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3,236,931

ELECTRONIC MUSICAL INSTRUMENT

Filed Jan. 15, 1960

2 Sheets-Sheet 1

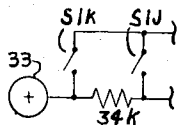
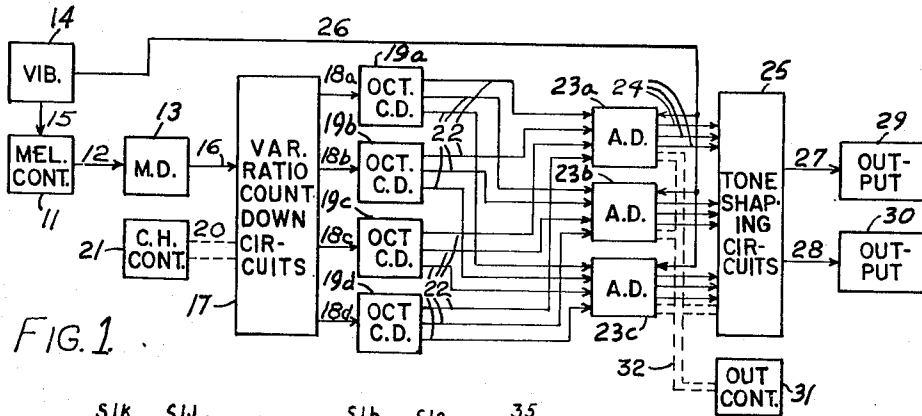


FIG. 2

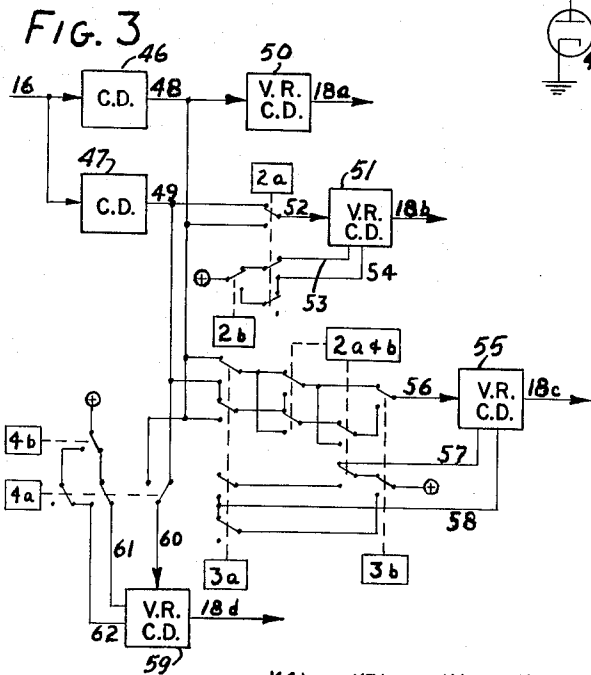
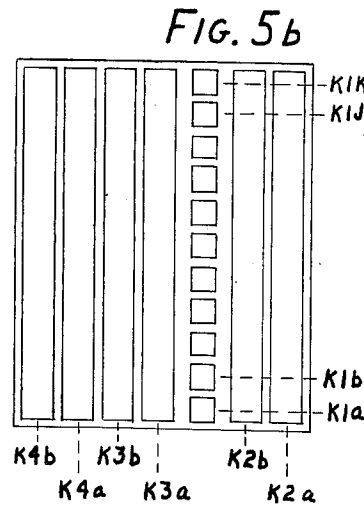


