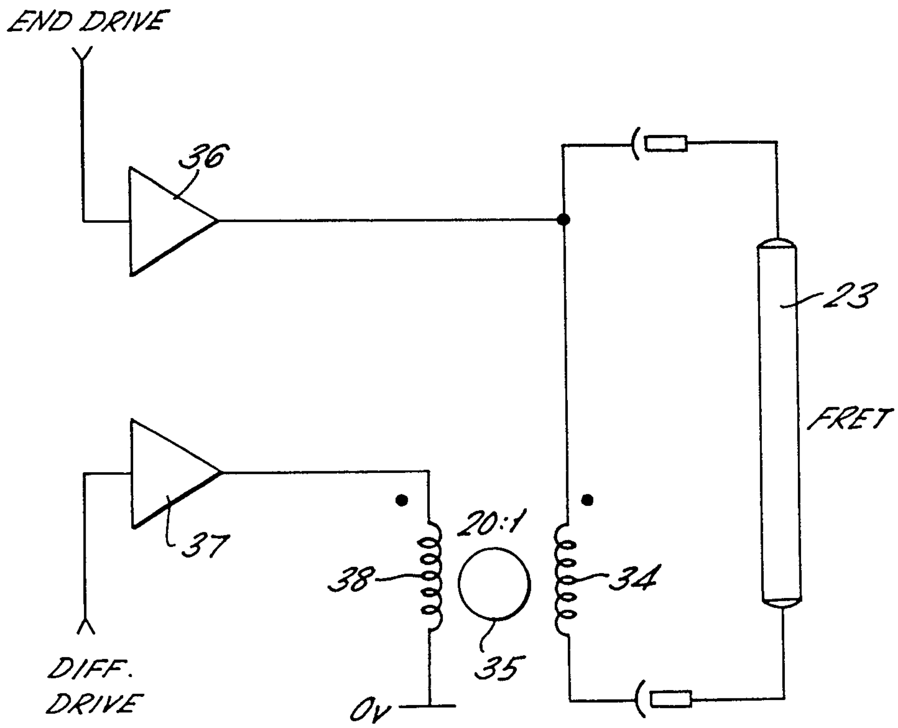


FIG. 5.



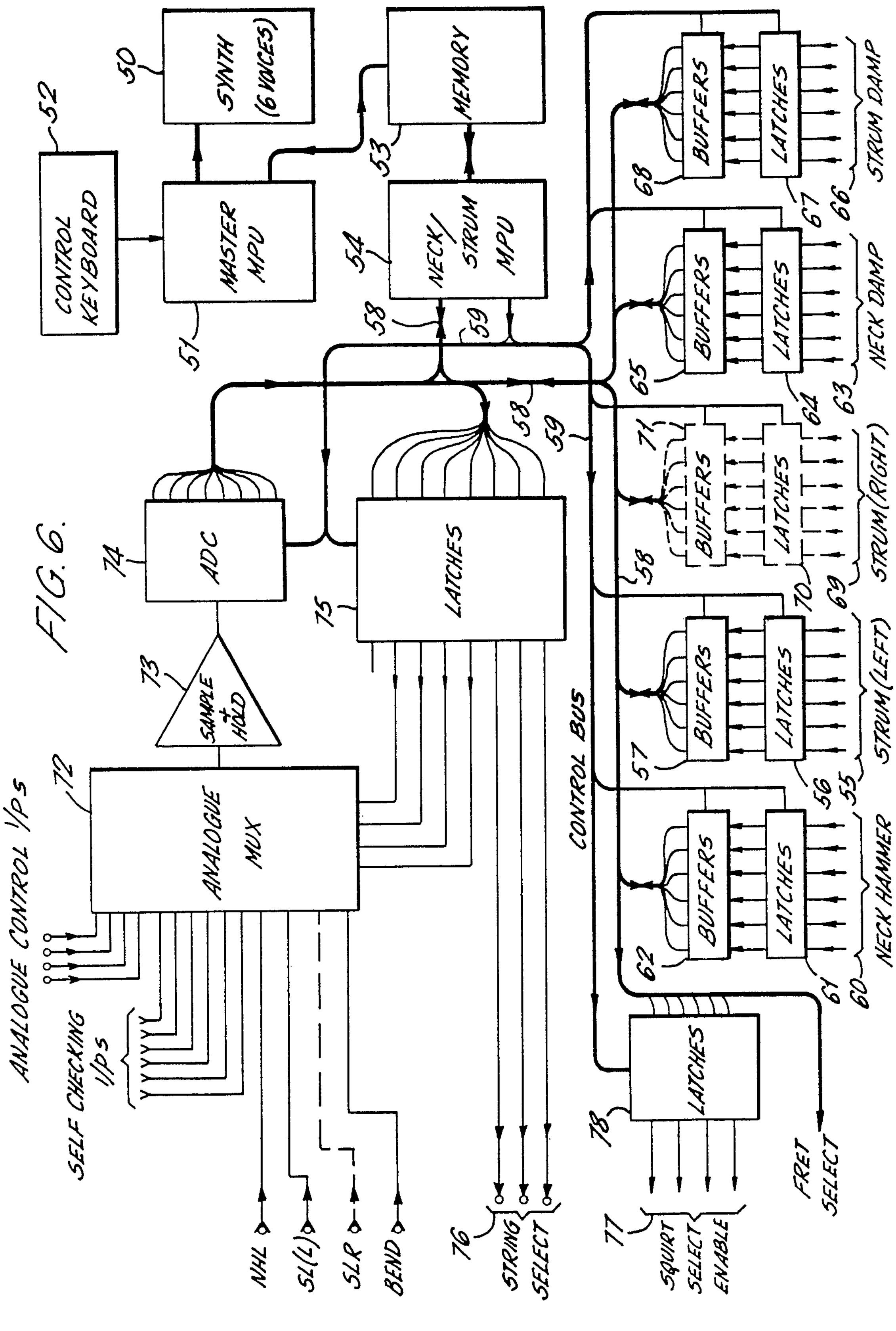

CONTROL KEYBOARD
52
MASTER MPU
51
SYNTH (6 VOICES)
50
MEMORY
53
NECK/ STRUM MPU
54
58
59
BUFFERS
LATCHES
68
67
66
STRUM DAMP
65
64
63
NECK DAMP
71
70
69
STRUM (RIGHT)
57
56
55
STRUM (LEFT)
62
61
60
NECK HAMMER
ADC
74
LATCHES
75
SAMPLE + HOLD
73
ANALOGUE MUX
72
ANALOGUE CONTROL I/Ps
SELF CHECKING I/Ps
NHL
SL(L)
SLR
BEND
76
STRING SELECT
CONTROL BUS
LATCHES
78
77
SQUIRT SELECT ENABLE
FRET SELECT

FIG. 6.

FIG. 7.

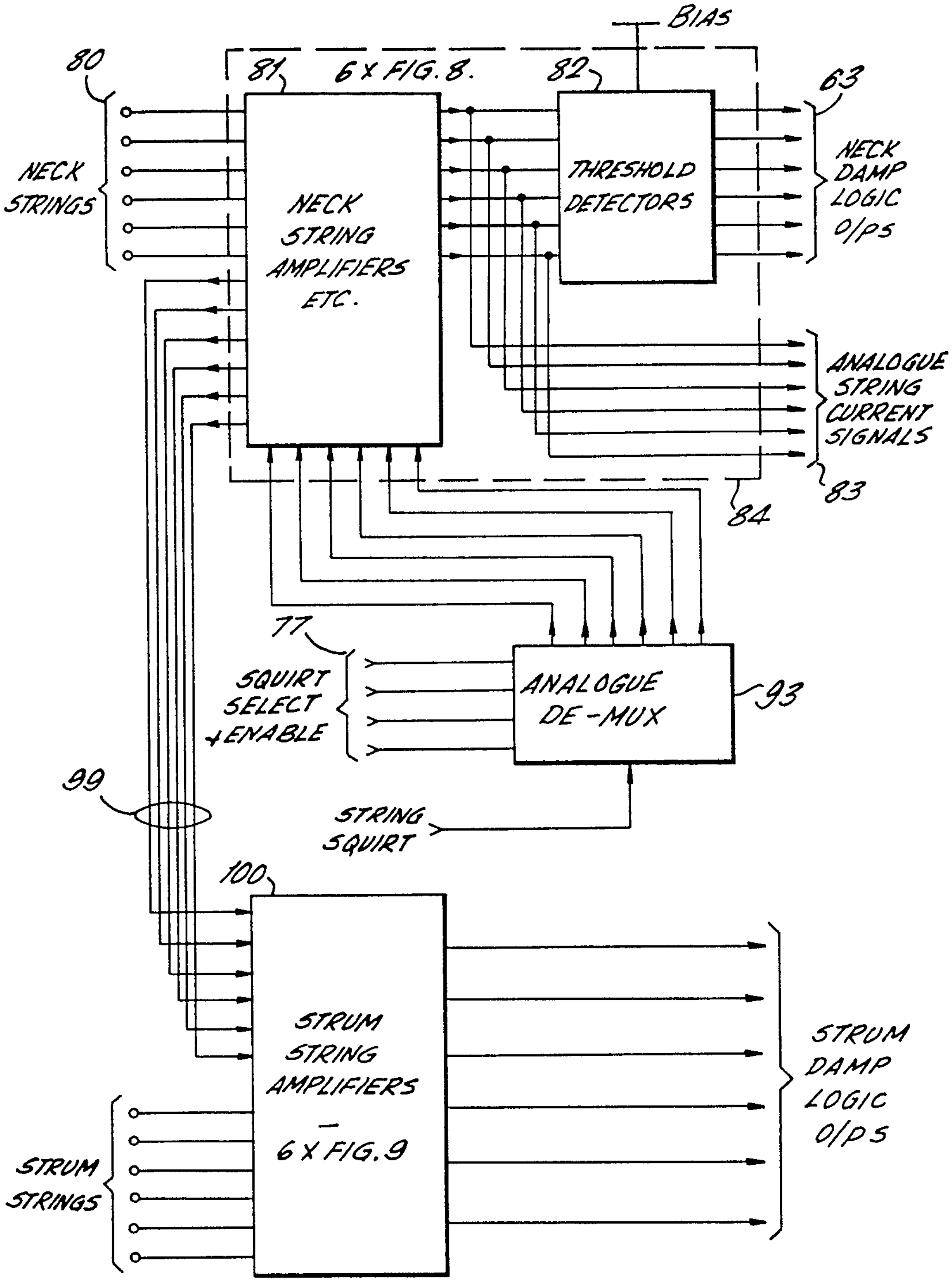
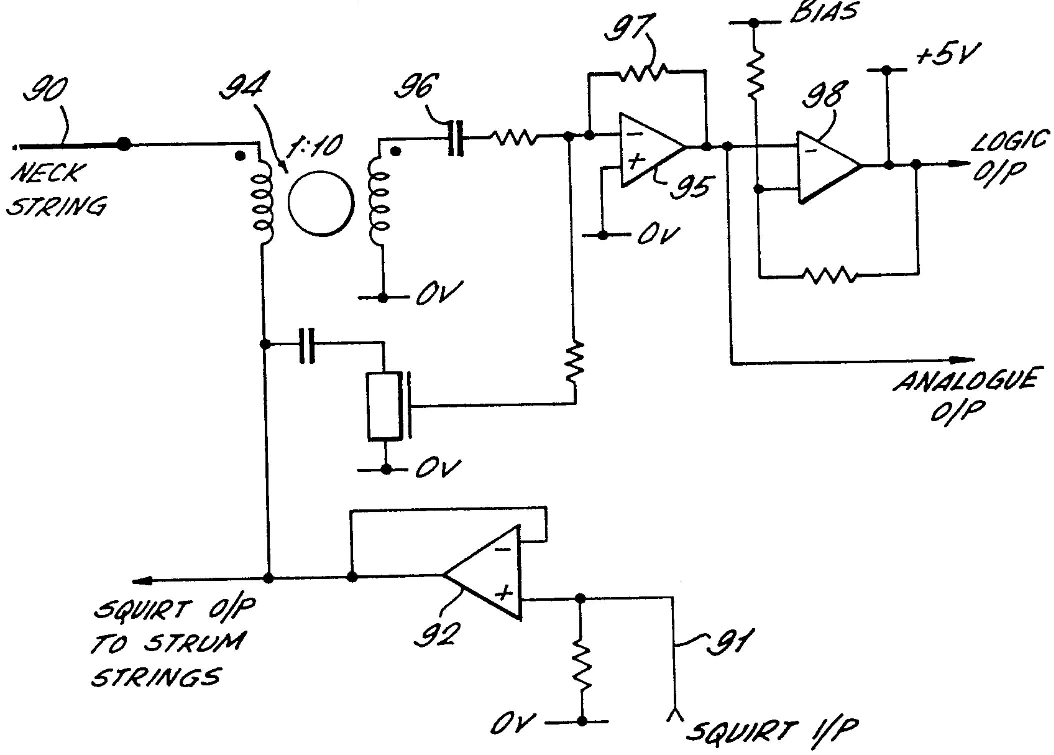
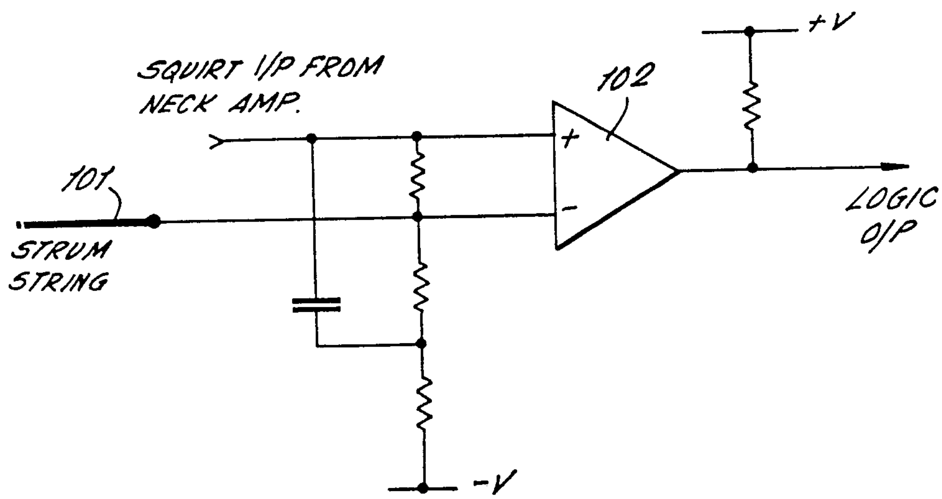

BIAS
80
81
6 x FIG. 8.
82
63
NECK STRINGS
NECK STRING AMPLIFIERS ETC.
THRESHOLD DETECTORS
NECK DAMP LOGIC O/PS
ANALOGUE STRING CURRENT SIGNALS
83
84
77
SQUIRT SELECT + ENABLE
ANALOGUE DE-MUX
93
99
STRING SQUIRT
100
STRUM STRING AMPLIFIERS
6 x FIG. 9
STRUM STRINGS
STRUM DAMP LOGIC O/PS

FIG. 8.