FIG. 3a



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Feb. 22, 1966

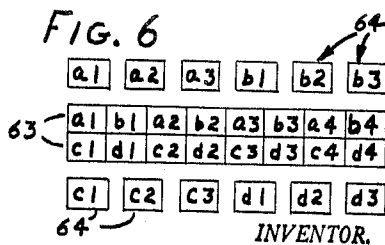
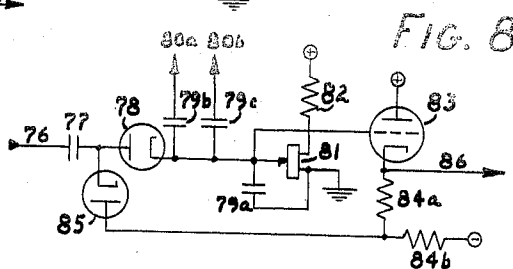
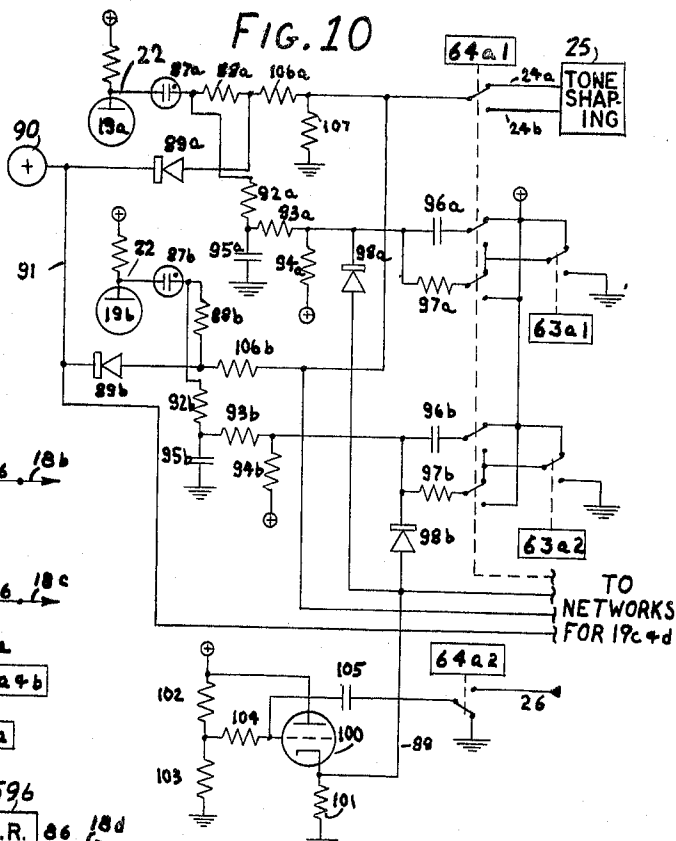
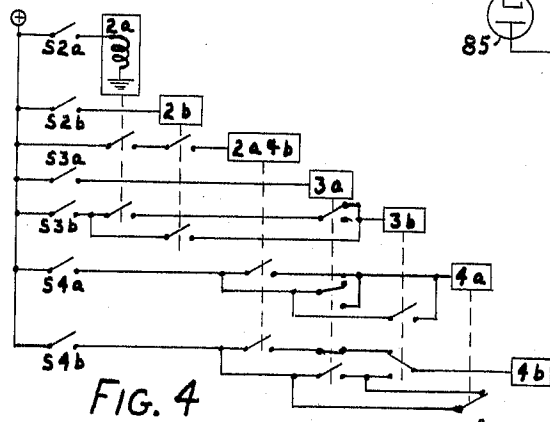
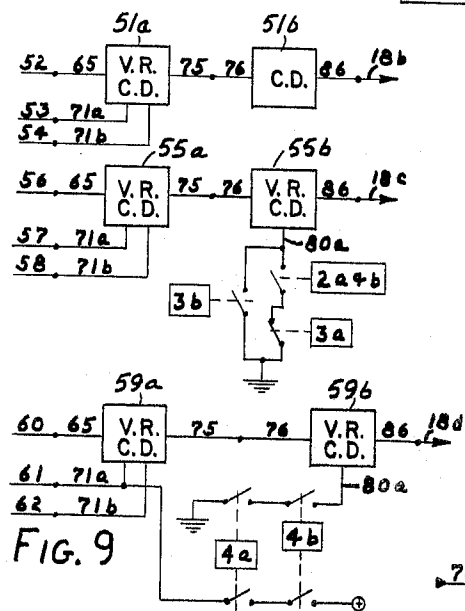
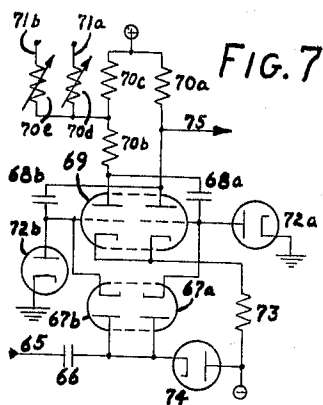
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2 Sheets-Sheet 2



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ELECTRONIC MUSICAL INSTRUMENT

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11 Claims. (Cl. 84-1.23)

This invention relates generally to improvements in electronic musical instruments and more particularly to novel tone generating and controlling means for such instruments.

Notes sounded together to form a chord must have their frequencies related to each other within rather narrow tolerances if the intended musical result is to be obtained. Most of the instruments which are capable of playing chords use separate generating means for each note to obtain the necessary frequency accuracy. Periodic tuning is usually required and instruments of this type have forced the adoption of the Equal Temperament scale because of the impractical number of individual generating means required for playing in all different keys of the more musically pleasing Just Intonation scale.

Where electronic generating means are used, it is a difficult problem to economically obtain adequate frequency stability. Electronic components drift with changes in temperature, humidity, and time in a rather unpredictable or random manner so that frequent tuning adjustments are necessary. The difficulty is increased by the fact that electronically generated and mixed tones do not blend as smoothly as tones generated by mechanical or pneumatically operated means when there are small errors in the frequency relations. Electronic instruments usually minimize the number of precision circuits and tuning adjustments required by using 12 oscillators for the 12 notes of one octave and by obtaining the notes of other octaves from frequency dividing circuits.

The "Encyclopedia of Chords" by Walter Stuart published by New Sounds in Modern Music, 111 West 48th Street, New York 36, New York, lists 21 different chords each having three or four different positions or inversions and each having any of the 12 different notes of the octave as the root note. The total of roughly 960 different chords seems an overwhelming number for the beginner to learn. Chord organs have been devised to simplify playing for the beginner by providing a set of chord buttons that each selects a different chord. The melody is usually played on a conventional keyboard with one hand while coordinated operation of the chord buttons is accomplished with the other hand. Some designs have as many as 96 buttons for eight different chords based on each of the 12 notes of the octave. The musical value of these controls is unfortunately severely restricted by the fact that each chord can be played in only one of its four possible positions. Modern arrangements may use all different positions so this type of playing must be restricted to specially prepared or selected arrangements of limited flexibility.

The instant invention provides a tone generating system consisting of a master oscillator driving one fixed ratio and several controllable ratio frequency divider chains. The fixed ratio chain produces a plurality of octavely related outputs for the melody part which track the master

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oscillator frequency. Melody patterns are produced by varying the master oscillator frequency. The number of controllable ratio chains is equal to the number of other parts to be sounded simultaneously and each also produces a plurality of octavely related outputs which track the master oscillator in frequency except when the ratio is changed to select a different harmony relation to the melody part. It has been discovered that only 31 different combinations of intervals from the melody note occur in all four part chords listed in the prior referenced "Encyclopedia of Chords" so only 31 different countdown ratios need be effected by chord controls to produce all of these.

Perfect harmony relations can be obtained as long as the selected countdown ratios can be maintained. The master oscillator may be subject to drift as is normal for electronic circuits but such drift will not effect anything but a slight shift in key which few ears will be able to detect and which can be corrected by a single tuning adjustment. The countdown ratios may be selected such that the harmony relations will be in accordance with Just Intonation relations for more musically pleasing effects.

The instant invention also includes a novel keyboard and control arrangement for the tone generating system. Keys for selecting the different melody notes in an octave are aligned in a row and bars to be operated in combination to select the different chords related to the selected melody note run parallel to the row. The melody notes can thus be played with one finger while the other fingers of the same hand operate the bars to select the chord. In one embodiment, six bars to be operated in 31 different combinations select all different chords for four part harmony. These 31 different combinations are the same for each melody note and learning of these is sufficient for playing all chords. An interlock system prevents unused combinations of the six bars from producing any but the harmony combinations for chords so that discords cannot be played and errors in playing will not be so musically damaging.

Operation of the preceding controls does not produce an output but simply sets up one of the notes of the octave as the melody note and other notes related to it for the selected chord. Another set of keys, to be played by the other hand, determines in which octaves the melody note and the other notes of the chord will be sounded. Each part may be sounded in any one, two, or all octaves over the instrument range, or omitted, so effects may be varied from solo to a full orchestra. Where melody runs in chord sequence, these controls may also be used to execute fast runs, trills, or slurs which would be difficult with single finger playing of the melody keys.

The instant invention further includes a novel keying circuit to impose the proper attack and decay of the amplitude envelope on a note sounded by operation of one of the second set of keys. These keying circuits are individual to each key and may be set for different attacks and decays, including those for percussion. Stops are included to individually set the attack, decay and timbre routing of signals controlled by each of several different groups of keys for different orchestral effects. Tremolo may also be applied individually to signals controlled by the different groups and synchronous vibrato of all out-

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puts may be obtained by applying a vibrato signal to vary the frequency of the master oscillator.