90
NECK STRING
94
1:10
96
97
BIAS
+5V
98
LOGIC O/P
95
0V
0V
0V
ANALOGUE O/P
SQUIRT O/P TO STRUM STRINGS
92
91
0V
SQUIRT I/P

FIG. 9.



+V
SQUIRT I/P FROM NECK AMP.
102
101
STRUM STRING
LOGIC O/P
-V

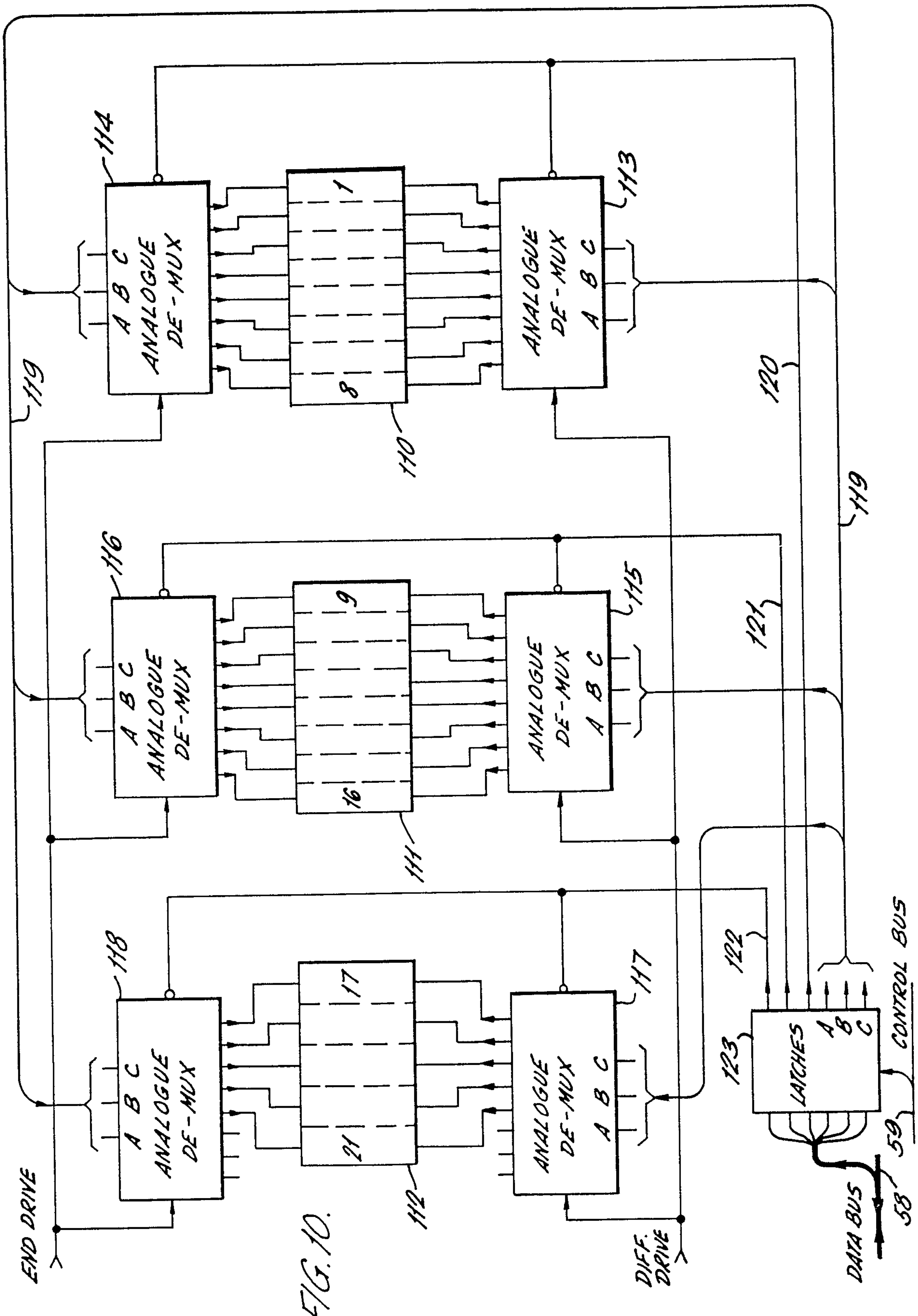

114
A B C
ANALOGUE
DE-MUX
1
8
110
113
ANALOGUE
DE-MUX
A B C
119
120
116
A B C
ANALOGUE
DE-MUX
9
16
111
115
ANALOGUE
DE-MUX
A B C
121
119
118
A B C
ANALOGUE
DE-MUX
17
21
112
117
ANALOGUE
DE-MUX
A B C
122
123
LATCHES
A
B
C
CONTROL BUS
59
DATA BUS
58
END DRIVE
DIFF. DRIVE

FIG. 10.

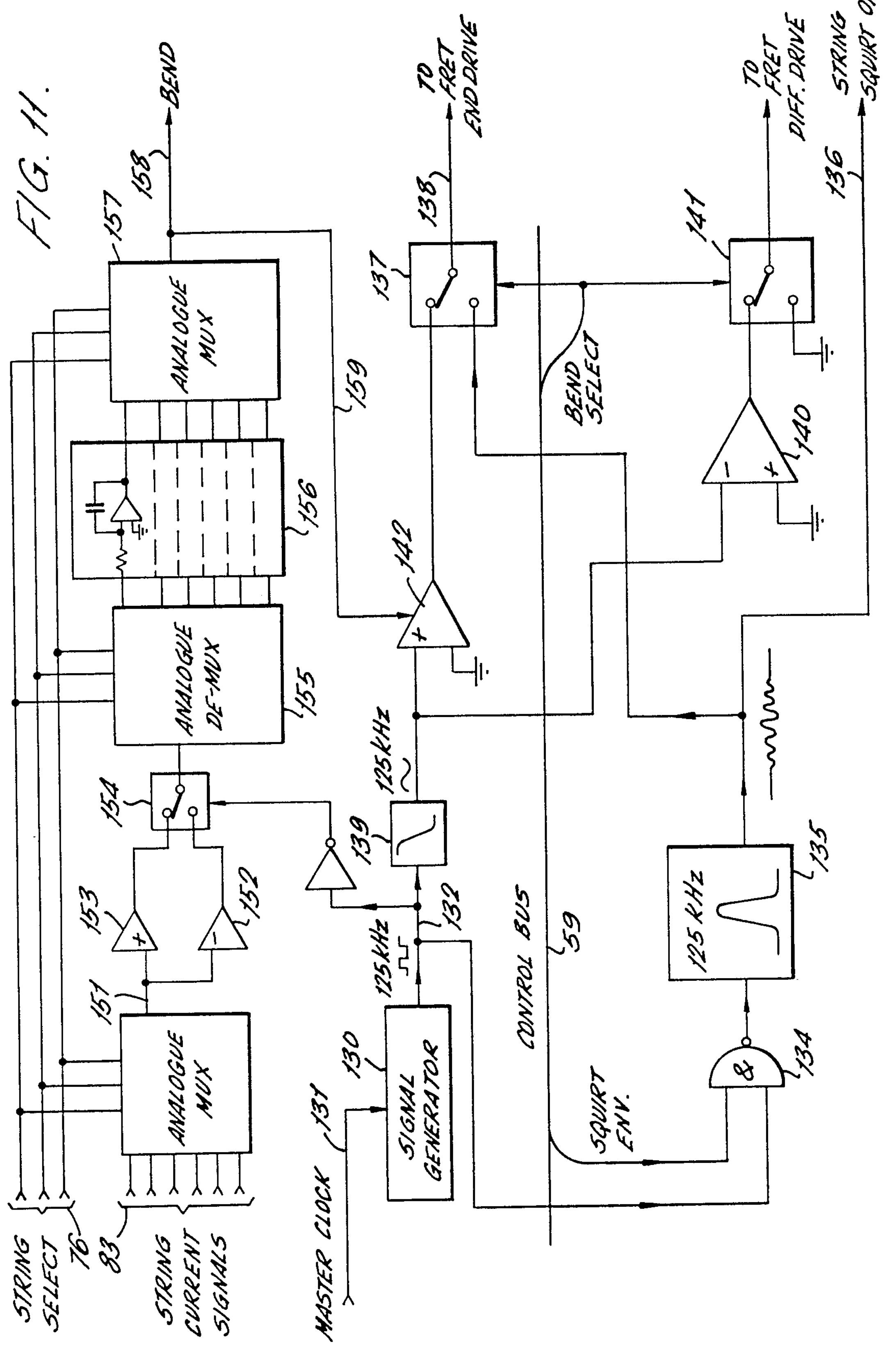

BEND
158
157
ANALOGUE MUX
159
156
ANALOGUE DE-MUX
155
154
153
152
151
ANALOGUE MUX
STRING SELECT
76
83
STRING CURRENT SIGNALS
139
125kHz
132
130
SIGNAL GENERATOR
131
MASTER CLOCK
142
137
138
TO FRET END DRIVE
BEND SELECT
CONTROL BUS
59
SQUIRT ENV.
134
&
135
125 kHz
140
141
TO FRET DIFF. DRIVE
136
STRING SQUIRT O/P

FIG. 11.

FIG. 12.

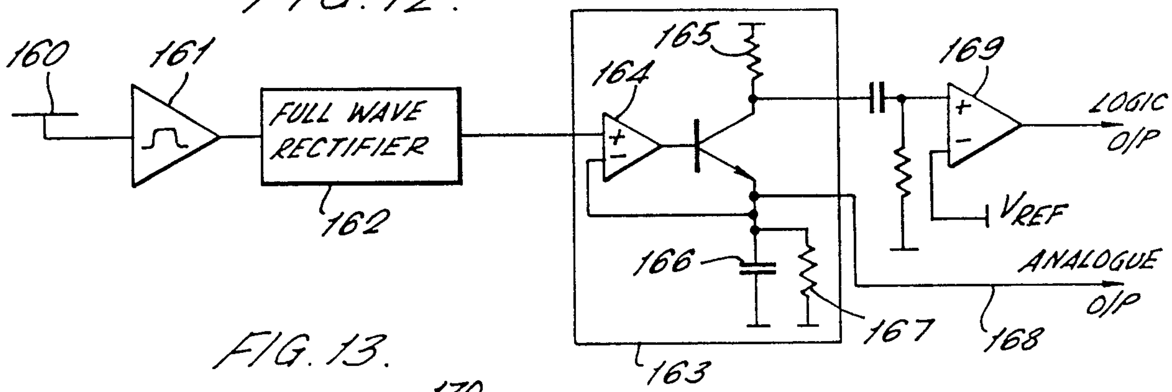
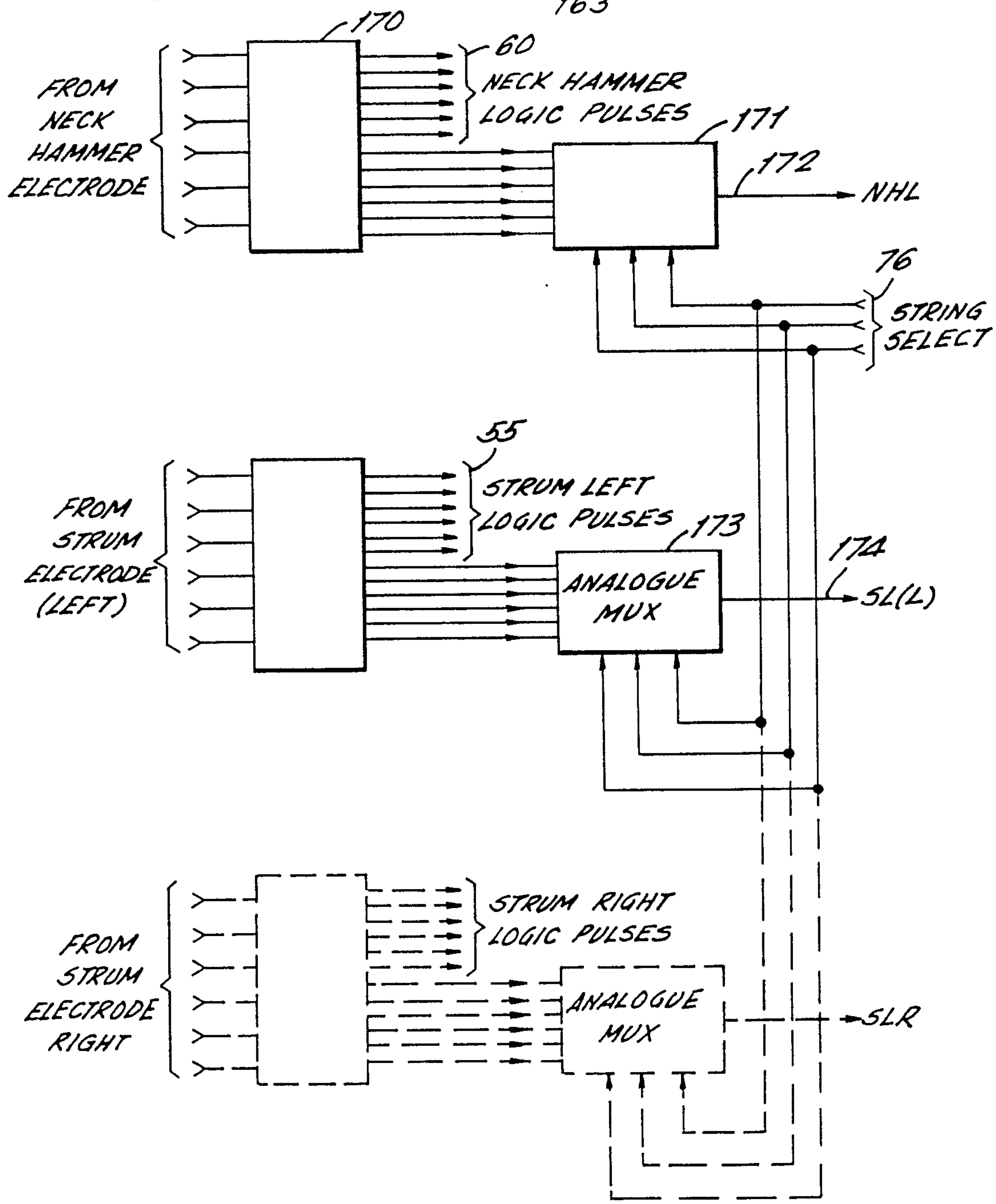
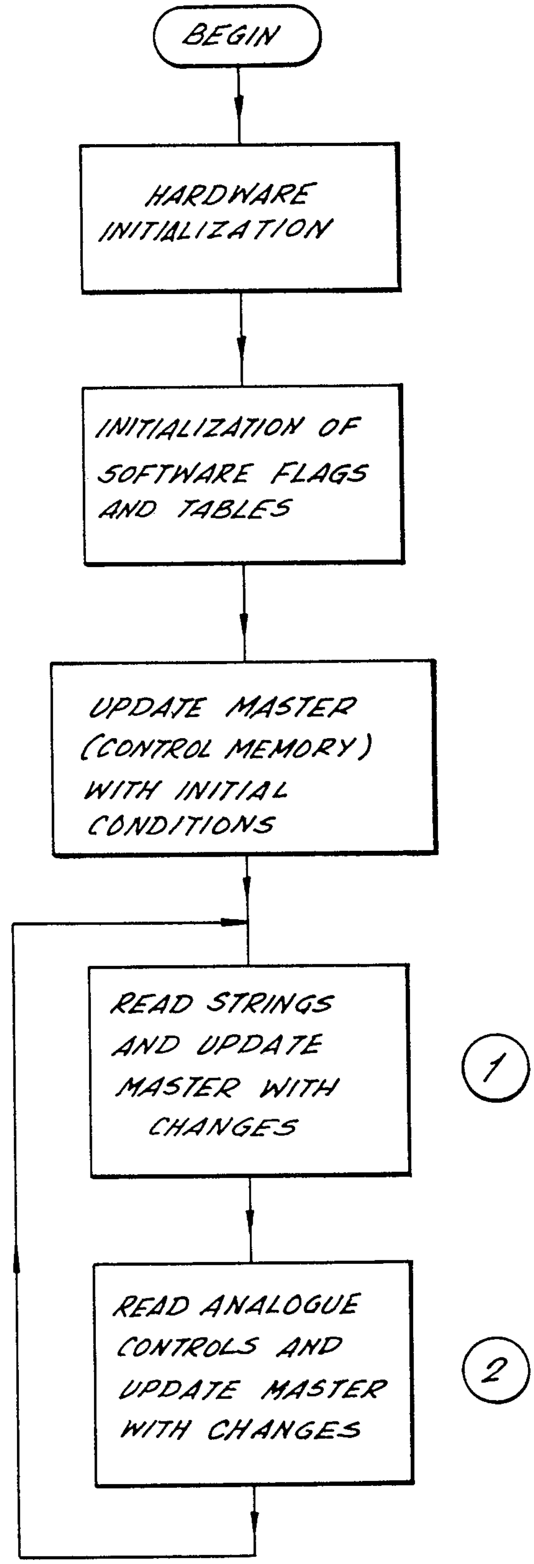

160
161
FULL WAVE
RECTIFIER
162
165
164
163
166
167
169
LOGIC
O/P
VREF
ANALOGUE
O/P
168

FIG. 13.


FROM
NECK
HAMMER
ELECTRODE
170
60
NECK HAMMER
LOGIC PULSES
171
172
NHL
76
STRING
SELECT
55
FROM
STRUM
ELECTRODE
(LEFT)
STRUM LEFT
LOGIC PULSES
173
ANALOGUE
MUX
174
SL(L)
FROM
STRUM
ELECTRODE
RIGHT
STRUM RIGHT
LOGIC PULSES
ANALOGUE
MUX
SLR

OVERALL SOFTWARE STRUCTURE

FIG. 14.



STRING ROUTINE

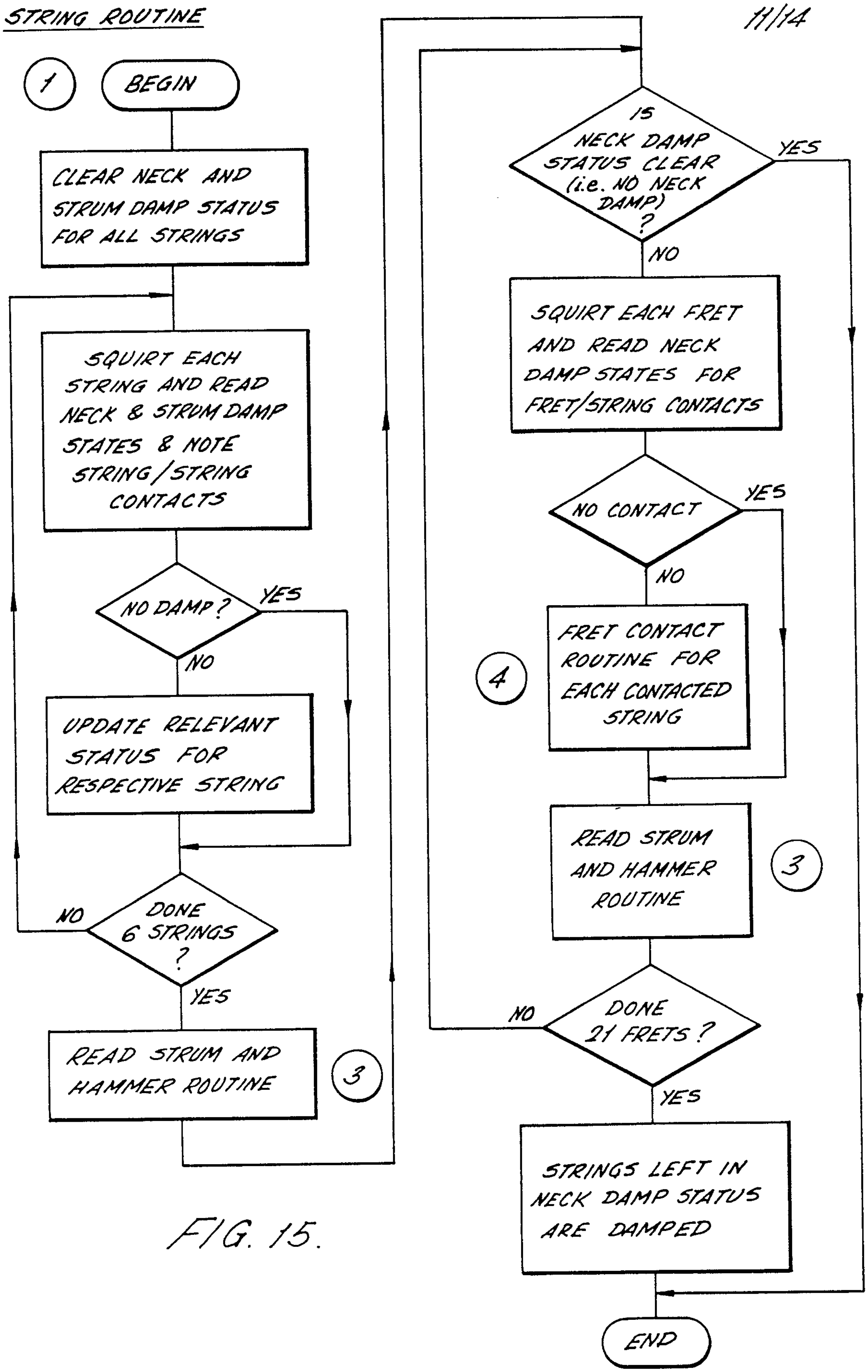
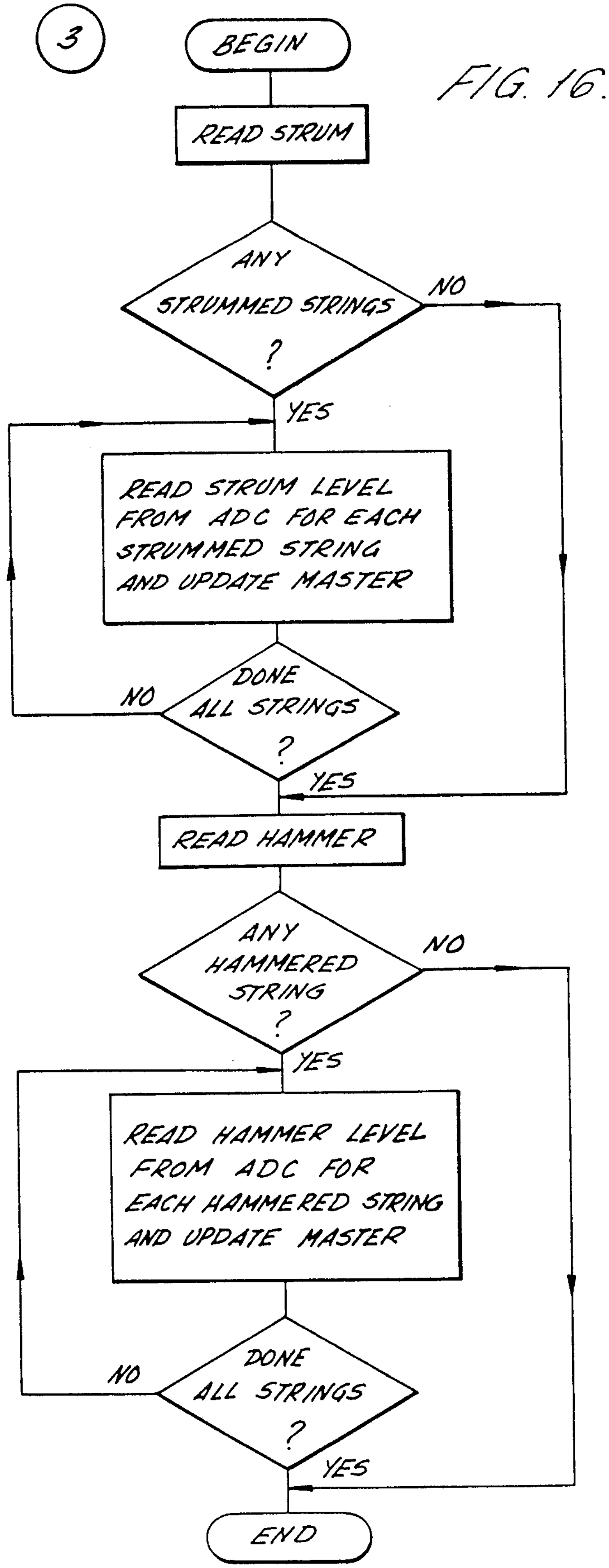


FIG. 15.