An object of the invention is a polyphonic electronic musical instrument which produces chords with notes locked in selected frequency relations and requires a minimum of skill for playing satisfactorily.

A further object of the invention is a polyphonic electronic musical instrument which provides a maximum of music producing capability with a minimum of playing skill and cost.

A still further object of this invention is a polyphonic electronic musical instrument which can play in any musical scale and which can produce true glissando and vibrato effects.

Other objects and advantages together with a fuller understanding of the invention will be had by referring to the following description and claims taken in conjunction with the accompanying drawings in which:

FIG. 1 is an overall block diagram of an embodiment of the invention.

FIG. 2 is a schematic diagram of one form of melody control and master oscillator which may be used with the apparatus of FIG. 1.

FIG. 3 is a partial schematic and partial block diagram of one form of the chord selector and count down circuits of the apparatus of FIG. 1.

FIG. 4 is a schematic diagram of the relay operating circuits of the apparatus of FIG. 3.

FIG. 5a is an elevation view of the melody and chord keys and switches for operating the apparatus of FIGS. 2 and 3.

FIG. 5b is a plan view of the melody and harmony keys in one possible arrangement.

FIG. 6 is a plan view of one possible arrangement of the keys and stops.

FIG. 7 is a schematic diagram of one possible circuit to provide a controllable countdown ratio in the apparatus of FIG. 3.

FIG. 8 is a schematic diagram of another possible countdown circuit for the apparatus of FIG. 3.

FIG. 9 is a partial schematic and partial block diagram of an alternate form for the final stages of the apparatus of FIG. 3.

FIG. 10 is a schematic diagram of attack and decay circuits of the apparatus of FIG. 1.

Referring now to FIG. 1, melody control 11 produces a voltage output via line 12 to master oscillator 13 to control its frequency of oscillation. The voltage output may be varied continuously or in steps in response to control operation and melody control 11 may further superimpose the output of vibrato unit 14 received via line 15 on its output. The output of vibrato unit 14 on line 15 will normally be a sine wave having a frequency of approximately seven cycles per second.

Master oscillator 13 produces a signal output on line 16 to countdown circuits 17 which is proportional in frequency to the voltage received via line 12. Countdown circuits 17 produce signal outputs on lines 18a through d to octaver units 19a through d respectively. The output signal on line 18a is a fixed fraction of the frequency of the output of master oscillator 13 while the signals on lines 18b through d are controllable fractions of the same frequency. These fractions are controlled by linkages 20 from operation of controls in chord unit 21 such that the frequencies of the outputs on lines 18b through d are related to the frequency of the output on line 18a as the frequencies of notes of the selected chord to the frequency of the melody note.

Octaver units 19a through d produce signal outputs on lines 22 which are octavely related to the signals they receive via lines 18a through d respectively. Units 19a through d may each consist of a chain of flip flop circuits arranged in a binary counter in a well known manner to produce a series of outputs each an octave

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lower than the preceding. The outputs on lines 22 may include the signals originally on lines 18a through d.

Attack and decay units 23a through c each receive an output signal from each of octaver units 19a through d. The signal from octaver unit 19a is the highest in frequency and the others are within the octave immediately below it. Each of attack and decay units 23a through d has several output lines 24 running to timbre circuits 25 and receives an input from vibrato unit 14 via line 26. Timbre circuits 25 produce two outputs via lines 27 and 28 to output units 29 and 30 respectively for stereophonic effects.

Output control unit 31 controls the operation of switches in attack decay units 23a through d via linkages 32. A first set of controls in unit 31 individually controls the passage of signals from the input of attack decay units 23a through d to a mixer in the unit with a predetermined attack decay envelope. A second set of controls, or stops, determines the attack and decay shape which will be imposed, the output line 24 to which the output of the mixer will be connected, and whether or not the signals passed will be amplitude modulated with the signal on line 26 for tremolo effects.