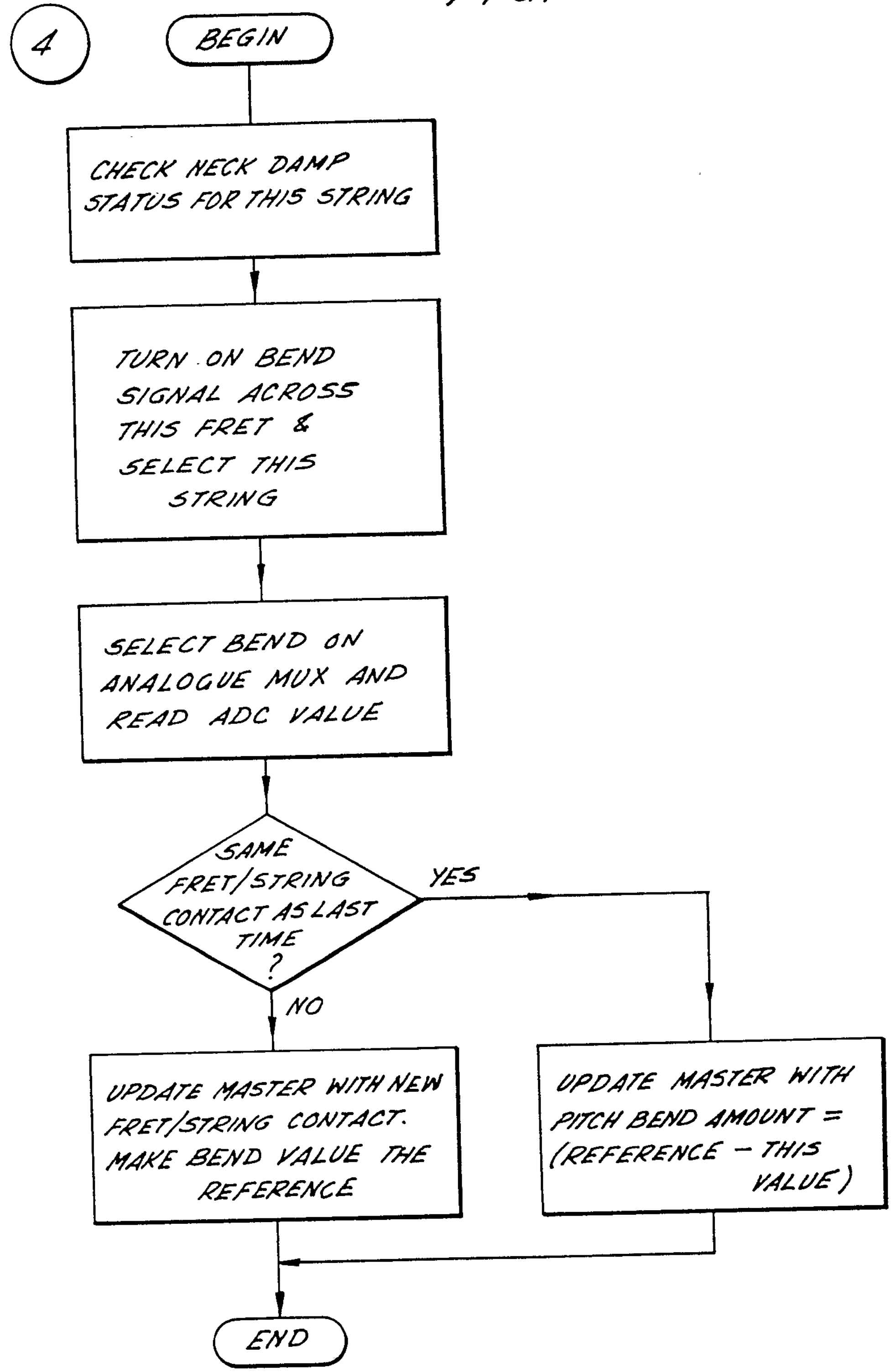
READ STRUM/ HAMMER ROUTINE

FIG. 16.



FRET CONTACT ROUTINE

FIG. 17.



READ ANALOGUE CONTROLS ROUTINE

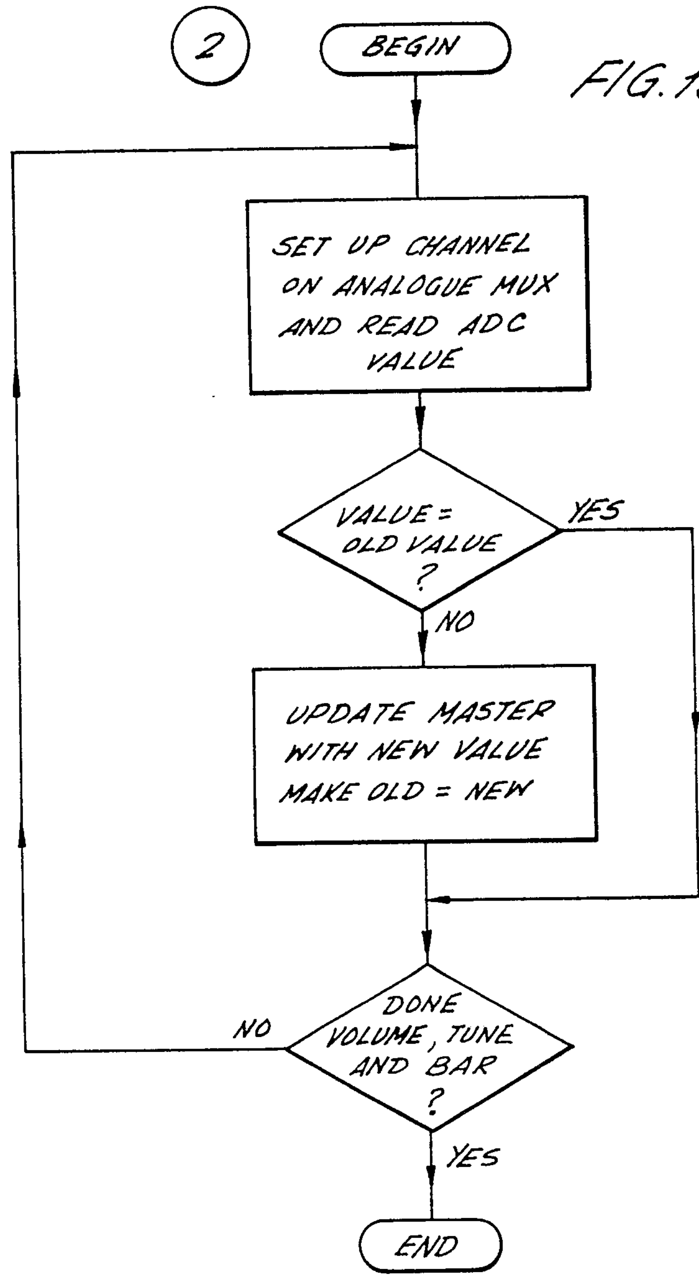


FIG. 18.

SPECIFICATION

Electronic musical instrument

Background of the Invention

The present invention concerns an electronic musical instrument and in particular a music synthesiser instrument in which the notes and tones produced by the instrument are generated electronically by oscillator circuits suitably controlled, rather than by the natural resonance or vibration of mechanical elements. This invention is particularly concerned with an electronic synthesiser instrument which has the general structure of a guitar, or other stringed instrument, i.e. with an elongate neck and fingerboard for fingering usually with the left hand of the player and a strumming or plucking section for playing with the right hand.

Prior Art

There have been various previous attempts to produce a music synthesiser instrument which has the playing configuration of a guitar, here called a guitar synthesiser. Guitar synthesisers generally differ from keyboard synthesisers in that the notes to be generated and emitted by the synthesiser are controlled by appropriate fingering on the fingerboard of the instrument but the initiation and timing of these notes is dependent on the detection of strumming or plucking events corresponding to the normal strumming or plucking action of the guitar player. It can be appreciated that an essential feature of a guitar synthesiser is to provide some sensing means. capable of detecting the fingering action of the player on the fingerboard of the instrument and thereby control the tone generation circuitry of the synthesiser. Some prior art arrangements have replaced the usual strings and frets along the neck of the instrument with arrays of keys in positions corresponding to the normal fret fingering positions of the instrument. Examples of this are included in US 3555166 and GB 1282364. Clearly, such instruments with key switches along the neck fall far short of providing any realistic feel when being played. Furthermore, the mechanisms necessary for such large quantities of key switches in a relatively confined space give rise to reliability problems and may be rather expensive.

Alternative prior art arrangements have employed essentially touch sensitive switches along the neck of the instrument for operation by the fingers of the player. Examples of this include US 3662641 and GB 2078427. Again such touch sensitive switches by no means provide a realistic feel when being played and also do not enable the player to employ many of the customary guitar playing techniques, such as neck hammer and pitch bend.

Neck Hammer is a technique whereby an ordinary guitar is sounded using the fret fingering hand of the player to strike or pluck the strings over the fingerboard of the instrument. Pitch Bend on the otherhand is the technique whereby a string which is depressed on to a fret to sound a particular note is pushed or pulled with the fret finger of the player along the particular fret bar to increase the tension of the string being sounded so as to raise the pitch of the note.

In further prior art arrangements, conductive frets and strings have been used in combination with electronic circuitry for detecting when a particular string is brought into contact with a particular fret. Such an arrangement is disclosed in US 4372187. However in such arrangements, the electrical contact between strings and frets are not always made and detected reliably. Furthermore, there is a difficulty in distinguishing various fret and string contacts when there are several strings brought into contact with a single fret and/or one string is simultaneously in contact with several frets. On the otherhand, US 4372187 is of particular interest because it discloses an arrangement for detecting Pitch Bend. The disclosed arrangement employs potentiometer devices attached to the ends of the strings extending over the neck region of the guitar and operated by shortening of the fret strings caused by the player pushing the string along a fret.

In US 4321852 and W084/04619, the problems of multiple fret/string contacts are resolved by providing frets which are segmented. However, this substantially increases the mechanical complexity of the fingerboard and the electrical complexity of the fret/string contact detection system.

Summary of the Invention

According to the present invention, a guitar synthesiser instrument has a fingerboard with electrically conductive frets, electrically conductive strings extending over the fingerboard, and circuit means connected to the strings and the frets responsive to electrical contacts made between the strings and the frets by fingering the strings during playing of the instrument to identify the string and fret between which each contact is made, wherein each of the frets is arranged to have a contact resistance to any contacting string which is high relative to the longitudinal resistance of the fret from end to end. With this arrangement, a string in contact with a fret results in relatively little current flowing between the string and fret due to the high contact resistance, so that the voltage conditions all along the fret are substantially unchanged. In this way, if several strings are in contact with the same fret, these multiple contacts do not materially affect each other and are quite independently detectable. Furthermore, because of the high contact resistance, it is possible to detect a string to fret contact by applying a voltage signal to a particular fret, while maintaining the other frets at ground, for example, and monitoring the strings to determine any current injected into the string from the energised fret. The circuitry for monitoring the current flowing into the strings can have a very low impedance to ground so that during this monitoring, the strings are themselves also at zero volts. This is only possible because of the high contact resistance between the string and the energised fret. However, as a result, the current injected into a string from an energised fret is substantially unaffected even if that string is in contact with another fret since both the string and fret are at substantially zero volts, and in view of the high contact resistance.

If the contact resistance between the strings and the frets is relatively low, problems arise if two separate strings are pressed into contact with respective adjacent frets, i.e. one string pressed into contact with one fret and another string pressed into contact with the next fret above. It is quite common for the string pressed into contact with the first fret to be making contact also with the fret above. It can be seen that current injected into this string from the first fret could flow through the second fret into the second string. This would be read by the circuitry of the instrument as indicating that both the first and second strings were in contact with the first fret. The high contact resistance provided by the present invention eliminates this problem.

Preferably, each fret comprises a first conductive material having a first resistivity, providing said longitudinal resistance and a layer of a second conductive material, having a second resistivity, on the said first conductive material, to form the surface thereof to which string contact is made during playing, the thickness of said layer and said second resistivity being chosen so that the resistance through the layer between the first conductive material and the string in contact with the fret constitutes said contact resistance.

In a preferred embodiment each fret comprises an elongate insulating substrate having a longitudinal surface forming the fingering surface of the fret in the fingerboard and a first layer on said longitudinal surface of said first conductive material to provide said longitudinal resistance, said layer of said second conductive material constituting a second layer over said first layer. The first layer may comprise a noble metal film and the second layer may compr ise a vitreous film loaded with carbon particles.

Conveniently said circuit means includes voltage signal generating means, fret sequencing means to apply said voltage signal to each fret in turn, string current indicating means for each string to indicate a current flowing in the string, and string to fret contact detecting means responsive to a string current indication from one of said indicating means which is synchronised with the application of said voltage signal to a fret by said fret sequencing means to provide an indication of contact between that fret and the respective string. Then, each said string current indicating means may provide a low impedance current sink for current injected into the respective string from a fret in contact therewith.

Preferably, both ends of each fret are connected to said circuit means and said circuit means includes difference signal generating means to apply a longitudinal resistance between the ends of any selected fret to produce a voltage gradient along the length of the fret, whereby the current injected into a string from a fret in contact therewith is dependent on the position of the fret/string contact point along the length of the fret, and each said string current indicated means includes means providing a current size signal representative of the amount of current flowing in the respective string, said circuit means being arranged to process said current size signal to provide an indication of pitch bend. Again the high contact resistance relative to the longitudinal resistance of the fret enables the contact point of the string along the length of the fret to be determined by this technique even if there are additional strings in contact with the fret. The additional string contacts with the fret do not significantly perturb the voltage gradient.

Preferably, said circuit means is arranged to determine from said current size signal the position along the fret of said fret/string contact point and to compare this determined position with a reference position for the respective string to determine the amount of pitch bend. Both the distance and direction along the fret of the predetermined contact point position from the reference position may be determined and the instruments may be arranged to vary the generated note upwards or downwards in accordance with said direction. This provides a possible playing technique not normally available with ordinary guitars.

In a preferred embodiment, said difference signal generating means generates a constant amplitude voltage difference signal and an adjustable amplitude common voltage signal applied to both ends of a fret, whereby the amplitude of said common voltage signal is adjustable in response to a control signal to vary the position along the length of the fret of a voltage null point at which a fret/string contact would inject no current into the string, and said difference signal generating means and each of said means providing a current size signal are connected in a respective feed back loop generating said control signal to adjust the ampl itude of the common voltage signal during a fret/string contact, to bring the current flowing in the respective string close to zero, said control signal constituting said current size signal. Said voltage difference signal and said common voltage signal may comprise oppositely phased periodic signals. Said difference signal generating means may comprise for each fret a transformer having a secondary winding connected across the ends of the fret, a first drive amplifier connected to one end of the fret to supply said common voltage signal and a second drive amplifier connected to the primary winding of the transformer to supply said voltage difference signal.

The current size signal may be employed to vary the pitch of the sound generated by the instrument, in accor dance with the familiar pitch bend technique. However, additionally or instead, the current size signal may be supplied to provide any other selected dynamic control input to a voice of the synthesiser.

A further aspect of the invention provides a guitar synthesiser instrument having a fingerboard with electrically conductive frets, electrically conductive strings extending over the fingerboard, and circuit means connected to the strings and the frets responsive to electrical contacts made between the strings and the frets by fingering the strings during playing the instrument to identify the string and fret between which each contact is made, wherein each of the frets has a longitudinal resistance from end to end and said circuit means includes difference signal generating means to apply a differential voltage across the ends of the fret to produce a potential gradient along the fret, and means responsive to a signal applied to a string by contact with a fret to determine the position of the point of contact along the length of the fret. Then said means responsive may be formed to generate a control signal representative of said point of contact position along the fret and said control signal may be supplied to provide a selected dynamic control input to a voice of the synthesiser.

Examples of the present invention will now be described with reference to the accompanying drawings.

Brief Description of the Drawings

Figure 1 is a general perspective view of a guitar synthesiser instrument embodying the present invention;

Figure 2 is a cross sectional view of the fingerboard of the instrument of figure 1;

Figure 3 is an enlarged cross sectional view of one end of a fret of the fingerboard of figure 2;

Figure 4 is a cross sectional view of an individual fret;

Figure 5 is a diagram of the drive circuitry for each fret;

Figure 6 is a block schematic diagram of the general control and data acquisition circuitry of the instrument;

Figure 7 is a block schematic diagram of the circuitry for detecting neck and strum damping;

Figures 8 and 9 are detailed circuit diagrams of the amplifiers for the neck and strum strings respectively employed in the circuit of figure 7;

Figure 10 is a block schematic diagram illustrating the fret drive selecting and sequencing circuitry;

Figure 11 is a block diagram of the circuit for generating the drive signals for the frets and also for determining the fret/string contact positions along any fret;

Figure 12 is a diagram of the circuit for detecting strum and neck hammer events from sensors provided for each string;

Figure 13 is a block diagram of the neck hammer and strum detection circuitry of the instrument; and

Figures 14 to 18 are flow charts representing the operating sequence of the electronics of the instrument under the control of a microprocessor programme.

Detailed Description of the Preferred Embodiment General Arrangement and Sensors

Referring to Figure 1, a guitar synthesiser instrument 10 has a body portion 11 with a neck 12 extending from it. The neck 12 has a fingerboard 13 with neck strings 14 extending over frets 15 provided along the length of the fingerboard.

It will be appreciated that the strings in the instrument are provided purely to generate control signals for the synthesiser circuitry of the instrument. Strings themselves are used for this purpose only to make the instrument have a playing feel which is as close as possible to that of an ordinary acoustic or electric guitar. In the example described, the guitar has six separate strings. However each "string" is in fact formed of two separate string elements, one constituting the neck strings 14 which extend from an outer end 16 of the neck of the instrument to a fixing block 17 mounted on the body 11 of the instrument. These neck strings 14 are used solely to detect control inputs from the fret fingering hand (usually the left hand) of the player, and play no part in detecting any strumming or plucking action normally made by the right hand of the player.

Separate strum string elements 18 are provided on the body 11 of the guitar extending between fixing blocks 19 and 20. In the illustrated example, the strum string elements 18 are shown aligned with their corresponding neck strings 14. However, it will be appreciated that these two sets of strings need not be parallel to one another or aligned.

In common with prior art guitar synthesisers, the instrument includes electronic synthesiser circuitry which is capable of providing six separate sounds (voices), i.e. one for each string of the guitar. In one operating mode, the synthesiser has its tone selection controlled in accordance with detected contacts between each neck string 14 and the frets 15, and the initiation and quality of the sound generated determined by sensors detecting strumming or plucking of the string elements 18. Strum detection sensors 9 are illustrated in figure 1 provided near one end of the strum elements 18. Strum detection sensors 9 are arranged to enable detection of disturbances in the string elements 18, for example vibration resulting from a plucking or strumming action. A particular form of sensors for this purpose is described later herein.

As mentioned above, the tone selection is controlled by sensing fret/string contacts along the fingerboard 13. Both the frets 15 and the strings 14 are electrically conductive and contacts between the two are determined by sequentially applying a voltage signal to the frets 15 in turn whilst monitoring the stringl4.

Figures 2 to 4 show the structure of the fingerboard and in particular the frets in detail. The fingerboard is formed of a printed circuit board 21 which has mounted on an undersurface 22 thereof various components of the circuit for sequentially applying a voltage signal to the frets on the fingerboard and monitoring the strings to detect fret/string contacts.

Each fret is formed of an elongate substrate element 23 of an insulating material, typically a ceramic such as alumina. The substrate element has a lower plane face 24 which overlies the upper surface of the printed circuit board 21, and an upper convex surface 25. A first conductive layer 26 of a relatively low resistivity material is provided on the convex surface 25 of the substrate element 23 and a second outer layer 27 of a relatively low conductivity material is provided on top of the layer 26.

The layer 26 has a conductivity such that the longitudinal resistance of each fret from end to end across the width of the fingerboard is substantially less than the resistance from the layer 26 to a string in contact with the outer surface of the layer 27. The longitudinal resistance of the fret in the layer 26 is not, however, negligible since it is required, as will become apparent, to generate a potential gradient along the fret. In an example of the invention, the layer 26 is chosen to provide a longitudinal resistance from end to end of about 10 ohms, and the resistivity of the outer layer 27 is chosen to provide a typical contact resistance from the layer 26 to a string, such as string 28 in contact therewith of about 1 kilohm.

The lower layer 26 may be formed of screen printed palladium silver ink that is subsequently fired. The upper layer 27 may be formed of a glass which is loaded with carbon ink to provide the desired resistivity. Use of a vitreous upper layer 27, also provides a surface for the fret which is relatively resistant to the wear caused by the strings. The surface of the upper layer 27 of the fret may be given a polished finish to provide an even and reliable contact resistance with the strings of the instrument.

Each fret is fastened in position on the upper surface of the printed circuit board 21 by means of end clips or caps 28. The clips 28 are formed of metal and have an upper flange 29 which locates in a rebate 30 provided in the ends of the frets, and a lower flange 31 which clips under the printed circuit board. The undersurface of the upper flange 29 of the clip 28 and the mating upper surface of the rebate 30 of the fret are slightly ramped as illustrated in Figure 3 to provide positive location of the frets by the clips.

The upper low conductivity, layer 27 on the frets terminates at the clips 28. However, the underlayer 26 of higher conductivity, continues into the rebates 30 at the ends of the frets so that electrical contact is made between the clips 28 and this underlayer. The lower flanges 31 of the clips 28 in turn make contact with respective contact pads 33 of the electrical circuitry provided on the underface 22 of the printed circuit board. This arrangement provides for electrical connection as required between the circuitry on the printed circuit board and each end of each of the frets. The contact between the clips 28 and the layer 32 and also with the contact pads 33 may be enhanced by the use of conductive paste or adhesive.

In order to determine any fret/string contacts, the circuitry on the printed circuit board 21 is controlled to apply a voltage signal sequentially to each fret 15 in turn. During this procedure, the voltage signal is applied to both ends of the fret so that there is no potential gradient along the length of the fret. However, in an additional procedure, a potential difference is applied across the fret in order to determine the position of the contact point along the fret. The drive circuitry for each fret is illustrated in Figure 5. Each fret 23 is connected, by means of the end caps 28 across the secondary winding 34 of a respective transformer 35. The voltage signal for simultaneously driving both ends of the fret, called the END DRIVE, is supplied via a drive amplifier 36 to one end of the secondary winding 34. The voltage signal used for applying the differential voltage across the length of the fret, to generate the potential gradient, called the DIFFERENTIAL DRIVE, is applied by means of a second drive amplifier 37 to a primary winding 38 of the trans former 35. In this way, when the END DRIVE signal is applied alone, both ends of the fret are driven simultaneously and equally. However, when both the END DRIVE and DIFFERENTIAL DRIVE signals are applied, a potential gradient is produced along the length of the fret.

Referring again to Figure 1, additional sensors 40 are provided to detect disturbance of the neck strings 14. These sensors 40, one per string, provide outputs enabling the detection of player actions on the neck strings 14 corresponding to Neck Hammer. Thus the sensors 40 may be similar to the sensors 9 used for detecting strumming or plucking action on the strum string elements 18.

In a modified embodiment of the invention, an additional set of strum sensors 41 are provided at the opposite ends of the strum string elements 18 to the sensors 9. These two sets of strum sensors 9 and 41 can then be used for detecting not only the incidence of a strum or plucking action on the strings 18 but also the position along the length of the string elements of the strumming or plucking. This may be used for providing additional dynamic control of the synthesiser in the instrument.

Control knobs 42 are also provided on the body part 11 of the instrument for controlling various preset variables such as volume, tone and bar (tremolo). In addition, a key pad 43 may be provided on the body part 11 of the instrument for the reprogramming and control of a microprocessor used for the control of the synthesiser. Displays 44 may provide indication of the current status of the instrument.

Electronics Control and Data Collection System

Referring to Figure 6, the instrument includes an electronic synthesiser 50 which is controlled by a master microprocessor unit 51. A control keyboard 52 enables preset control data to be supplied to the master microprocessor unit 51, setting up the way in which the microprocessor unit is programmed to resp-ond to the various dynamic control inputs from the playing of the instrument.

The synthesiser 50 has six separate tone generating circuits, known as voices, one voice for each string of the instrument. The master microprocessor unit 51 responds to the dynamic control signals generated during the playing of the instrument by accessing data defining these control signals contained in the memory 53. The memory 53 is also accessed by a second neck/strum microprocessor unit 54. The second microprocessor unit 54 controls the various circuitry of the instrument which monitor player actions on the instrument and updates the memory 53 with all changes in the dynamic condition of the various sensors of the instrument, so that the contents of the memory 53 is an up to date, substantially instantaneous, indication of the status of all the various sensors in the instrument which monitor playing activity.

It will be appreciated that the microprocessor units 51 and 54 and the various data acquisition circuitry of the instrument cycle sufficiently quickly that the synthesiser 50 is caused to respond with imperceptible delay following any player action on the instrument, such as strumming or plucking a string.

Signals representing a strum action as detected by means of the sensors 9 (Figure 1) are fed on lines 55 to latches 56. The signals on lines 55 are logic signals which provide an indication of a vibration of a respective one of the strum string elements 18 when the vibration is above a minimum threshold level. The latches 56 are set in response to such a transitory indication on any one of the lines 55.

Data defining the condition of the latches 56 is supplied to the microprocessor unit 54 via buffers 57 on a data bus 58 and subject to read control signals on a control bus 59. The latches 56 are reset immediately after they are read by the microprocessor unit 54, so that the latches, are then ready to respond to any subsequent strum signal. The microprocessor unit 54 is arranged to read the latches 56 sufficiently frequently so that there is imperceptible delay between a strum action and the corresponding latch being read and corresponding data being supplied by the microprocessor unit 54 to the relevant part of the memory 53.

In a similar fashion, signals representing neck hammer events as detected by sensors 40 are fed on lines 60 to set latches 61, which are in turn read by the microprocessor 54 via buffers 62.

The instrument is also arranged to respond to the player touching either the neck strings or the strum string elements. In normal play of a guitar, this action has the effect of damping an existing note. Signals representing a player touching the neck strings will be referred to herein as Neck Damp Signals, and signals corresponding to the player touching the strum string elements will be referred to hereinafter as Strum Damp. The circuitry for generating neck damp and strum damp signals will be described later herein.

Neck damp signals are supplied to the circuit of Figure 6 on lines 63 to set latches 64, which are read periodically by the microprocessor unit 54 via buffers 65. Similarly, strum damp signals are supplied to the circuit on lines 66 to set latches 67 which are read via buffers 68.