Each of lines 24 is routed through a different frequency discriminative network in timbre circuits 25 and the outputs of these networks are routed to either line 27 or 28. Another set of controls in control unit 31 effects switching via linkages 32 to timbre circuits 25 to connect the different network outputs to line 27 or line 28. Timbre circuits 25 may consist of any type of frequency discriminative network or circuit or other means in suitable numbers for modifying the timbre characteristics of complex waveforms. Output units 29 and 30 consist of amplifiers and sound reproducing means and a single unit may be used in place of the two if stereophonic effects are not desired. The output of vibrato unit 14 on line 26 will have a triangular or sawtooth waveform which can be applied to attack and decay units 23a through c to amplitude modulate the signal outputs on lines 24 for a tremolo effect. The line 26 output may be obtained in vibrato unit 14 by waveshaping the output of the same oscillator producing the sine waveform on line 15 or a different oscillator producing a triangular waveform directly may be used.

Referring now to FIG. 2, melody control 11 of FIG. 1 may consist of voltage source 33, switches S1a through S1k, resistors 34a through k, resistor 35, condenser 44, and switches 45a and b. Resistor 35 and resistors 34a through 34k are connected in series from the emitter of transistor 36 to the output of voltage source 33. The base of transistor 36 is grounded so that the emitter current depends upon the voltage output of source 33 and the size of the series resistance. The latter may be changed by the operation of any of switches S1a through k, each of which shorts out the chain of resistors 34a through k up to and including the one having its corresponding letter designation. Operation of switches S1a through k produces set step changes in the emitter current.

Condenser 44 has one side connected to a centertap on resistor 35 and the other side to switches 45a and b. Operation of switch 45a connects condenser 44 to ground so that the step changes of voltage and current resulting from operation of switches S1a through k are made gradually as the charge on condenser 44 must change. Operation of switch 45b connects condenser 44 to the output of vibrato unit 14 on line 15. The emitter current then varies about its normal value in accordance with the signal on line 15.

Resistors 34a through k may be sized to produce step changes of emitter current corresponding to the frequencies of the notes of any musical scale. Various other arrangements may be used to perform the preceding functions.

Transistor 36 is of the PNP type and has its collector

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connected to the plates of steering diodes 37a and b. The cathodes of diodes 37a and b are connected respectively to the junctions of condensers 38a and b with the grids of twin triode tube 39. The other sides of condensers 38a and b connect to the opposite plates of tube 39 which further connect to a positive voltage supply through load resistors 40a and b. Clamping diodes 41a and b have their plates connected to the respective grids of tube 39 and their cathodes connected to ground so that the grids are prevented from going positive. The cathodes of tube 39 are connected together through resistor 42 to a negative voltage supply.

Tube 39 and its associated circuitry thus forms a multivibrator circuit in which the grid returns are through steering diodes 37a and b and the collector of transistor 36. Just after switching action has taken place, one grid will be held substantially at ground potential and the other grid will be negative by an amount equal to the plate swing. The collector current will then flow through the one of diodes 37a or b connected to the negative grid and charge the respective condenser 38a or b at a linear rate. When the grid rises sufficiently toward ground potential switching will again be effected in the conventional manner of multivibrator circuits and the collector current will be routed through the opposite one of diodes 37a or b to the other grid now negative.

Use of a relatively large value of resistor 42 and negative supply voltage keeps the tube current relatively independent of changes in tube characteristics. The time constant of condenser 38a or b and its associated resistor 40b or a and clamping diode 41a or b should be kept short enough so that the plate voltage on the cutoff section has time to rise substantially to the positive supply voltage in the shortest interval between switching. The frequency of oscillation will then be proportional to the collector current which in turn is proportional to the emitter current. Control of the emitter current as previously described thus controls the frequency of the output taken from one plate through circuit 43 to line 16. Circuit 43 may consist of a squaring amplifier and cathode follower or other means for providing a low impedance large amplitude output.

Referring now to FIG. 3 which shows one possible specific arrangement for the countdown circuits 17 of FIG. 1, the master oscillator output on line 16 is applied as input to fixed ratio counters 46 and 47. Counters 46 and 47 produce outputs on lines 48 and 49 respectively which are submultiples of the frequency of the input on line 16 and which are different from each other such as one cycle for 15 and one for 16 respectively.

Counter 50 receives an input from line 48 and produces an output on line 18a which is a fixed submultiple of the input frequency. The output on line 18a is thus always a fixed submultiple of the signal frequency on line 16. Variable counter 51 receives an input via line 52 from either line 48 or 49 dependent on the position of the contacts of relay 2a. The countdown ratio which the output of counter 51 on line 18b has to the input depends upon whether line 53 or line 54 or neither is connected to the positive voltage source through the contacts of relays 2a and 2b. The output on line 18b will thus be a different submultiple of the frequency on line 16 for each of the four different conditions of operation of relays 2a and 2b.

Variable counter 55 likewise receives an input on line 56 from line 48 or 49 depending upon the condition of operation of relays 2a and b, 3a and 3b and produces an output on line 18c which is a submultiple of the input depending upon whether line 57 or 58 or neither is connected to the positive voltage supply by other contacts of the same relays selecting the input source. Variable counter 59 also receives an input via line 60 from either line 48 or 49 depending upon the condition of relay 4a and produces an output on line 18d which is a submultiple of the input whose value depends upon whether

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line 61 or 62 or neither is connected to the positive supply by contacts of relays 4a and 4b.

The different combinations of intervals down from the melody note for the other three harmony parts to make up all the four part chords listed in the prior referenced "Encyclopedia of Chords" is shown in Table A below. The numbers in the columns for each of parts 2, 3 and 4 indicate the number of semitone intervals down from the melody note.

Table A

No. 2	No. 3	No. 4	No. 2	No. 3	No. 4	No. 2	No. 3	No. 4
1	4	8	1	5	8	1	5	9
2	4	8	2	5	8	2	5	9
2	6	8	2	6	9	2	6	10
3	4	8	3	5	8	3	5	9
3	6	8	3	6	9	3	6	10
3	7	8	3	7	9	3	7	10
3	7	11	4	5	8	4	5	9
4	6	7	4	6	9	4	6	10
4	7	8	4	7	9	4	7	10
4	7	11	4	8	9	4	8	10
4	8	11						

It will be noted that No. 2 can be any interval down from one to four, No. 3 any from four to eight, and No. 4 any from eight to eleven. No. 3 can be eight down only when No. 2 is four down. The countdown ratios of the apparatus of FIG. 3 with no relays operated will be such that the output on line 18b is one interval down from that on line 18a, that on line 18c four intervals, and that on line 18d eight intervals down. The outputs on lines 18a through d thus correspond to the melody, No. 2, No. 3, and No. 4 parts for the first chord listed in Table A.

Operation of relay 2a changes the output on line 18b to two intervals down by switching line 52 from line 49 to line 48 and the positive supply from line 53 to 54. Operation of relay 2b changes it to three down by switching the positive supply from line 53 to 54. Operation of both relays 2a and 2b changes it to four down by switching line 52 from line 49 to 48 and by disconnecting the positive supply from both lines 53 and 54.

Operation of relay 3a changes the output on line 18c from four to five down by switching line 56 from line 48 to 49. Operation of relay 3b changes it to six down by switching line 56 from line 48 to 49 and the positive supply from line 57 to 58. Operation of both relays 3a and 3b changes it to seven down by maintaining line 56 connected to line 48 and by disconnecting the positive supply from both lines 57 and 58. Operation both relays 2a and 2b operates relay 2a and b by means to be described later and this in turn switches line 56 from line 48 to 49 and disconnects the positive supply from both lines 57 and 58 if neither of relays 3a or 3b are operated to change the output on line 18c from four to eight down. With relay 2a and b operated, operation of relay 3a changes the output to five down in a different way than previously by switching line 56 back to line 48 and by switching the positive supply to line 58. With relay 2a and b operated, operation of relay 3b changes the output to six down as previously by connecting line 56 to line 49 and the positive supply to line 58. Operation of both relays 3a and 3b with relay 2a and b also operated effects seven down by connecting line 56 to line 48 and by disconnecting the positive supply from lines 57 and 58 as previously.

Operation of relay 4a changes the output on line 18d from eight to nine intervals down from that on line 18a by switching line 60 from line 49 to 48 and the positive supply from line 61 to 62. Operation of relay 4b changes it to ten down by switching the positive supply from line 61 to 62. Operation of both relays 4a and 4b changes it to eleven down by switching line 60 from line 49 to line 48 and the positive supply from both lines 61 and 62.

Operation of the preceding relays as described can thus control the outputs on lines 18b through d to the com-

bination of intervals for all the chords listed in Table A. Other combinations of intervals can also be produced, however, and this may be undesirable. The use of the operating paths for these relays shown in FIG. 4 prevents these unwanted combinations from being produced.