In the modified embodiment with an additional set of strum sensors 41, logic signals corresponding to the detection of a strum event by this second set of sensors 41 are supplied on lines 69 to respective latches 70 and read by the microprocessor unit 54 via buffers 71.

It is also necessary for the microprocessor unit 54 to be able to read various analogue control values. For example, the amplitude of a strum event might be determined and used to control the volume of the corresponding voice produced by the synthesiser 50. An analogue multiplexer 72 is controlled by the microprocessor unit 54 to select any one of up to sixteen analogue inputs and supply the selected analogue signal via a sample and hold circuit 73 for analogue to digital conversion in a converter 74. The digitally converted output of the ADC 74 is then read over the data bus 58 by the microprocessor unit 54.

The analogue multiplexer 72 is itself controlled to select the analogue signal to be supplied to the analogue to digital converter by control signals supplied by the microprocessor unit 54 on the data bus 58 to latches 75. The data bus is an eight bit bus of which seven bits are used to supply data for holding in the latches 75. Four bits of the data are fed from the latches to the control inputs of the analogue multiplexer 72 to select any one of up to sixteen inputs for supply via the sample and hold circuit 73 to the converter 74. The remaining three bits of data from the latches 75 are supplied on lines 76 to other circuit elements to select one of the six strings of the instrument.

The analogue signals supplied to the multiplexer 72 include up to four analogue control inputs to the instrument which may be used for setting various parameters such as volume, tuning, and bar. The analogue multiplexer 72 can also receive up to five analogue inputs from other parts of the circuitry of the instrument for self checking purposes. Such inputs may represent the supply voltages to various parts of the circuit and be used by the microprocessor for self checking and error indication.

There are up to four further analogue inputs to the multiplexer 72 which can represent "analogue" variables during the playing of the instrument. These signals include the Neck Hammer Level, the Strum Level and a signal representing the amount of bend applied to a note. In addition if two sets of sensors are used on the strum string elements 18, separate strum levels may be provided for strum events detected at each end of the respective string element 18. This is represented in the drawing by a first Strum Level Left (SLL) and Strum Level Right (SLR).

The microprocessor unit 54 is arranged to respond to detection of a neck hammer event on one of the strings, as indicated by a logic signal on a respective one of the lines 60, by selecting that string, using the string select line 76 to supply on the Neck Hammer Level (NHL) line an analogue signal representing the amplitude of the neck hammer signal detected by the respective sensor 40. Similarly, if a strum event is detected, as represented by a logic signal on one of the lines 55, the microprocessor unit 54 selects that corresponding string to supply an analogue signal representing the level of the strum signal detecting by the respective strum sensor 9 on the line SLL. If the dual sensor arrangement is provided for the strum string elements 18, an analogue signal representing the level detected by the respective sensor 41 is also supplied on the line SLR.

As will be explained in more detail later, fret/string contacts are determined by applying a voltage signal successively to each fret in turn and monitoring the resultant current injected into the neck strings 14. The fret are selected by means of fret select signals supplied on data bus 58 to fret selection circuitry which will be described later. The presence of a corresponding string current, resulting from a fret/string contact is indicated by a logic signal appearing on the corresponding neck damp line 63. The microprocessor unit 54 responds to the detection of a fret/string contact to select the identified string, on the select lines 76, and also the identified fret by means of fret select signals supplied on the data bus 58 and to apply a differential voltage across the selected fret to produce an analogue signal representing the position of the point of contact along the length of the fret. This analogue signal is supplied on the BEND line to the analogue multiplexer 72.

In order to determine if one of the neck strings 14 is being touched by the player, indicating an intention to damp the string, a voltage signal is applied to each string in turn under the control of Squirt Select and Enable control logic on lines 77. The control logic on lines 77 is set up under the control of the microprocessor unit 54 from logic supplied on the data bus 58 to latches 78 which are controlled by control signals on the control bus 59.

The circuitry for generating the various logic and analogue signals for supply to the microprocessor unit 54 via the circuit of Figure 6 will now be described in more detail.

Test Strings for Damping

Figure 7 is a block schematic diagram of the circuitry employed to determine when any of the neck strings 14 or the strum string elements 18 are being touched by the player of the instrument. Each of the neck strings is electrically connected by a respective line 80 to a respective neck string amplifier contained in the box 81 in Figure 7. The neck string amplifiers amplify any current flowing in the respective string and supply analogue output signals corresponding thereto to respective threshold detectors contained in box 82. The threshold detectors are arranged to produce a logic output in the event that the analogue input to the threshold detector indicates a detected current in the respective string which is above a preset threshold level. The logic output signals are called the Neck Damp signals and are provided on the lines 63 to the latches 64 in figure 6. Additional analogue outputs are taken directly from the neck string amplifiers 81 on lines 83 for supply to the bend detection circuitry which will be desribed later.

Figure 8 illustrates the circuit of the neck string amplifier and threshold detector used for each of the six neck strings. Thus, the dotted box 84 in Figure 7 is formed of six circuits as shown in Figure 8.

In order to detect whether the player of the instrument is touching the respective neck string (indicated 90 in Figure 8), a voltage signal, called a SQUIRT signal is applied to the respective neck string from an input line 91 via a voltage follower amplifier 92. The SQUIRT signal is supplied to the respective string by means of an analogue demultiplexer 93 (Figure 7) in accordance with Squirt Select and Enable control signals supplied to the demultiplexer 93 on the lines 77 from the latches 78 of Figure 6. The SQUIRT signal is a burst of alternating voltage signal, the generation of which will be described in more detail later. The generation of the SQUIRT signal and selection of the string to which it is applied is under the control of the microprocessor unit 54 as has been described. If the neck string is not being touched by the player of the instrument and is also not in contact with any other string or with any fret, then no substantial current flows into the string when the string is driven with the SQUIRT signal by the voltage follower amplifier 92. However, any current that does flow into the neck string 90 generates a corresponding current in the secondary of a transformer 94. The secondary of the trans former 94 is connected to the input of a virtual earth current amplifier 95 so that the secondary voltage is maintained very low resulting in negligable voltage being generated across the primary winding of the transformer 94. Series input capacitor 96 resonates at the Squirt Drive frequency with the apparent input inductance of the amplifier 95 caused by the effect of phase lag in the amplifier and the feed back resistor 97, resulting in an apparently very low inpedance across the secondary winding of the transformer 94. The amplified output voltage from the amplifier 95 is applied to a high speed voltage comparator 98 which produces an output logic signal if the analogue voltage from the amplifier 95 exceeds a predetermined threshold as set by a Bias applied to the comparator 98. The logic output from the comparator 98 is fed on a respective one of the lines 63 and sets a respective one of the latches 64 (Figure 1) for subsequent reading by the microprocessor unit 54.

The amplified analogue voltage signal from the amplifier 95 is also supplied on a respective one of the lines 83.

Current sufficient to provide a logic output signal to set the respective latch 64 when the neck string 90 is being driven by the Squirt signal on line 91, is indicative of one of the following three possibilities: the neck string 90 is in contact with the fret, the neck string 90 is in contact with another string, or the neck string 90 is being just touched by the player of the guitar so that the detected current is flowing through the players finger to earth. The microprocessor unit 54 is programmed to perform further checks to establish which of these possibilities is true and to update the data in the memory 53 accordingly for controlling the synthesiser.

The circuitry of Figure 8 is also used to detect current injected into the neck string by the neck string being in contact with a selected fret. The frets are selected in turn by application thereto of Squirt signals corresponding to the Squirt signal supplied on line 91 and as described above. However, when the frets are selected in sequence, the analogue demultiplexer 93 is controlled to maintain all the input lines 91 to the amplifiers 92 for each of the six strings substantially at ground, so that any current injected into the neck string 90 from a selected fret flows through the primary of the transformer 94 to ground via the amplifier 92. The amplifier 95 and comparator 98 then work in the same way to provide on the one hand a logic output from the comparator 98 indicative of a current in the string above the threshold, and the analogue value of the current respectively.

The Squirt signal output from the voltage follower amplifier 92 is also supplied by lines 99 (Figure 7) to strum string amplifiers 100. Figure 9 is a circuit diagram of a strum string amplifier and the box 100 in Figure 7 contains six such amplifiers, one for each strum string element. A respective strum string element, indicated 101 in Figure 9 is connected to the inverting input of an operation amplifier 102 and the Squirt signal input is connected to the non inverting input. The arrangement of resistors and capacitor illustrated in Figure 9 is such that the squirt voltage signal is applied to the strum string 101 and any resultant current flowing from the strum string 101 (indicative of contact with the finger of a player of the instrument), results in a differential voltage across the inputs of the amplifier 102 and produces a logic output which is latched into a respective one of the latches 67 in Figure 6.

Test Frets for String/Fret Contact

As mentioned above, a neck string current detected when the string is supplied with a Squirt signal by the circuitry of Figure 8, may be indicative of a string being held in contact with one or more of the frets. To detect any fret/string contacts, the Squirt signal is applied sequentially to each of the frets in turn. During this process, the squirt signal is applied to each fret as the END DRIVE signal (Figure 5) so that there is no substantial voltage difference between the ends of the selected fret.

Figure 10 illustrates the circuitry for sequentially selecting the frets. In this example of guitar, there are 21 frets each provided with end drive and differential drive circuitry as shown in Figure 5. The drive circuitry for each fret is represented in Figure 10 by the boxes 110, 111 and 112. The drive circuitry for the frets are collected into two groups of 8 (boxes 110 and 111) and a group of five (box 112). Analogue demultiplexers 113 and 114 are arranged to supply the differential drive signal and end drive signal respectively to selected ones of the fret drive circuitry in box 110. Similarly, demultiplexers 115 and 116 supply the differential drive and end drive signals to selected fret drive circuitry in the box 11 and demultiplexers 117 and 118 supply the differential drive and end drive respectively to the drive circuitry of box 112. Each of the demultiplexers 113 to 118 is an eight channel demultiplexers, capable of sending a single input to a selected one of eight possible outputs. The output for each demultiplexer is selected in accordance with the state of a three bit control signal supplied to the demultiplexer on control lines 119. In addition, each demultiplexer has an enable input so that the pairs of demultiplexers for each of the boxes 110, 111 and 112 can be separately enabled by enable signals on lines 120, 121 and 122. The logic signals on the control lines 119 and enable lines 120 to 122 are all supplied from latches 123 set by control signals from the control bus 59 in accordance with data signals on the data bus 58, all under the control of the microprocessor unit 54.

Thus, the microprocessor unit 54 can select a single one of the fret drive circuits corresponding to a selected fret so that a difference drive or an end drive signal is supplied only to that selected fret.

As explained previously with respect to Figure 7, a fret/string contact is determined by supplying an end drive signal to each fret in turn and monitoring a corresponding current flowing in any of the neck strings, sufficient to switch the threshold detectors 82 and provide a neck damp logic signal on a respective one of lines 63.

Test for Pitch Bend

On identification of a fret/string contact, the microprocessor 54 controls the circuitry to measure the position along the indicated fret of the contact with the respective string. In this way bend of the selected note can be achieved if the measured contact position moves away from an initial reference position.

Figure 11 illustrates the circuitry for determining the position of any fret/string contact along the length of the fret.

Figure 11 also illustrates the circuit which generates both the Squirt signal, used on the one hand to drive the neck and strum string elements themselves for detecting damping actions and on the otherhand for supplying to the end drive of each fret in turn to detect fret/string contacts, and also the difference signal which is supplied to a selected fret for determining the contact position along the fret.

A signal generator, 130 clocked by a master system clock on a line 131 produces a square wave output signal on line 132 which in the present example has a frequency of about 125 kHz. This 125 kHz square wave signal is suppl ied on a line 133 to an NAND gate 34. The output on the nand gate 34 is supplied through a bandpass filter 135 centered at 125 kHz to supply the Squirt output for the string drive circuitry of Figure 7 on a line 136. The second input of the NAND gate 134 is provided by a control signal from the control bus 59 to permit a short package of pulses from the signal generator 130 to be supplied to the bandpass filter 135, under the control of the microprocessor 54. The bandpass filter 135 effectively smooths out the rise and fall times of the resultant envelope so that the Squirt signal supplied on line 136 is formed of a gently rising and falling package of sinusoidal pulses at the 125 kHz frequency. This shaping of the Squirt signal substantially reduces the amount of radio frequency emission produced by the guitar instrument.

Analogue switch 137 also permits the Squirt signal to be supplied on a line 138 to provide the end drive signal for the frets (see figure 10) during the sequential fret testing operation for detecting fret/string contacts.

The square wave output on line 132 from the signal generator 130 is also supplied to a low pass filter 139 which is designed to block the higher harmonics of the square wave so that the output of the filter 139 is a substantially sinusoidal signal at the frequency 125 kHz. The 125 kHz sinusoidal signal from the filter 139 is fed via an inverting amplifier 140 to a second analogue switch 141. The sinusoidal signal is also fed via a non inverting transconductance amplifier 142 to one pole of the analogue switch 137. The sinusoidal signal constitutes the test signal supplied to the selected fret during the test sequence to identify the position of a fret/string contact along the length of the fret. Accordingly, the analogue switches 137 and 141 are controlled by the microprocessor 54, by means of control signals from the control bus 59 to select the outputs of the amplifiers 140 and 142 when the contact position on a fret is to be determined. When selected, the output of the amplifier 140 is fed to the selected fret drive circuit as the difference drive signal and the output of the transconductance amplifier 142 is fed to the selected fret drive circuit as the end drive signal.

When the contact position is not being measured, the switch 141 connects the fret difference drive input of the fret drive circuit to earth, whilst the end drive input in supplied with the Squirt signal as described above.

When the switches 137 and 141 are selected by the microprocessor to supply the 125 kHz sinsusoidal signal to the fret end drive and fret differential drives inputs of the selected fret drive circuitry, it may be appreciated that the combination of the two drives to the fret, with the circuit illustrated in Figure 5, results in the production of an alternating voltage signal which has an amplitude which varies across the length of the selected fret. Suitable selection of the gains of the amplifiers 140 and 142 (together with amplifiers 36 and 37) results in the production of a null point at some position along the length of the fret at which the two drives cancel out.

The analogue string current signals detected in each of the neck strings are supplied on lines 83 (Figure 7) to the inputs of an analogue multiplexer 150. The analogue multiplexer 150 is controlled in accordance with string select signals on lines 76 to select a corresponding one of the analogue signals for supply on an output line 151 to inverting and non inverting amplifiers 152 and 153 respectively.

When a fret/string contact is detected by the microprocessor 54, the microprocessor supplies control signals to switch the analogue switches 137 and 141 to supply the outputs of amplifiers 142 and 140 respectively to the fret end drive and fret difference drive lines. Meanwhile, the control signals from the latches 123 (Figure 10) ensure that these drive signals are supplied to the appropriately selected fret drive circuitry. At the same time, the microprocessor supplies string select signals on the lines 76 so that the multiplexer 150 selects the string current signal from the designated string, corresponding to the detected fret/string contact.

The resulting sinusoidal signal on the line 151 from the multiplexer 150 is supplied via the amplifiers 152 and 153 to respective input poles of an analogue switch 154 which is controlled to switch over in synchronism with the square wave signal on the line 132 from the signal generator 130. This arrangement provides for synchronous rectification of the analogue string current signal on the line 151, producing on the output pole of the switch 154 a dc voltage with some switching noise. The amplitude and sign of this dc voltage is dependent on the amplitude and phase, relative to the output of the signal generator 130, of the selected string current signal on the line 151.

This dc voltage signal is supplied via an analogue demultiplexer 155 to a respective integrator in a bank of six integrators 156. One integrator is supplied corresponding to each string of the instrument and the analogue demultiplexer 155 is arranged to supply the dc level to the corresponding respective integrator under the control of string selection signals on the control lines 76. The filtered signal of the respective integrator 156 is in turn supplied to a further analogue multiplexer 157, again controlled by the string select signals on line 76, to apply the output of the integrator to a common signal line 158.

The resultant signal on the line 158 is a dc voltage signal which is proportional to the amplitude, and has a sign corresponding to the phase of the current flowing in the selected neck string. This dc voltage is supplied on a line 159 as the control input to the transconductance amplifier 142. This produces a feed back loop so that the gain of the amplifier 142 adjusts the level of the sinusoidal signal supplied to the end drive of the selected fret drive circuit, so as to move the null point along the length of the fret to minimise the sensed current in the selected string. In this way, the current actually injected into the string during the contact position measuring operation is kept to a minimum so that the effect of variation in contact resistance between the string and the fret is also minimised.

In the circuit of Figure 11, a separate integrator 156 is used for each string to reduce the loop stabilisation time when switching from string to string during the normal operation of the system. Non selected integrators are isolated and will tend to hold their existing charge so that on next selection, i.e. when the same string is again interrogated, the integrator need respond only to the change in output level since the last interrogation. It will be appreciated that each string will be interrogated for contact position a substantial number of times dur ing one single contact event.

The analogue voltage signal on the line 158 is supplied as the BEND signal to the analogue multiplexer 72 in Figure 6 for analogue to digital conversion and reading by the microprocessor unit 54.

Detect Strum and Neck Hammer

Figure 12 illustrates the circuit used to detect perturbations of the neck strings 14 or strumming string elements 18, by means of the respective sensors 9 and 40 (Figure 1). Each sensor comprises a respective metal electrode mounted on the body of the instrument immediately beneath the string which it is to sense. The metal electrode is indicated at 160 in Figure 12. The sensors work by detecting variations in the capacitance between each metal electrode 160 and its respective string, caused by movement or vibration of the string. The strings are typically held nominally at earth potential whilst the electrodes are biased to a potential of a few volts. A high gain amplifier 161 amplifies the current produced by variation in the capacitance caused by movement of the string relative to the electrode. The amplifier 161 is a high gain amplifier and has a band width which is optimised around the resonant frequency of vibration of the string to be detected. Typically the strings resonant at about 400 Hz but the bandpass of the amplifiers

161 should extend from about 100 Hz up to about 4 kHz in order to react quickly to a strumming pulse. However the bandpass must reject the 125 kHz Squirt signal used in the damping measurement system.

Since the amplifier 161 is arranged as a current amplifier, the output is to a first approximation proportional to the velocity of the string. The output of the amplifier 161 is rectified by a precision full wave rectifier 162 which is arranged to have a high frequency roll off at about 10 kHz. This rectified output in then fed into a peak detector 163. The peak detector comprises an operational amplifier 164 having the input signal supplied to its non inverting input. The output of the operational amplifier is fed to the base terminal of a transistor connected to supply a charging current via a resistor 165 to charge up a capacitance 166 to the peak input voltage level. The rate of decay of the voltage across the capacitor 166 is determined by the relative values of the capacitance 166 and a parallel resistance 167. The voltage across the capacitor 166 is supplied on a line 168 as the analogue output voltage representing the amplitude of the strum or pluck event, or the hammer event in the case of neck hammer. The rate of decay set by the values of the capacitance 166 and resistance 167 permits a smooth output decay for a hard staccato strum input but ensures that the voltage signal across the capacitor 166 has decayed quickly enough to be recharged again to a new lower level in the event of a soft strum quickly following a loud strum.

It can be seen that the transistor at the output of the amplifier 164 turns on, causing a reduction in the voltage at the collector, whenever the input signal to the amplifier 164 exceeds the current voltage level on the capacitor 166. The collector of the transistor is supplied via a decoupling capacitor to one input of a comparator 169 which has its other input supplied with a reference voltage. Thus, any change in the collector voltage of the transistor in the peak detector 163 in excess of the reference voltage produces a change in the output logic state of the comparator 169.

Referring to Figure 13, six circuits as illustrated in Figure 12 are provided (box 170) one for each of the sensors 40 for detecting neck hammer on the neck strings 14. The logic output signals are supplied from the circuits 12 on a set of six lines which correspond to the lines 60 supplied to the latches 61 as shown in Figure 6. Any change in the logic state on one of the lines 60 representing an increase in the detected vibration amplitude of the string, sets the corresponding one of the latches 61. The latch 61 remains set until it is read by the microprocessor unit 54 whereupon the latch is reset ready for a new Hammer indication. The analogue output signals from each of the six circuits of Figure 12, are supplied to an analogue multiplexer 171. String select signals on line 76 control the multiplexer 171 to supply a selected one of the analogue voltage signals on an output line 172 for supply as the NHL signal to the analogue multiplexer 72 in Figure 6.

Figure 13 also shows the corresponding circuitry for detecting and producing the strum logic and analogue signals from the strum sensors 9. The strum logic signals are supplied on the lines 55 to the latches 56 for reading by the microprocessor unit in the same way as the neck hammer logic pulses. Further the strum level analogue voltages are supplied to a further analogue multiplexer 173 for selectively supplying on a common signal line 174 as the strum level signal on line SL(L) to the analogue multiplexer 72 in Figure 6.

In the event that a further set of strum sensors 41 are provided for detecting the strum level at the other end of the strum string elements 18, an additional set of detection and signal generating circuits are provided as shown.

In this way, data identifying strum or neck hammer events is entered into the memory 53 together with additional data defining the amplitude of the event. Thus, the master microprocessor unit 51 is able to control the synthesiser 50 to initiate sounds in response to strumming, plucking or neck hammering.

System Operational Sequence

Figures 14 to 18 are flow charts of the operational sequence of the system under the control of the microprocessor. The overall software structure is shown in outline in Figure 14. On initially turning on the instrument, or resetting, the microprocessors perform hardware initialisation, e.g. resetting latches etc., followed by the initialisation of various software flags and tables in the memory 53. The microprocessor units have access to dedicated memory for controlling these initial procedures.

Once initialisation is completed, the control memory 53 (called MASTER in the flow chart) is updated with initial conditions and the microprocessor unit 54 then proceeds to produce the control signals necessary to read the various string conditions of the instrument and update the MASTER with any changes resulting from player actions. Thus, the updated information entered into the memory 53 indicates any neck or strum triggers, corresponding to the neck hammer or strumming action, together with data defining the amplitude of the detected hammer or strum; for each string the fret number of any detected fret/string contact, together with an indication of the position along the fret of the contact point; and data identifying neck and/or strum damping. From this information continuously updated by the microprocessor unit 54, the master microprocessor unit 51 is able to control the six voices of the synthesiser 50.

After reading the various string data, the microprocessor unit 54 also reads the current state of the various analogue controls of the instrument and again updates the Master with any changes. This operation is repeated successively at a very fast rate dependent on the clock speed of the microprocessor.

Figure 15 gives further detail of the string reading routine identified No.1. in Figure 14. Flags are provided in the memory 53 indicative of the current Damp status of the various strum and neck strings, i.e. damp or no damp. Initially, the string reading routine clears the damp status for all strings to indicate no damp. Then, the microprocessor unit 54 controls the circuitry to produce Squirt signals successively to each string in turn. As each string is squirted, the neck damp logic signal for that and each of the other five strings is monitored. A current indication from the squirted string causes the damp status for that string to be altered to indicate string damping. Furthermore, any currents on other strings are noted to provide an indication of string to string contacts.

When all six strings have been checked for damping, both strum and neck damping, the microprocessor unit 54 moves on to the read strum and hammer routine (No. 3). This is shown in more detail in Figure 16. Initially, the microprocessor unit 54 reads the state of the strum latches 56. If there are any strummed strings, the strum level for those strings is read by suitably controlling the analogue multiplexer 72 and the analogue multiplexer 173. Next, the state of the neck hammer latches is read and if there are any hammered strings indicated, the hammer level for those strings is read.

Following reading the strum and hammer routine, the microprocessor unit 54 tests if there are any neck damp indications as determined previously. Any such indications suggest that a player's finger is touching the relevant string which may imply a fret/string contact. Accordingly each fret is then squirted in turn and the state of the neck damp latches 64 is read to determine any current injected into the strings. A current injected into a particular string when squirting a particular fret is indicative of a contact between that fret and that string.

If there is a detected contact, the microprocessor unit 54 performs the fret contact routine (No.4) for each contacted string. This is shown in more detail in Figure 17. The first thing done in the fret contact routine is to clear the neck damp status for this string. Since a fret/string contact has been identified, there is no call for any neck damping action. The microprocessor unit 54 then turns on the bend measuring signal, by operating the analogue switches 137 and 141 and applies the bend signal to the currently selected fret. The analogue multiplexer 72 is controlled to select the Bend signal and this is read from the analogue to digitial converter 74.

The microprocessor then tests to see if the current fret string contact indication was also indicated on a previous sequence of the control system. It will be appreciated that the microprocessor unit works at such a rate that a great many tests of each fret/string contact will be made during the time a player holds a string against a particular fret. If the latest contact indication is a new one for this fret and string, then the microprocessor updates the Master to indicate a new fret/string contact and to make the measured Bend value the reference position for this contact.

On the otherhand if the current contact indication is a repeat indication of an existing contact, then the microprocessor updates the Master to indicate the pitch bend amount (which equals the reference value originally entered minus the new bend value).

Reverting to Figure 15, on completion of the fret contact routine (No.4) the microprocessor then repeats the read strum and hammer routine (No.3) before testing to see if all 21 frets have been interrogated. If further frets remain, the microprocessor starts again to interrogate the next fret.

Once all 21 frets have been interrogated, reading the strum and hammer routine (No.3) following each fret interrogation, the microprocessor moves on leaving any neck damp status indications remaining as firm indications of a neck damping action.

Figure 18 shows the read analogue controls routine (No.2) which follows routine No.1. In this routine, the microprocessor unit 54 cycles through the analogue control inputs of the multiplexer 72 reading the resultant analogue to digital conversions from the ADC 74. If the values are changed from those previously read, the Master is updated. The routine is completed when all control inputs have been read. The microprocessor unit 54 then starts again with routine No.1.

It can be seen from the above summary that the read strum and hammer routine No.3. is repeated more frequently than other routines. This is to ensure that new strum or hammer events are promptly noted and the Master appropriately updated.

Modified Embodiments

The possibility has been mentioned above of including a second set of sensors for detecting strum action on the strum string elements 18. The two sets of sensors located at opposite ends of the strum string elements 18 can be used to provide an indication of the position along the length of the elements 18 of the strumming or plucking action. For example, the relative amplitudes of the indications from the sensors at the opposite ends of the elements 18 may be used for this purpose, or alternatively the relative time difference between the vibration wave fronts generated by a plucking action reaching the opposite ends of the string.

In the above described preferred embodiment, Squirt signals are supplied to respective strum string elements 18 only at the same time as they are applied to the corresponding neck strings 14 for detecting neck and strum damping. However, the strum string elements 18 may be continuously energised with the 125 kHz sinsusoidal wave form and strum damping detected by monitoring any current flowing into the string elements.

In a further modification, instead of applying SQUIRT signals individually to the neck strings 80 as selected via analogue multiplexer 93 by Squirt Select and Enable signals on lines 77 (Figure 7), all six neck strings may be energised with the SQUIRT signal simultaneously, damping of the individual neck strings being still detectable independently provided no two strings are touching at the time. Then analogue multiplexer 93 is replaced by an analogue switch controlled by a Neck String Squirt Enable signal on a single select line to apply the SQUIRT signal to all neck strings simultaneously.

Also, it may not be necessary to apply the SQUIRT signal to individual selected strum strings via lines 99 as illustrated in Figure 7. Instead, the strum strings may be continuously energised with an alternating signal derived independently from the Master Clock signal on line 131 (Figure 11). Signal generator 130 may provide a further output signal at a different frequency to the signal on line 132, which further output signal is continuously fed to all six strum strings. The use of a different frequency reduces stray pick-up or "cross-talk" between the circuits detecting neck damp and strum damp. The further output signal supplied to the strum strings may be inhibited during application of the SQUIRT signal to the neck strings for detection of neck damp.

The conductive layers 26 and 27 (Figure 4) over the ceramic substrate element 23 of the frets is shown in the previously described embodiment as lying symmetrically over the upper convex surface of the substrate. In an alternative arrangement, the conductive layers may extend over the shoulders of the fret (that is on each side as seen in cross section in Figure 4) to improve the contact performance and make the instrument less sensitive to careless fret fingering by the player of the instrument.

Provision may be made to set the instrument, e.g. by operating a switch or a key, to sound immediately in response to detecting a fret/string contact. The instrument can then be played with the fret fingering (left) hand of the player. With such a setting the neck hammer sensors 40 and their attendant circuitry can be omitted.

In an alternative construction, the fret bars are each formed with wire legs at each end. The high conductivity layer on the fret bar is continued over the ends of the bar and down the lengths of the legs. The bars are then secured directly to the underlying printed circuit board by passing the legs through holes in the board and soldering them to respective printed circuit elements on the underside of the board.

In the above described embodiments illustrated in Figures 11 and 6, the analogue voltage signal on the line 158, representing the position along a fret of a string/fret contact, is supplied as the BEND signal to the analogue multiplexer 72. The voltage signal may however be used instead (or additionally) to control any other selected dynamically controllable parameter of the synthes iser. For example, the voltage signal may be used to control any one or a combination of the following effects: volume, pitch, vibrato, wah-wah, flanging, phasing, fuzz, octividing, compression, envelope shaping, timbre.

In particular, a control may be provided of the synthesiser such as to permit variation of the general sound of the instrument, e.g. as between sounding like a piano to sounding like a harpsichord. Other parameters which may be controlled include the length of the vibrato, the frequency shift of the wah-wah and the repeat time of the echo.

A switch may be provided on the instrument enabling the player to select the parameter to be controlled.

It can be appreciated that the invention thus allows the player to perform completely new musical techniques in "real time", that is during a playing sequence, which are impossible with other instruments.

In a preferred embodiment, the microprocessor 54 may be programmed to perform tests on the data defining the condition of the various sensor inputs, so as to eliminate as far as possible spurious inputs which might result in the event of faulty contacts between the strings and frets. More particularly, specific test algorithms may be devised to reduce or eliminate the effects of certain short comings which are common-place in the fret-fingering technique of most guitar players.

In particular, the microprocessor 54 is programmed to test for string-to-fret contacts in successive cycles, checking every available string-to-fret contact position each cycle. Data defining the results of these tests each cycle may then be stored in a circular buffer in the memory 53, so that the buffer contains at any time not only the test results for the latest cycle, but also the results for a number of preceding cycles. Typically, the buffer may in this way contain historical data for the last 0.5 sec. Then, each cycle, for any string detected to be in contact with a fret, the contact position (or fret) representing the highest frequency note is identified, and the contact status recorded in the buf fer for this contact position is checked for a selected number of immediately preceding cycles. Only if the contact proves to have been consistent during this number of previous cycles is an indication of a valid string-to-fret contact sent to the Master MPU for use in controlling the respective voice of the synthesiser. In this way the string-to-fret contact indications are in effect filtered digitally with a filtering "time constant" determined by the selected number of previous cycles used for the consistency checking. The selection of these "time constant" or filtering values may be determined empirically and are of course dependent on the typical cycle time for the string-to-fret contact test routine.

In additional tests, the microprocessor may be programmed to react differently in response to detection in any particular cycle of a string in contact with an adjacent pair of frets, compared with detection of contact with only a single fret. Normal positive fret fingering causes the fingered string to contact not only the fret for the intended note, but also the adjacent fret nearer the head of the neck, which would represent a note one semi-tone lower. However some fingering techniques may result in only the intended fret being contacted.

The microprocessor may be programmed to have a first, relatively short, filtering time in response to detection of a pair of contacts and a second, relatively longer, filtering time in response to detection of a single contact.

Further, the microprocessor may be programmed to bypass the filtering step and update the Master MPU immediately in response to a new fret contact for a particular string following within a preset short time of a previous contact. Normally this bypassing is permitted only if the new fret contact is one semi-tone different from the previous contact. In this way, should the initial consistently detected note in fact be wrong (out by a semitone), it is correct immediately the correct fret is contacted, and is not maintained whilst the new correct contact is proved consistent.

Another test may be made to prevent a semi-tone drop in frequency when one contact (with the high frequency fret) of a previously detected pair is lost. This is achieved by setting a higher than usual time constant value on first detecting a single fret contact when that contact follows immediately a fret pair contact for which the new single fret contact is the same as the low frequency fret of the previous pair. Then, the note represented previously by the fret pair contact is maintained until the new single fret contact acquires consistency after the set number of cycles, or else the original fret pair contact is reestablished.

In a further test, the number of strings being fretted in successive cycles is monitored, and a flag set if the running average of fretted strings is relatively high. This indicates that the instrument is being used to play chords rather than individual notes or lead. The various preset filtering values can then be varied automatically to suite the differing conditions of chord and lead playing. Generally the settings in chord mode may be more tolerant of fingering errors. For example, whereas detected single fret contacts are sounded normally when in lead mode, when more than a set number of strings are being fretted simultaneously any detected single fret is sounded but followed by a neck string damp envelope to damp the sound.

Yet another test checks for a bar chord which requires a player to depress typically five or six of the strings simultaneously on to the same fret with his index finger stretched across the fret board. With a flat fret board, it may be difficult if not impossible for the player to reliably depress all the strings with his one finger. The microprocessor is programmed to check if five or more strings are fretted and four or more are on the same lowest frequency fret. If so, a bar chord is indicated and the software corrects for one or two missing string contacts along the next fret up in frequency.

It may be convenient to programme the microprocessor 54 so as to measure any bend applied to a fretted string only if a consistent fret pair contact is detected. Deliberate bending by the player will invariably result in a good fret pair contact rather than a single fret contact and attempting to measure bend on a single fret contact may give spurious results due to variable contact resistance between the string and fret. Then, when determining the contact position along a fret to measure bend, the microprocessor may be programmed to measure bend from the two contacted frets of the pair in turn and take on average of the measured position values for use as the present contact position on the high frequency fret of the pair. Typically, the bend measurements alternately on the pair of frets are repeated several times in the cycle and an average of the results taken to provide a settled position value for sending to the Master MPU. After each measurement, a check is made to ensure that there is still contact between the relevant string and fret. If contact is broken at any time, measurement on that string is discontinued and no position update is sent to the Master MPU.

CLAIMS

1. A guitar synthesiser instrument having a fingerboard with electrically conductive frets, electrically conductive strings extending over the fingerboard, and circuit means connected to the strings and the frets responsive to electrical contacts made between the strings

and the frets by fingering the strings during playing of the instrument to identify the string and fret between which each contact is made, wherein each of the frets is arranged to have a contact resistance to any contacting string which is high relative to the longitudinal resistance of the fret from end to end.

2. An instrument as claimed in claim 1 wherein each fret comprises a first conductive material, having a first resistivity, providing said longitudinal resistance, and a layer of a second conductive material, having a second resistivity, on said first conductive material, to form the surface thereof to which string contact is made during playing, the thickness of said layer and said second resistivity being chosen so that the resistance through the layer between the first conductive material and a string in contact with the fret constitutes said contact resistance.

3. An instrument as claimed in claim 2, wherein each fret comprises an elongate insulating substrate having a longitudinal surface forming the fingering surface of the fret in the fingerboard and a first layer on said longitudinal surface of said first conductive material to provide said longitudinal resistance, said layer of said second conductive material constituting a second layer over said first layer.

4. An instrument as claimed in claim 3, wherein said first layer comprises a noble metal film.

5. An instrument as claimed in claims 2 to 4 wherein said layer of said second conductive material comprises a vitreous film loaded with carbon particles.

6. An instrument as claimed in any preceding claims, wherein said circuit means includes voltage signal generating means, fret sequencing means to apply said voltage signal to each fret in turn, string current indicating means for each string to indicate a current flowing in the string, and string-to-fret contact detecting means responsive to a string current indication from one of said indicating means, which is synchronised with the application of said voltage signal to a fret by said fret sequencing means, to provide an indication of contact between that fret and the respective string.

7. An instrument as claimed in claim 6 wherein each said string current indicating means provides a low impedance current sink for current injected into the respective string from a fret in contact therewith.

8. An instrument as claimed in claim 7 wherein both ends of each fret are connected to said circuit means and said circuit means includes difference signal generating means to apply a predetermined voltage difference across said longitudinal resistance between the ends of any selected fret to produce a voltage gradient along the length of the fret, whereby the current injected into a string from a fret in contact therewith is dependent on the position of the fret/string contact point along the length of the fret, and each said string current indicating means includes means providing a current size signal representative of the amount of current flowing in the respective string, said circuit means being arranged to process said current size signal to provide an indication of pitch bend.

9. An instrument as claimed in claim 8 wherein said circuit means is arranged to determine from said current size signal the position along the fret of said fret/string contact point and to compare this determined position with a reference position for the respective string to determine the amount of pitch bend.

10. An instrument as claimed in claim 9 wherein the distance and direction along the fret of the determined contact point position from the reference position are both determined and the instrument is arranged to vary the generated note upwards or downwards in accordance with said direction.

11. An instrument as claimed in any of claims 8 to 10 wherein said difference signal generating means generates a constant amplitude voltage difference signal and an adjustable amplitude common voltage signal applied to both ends of a fret, whereby the amplitude of said common voltage signal is adjustable in response to a control signal to vary the position along the length of the fret of a voltage null point at which a fret/string contact would inject no current into the string, and said difference signal generating means and each of said means providing a current size signal are connected in a respective feed back loop generating said control signal to adjust the ampl itude of the common voltage signal, dur ing a fret/string contact, to bring the current flowing in the respective string close to zero, said control signal constituting said current size signal.

12. An instrument as claimed in claim 11, wherein said voltage difference signal and said common voltage signal comprise oppositely phased periodic signals.

13. An instrument as claimed in claim 12, wherein said difference signal generating means comprises for each fret a transformer having a secondary winding connected across the ends of the fret, a first drive amplifier connected to one end of the fret to supply said common voltage signal and a second drive amplifier connected to the primary winding of the transformer to supply said voltage difference signal.

14. A guitar synthesiser instrument having a fingerboard with electrically conductive frets, electrically conductive strings extending over the fingerboard, and circuit means connected to the strings and the frets responsive to electrical contacts made between the strings and the frets by fingering the strings during playing the instrument to identify the string and fret between which each contact is made, wherein each of the frets has a longitudinal

resistance from end to end and said circuit means includes difference signal generating means to apply a differential voltage across the ends of the fret to produce a potential gradient along the fret, and means responsive to a signal applied to a string by contact with a fret to determine the position of the point of contact along the length of the fret.

15. A guitar synthesiser instrument having a fingerboard with electrically conductive frets, electrically conductive strings extending over the f ingerboard, and circuit means connected to the strings and the frets responsive to electrical contacts made between the strings and the frets by fingering the strings during playing of the instrument to identify the string and fret between which each contact is made, wherein said circuit means is operative to keep a record, for each string-to-fret contact position, of the history of detected string-to-fret contacts at the respective said position during an immediately preceding period of predetermined duration, and is arranged to indicate a valid string-to-fret contact at the respective position only if the detected contacts at the respective position in said historical record show that the contact has acquired a predetermined level of consistency.

16. A guitar synthesiser as claimed in claim 15 wherein said circuit means includes a microprocessor with associated alterable memory, the microprocessor being programmed to perform successive cycles, each cycle comprising recording in successive buffer locations in the memory the detected contact status of each possible string-to-fret contact position, so that the memory contains in the buf fer locations the contact status of each said contact position for a predetermined number of successive cycles, the microprocessor being further programmed so as each said cycle to identify for any string the string-to-fret contact position detected in the current cycle which represents the highest frequency, to check the contact status of the identified contact position in a selected number of immediately preceding cycles, and to indicate a valid string-to-fret contact for the respective contact position only if said status has been consistent during said selected number of preceding cycles.

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