Referring now to FIG. 4, relays 2a, 2b, and 3a operate whenever switches S2a, S2b, and S3a respectively are closed. Relay 2a and 2b operates when relays 2a and 2b are both operated. Relay 3b operates when switch S3b is closed if relay 2b is operated or if relay 2a is operated and relay 3a is not. Relay 4a is operated when switch S4a is closed if any of relays 2a and 2b, 3a, or 3b is operated. Relay 4b is operated when switch S4b is closed if relay 2a and 2b is operated and relays 3a and 3b are not or if relays 3a and 3b are operated or if relay 3b is operated and relay 4a is not.

A keyboard arrangement for operating switches S2a through S4b of FIG. 4 and switches S1a through S1k of FIG. 2 is shown in FIGS. 5a and 5b. Bars K2a through K4b are mechanically linked to switches S2a through S4b respectively so that depression of a bar closes the corresponding switch. Keys K1a through K1k are mechanically linked to switches S1a through S1k respectively so that depression of a key closes the corresponding switch.

Keys K1a through K1k are arranged in a row and bars K2a through K4b run parallel to the row so that any combination of bars may be operated by the other digits of one hand when one digit is operating any one of the keys. The bars are spaced so that one digit of the hand can operate either one or two together. The arrangement shown is one believed to be convenient for playing with the left hand but it is obvious that various modifications might be made thereto and still accomplish the objective of allowing control to be effected by one hand.

As previously mentioned, operation of switches S1a through S1k controls the frequency of master oscillator 13 and so selects the melody note output on line 18a. Operation of a particular combination of switches S2a through S4b sets the outputs on lines 18b through d to a particular combination of intervals lower than whatever output is on line 18a. The same fingering of bars K2a through K4b thus produces the same chord related to any melody note selected.

The arrangements of FIGS. 2, 3, 4, 5a and 5b are particular illustrations of one embodiment of the invention using particular circuits in a design with particular musical objectives. It will be obvious to those skilled in the art that a large number of different combinations are possible within the scope of the invention and a changing of the musical objectives or the detailed circuits used may make rearrangements more advantageous. The arrangement of FIG. 3 was made for a particular design using a particular type of countdown circuit to be described later and having particular musical objectives also to be described later.

The apparatus of the invention could be adapted for a wide range of different musical scales and systems but the discussion here will be limited to a few. The scale of Equal Temperament has long been used almost exclusively in Western music and most existing musical arrangements were written for it. The Equal Temperament scale is composed of twelve equal intervals which approximate twelve intervals of the Just Intonation scale which has more musically pleasing harmony relations but which requires a considerably greater number of fixed tuned tone generators if all keys are to be used.

Table B following shows the frequency ratios of the notes over an octave of the Equal Temperament scale and of twelve notes of the Just Intonation scale which are closest to them. Column 4 shows the lowest numbered set of integral countdown factors which can produce the Just Intonation ratios listed exactly and the remaining columns show some of the ways in which these numbers can be factored.

Table B

Interval Number	Frequency Ratios		Countdown Factors			
	E.T.	J.I.	4	5	6	7
0	1.0	1	360	15-24	15-3-8	15-8
1	0.9439	15/16	384	16-24	16-8-3	16-8
2	0.8909	8/9	405	15-27	15-9-3	15-9
3	0.8409	5/6	432	16-27	16-9-3	16-9
4	0.7937	4/5	450	15-30	15-10-3	15-10
5	0.7492	3/4	480	15-32	15-8-4	15-11
6	0.7071	45/64	512	16-32	16-8-4	16-10
7	0.6674	2/3	540	15-36	15-9-4	16-11
8	0.6300	5/8	576	16-36	16-9-4	16-12
9	0.5946	3/5	600	15-40	15-10-4	16-13
10	0.5612	9/16	640	16-40	16-10-4	16-13
11	0.5297	8/15	675	15-45	15-9-5	15-15

It will be seen that if counters 46 and 47 countdown by 15 and 16 to one respectively, the switching of the apparatus of FIG. 3 previously described to effect the different intervals will apply the factors first listed for the intervals in columns 5, 6, and 7 to lines 52, 56, and 60. The different switching for interval 5 gets 15 in one case and 16 in the other but it is seen that a combination with either of those factors may be used.

If counter 50 has a countdown ratio of 24 and counter 51 a ratio of 24 when line 53 is connected to the positive supply, and a ratio of 27 when line 54 is connected, and 30 when neither is connected, the proper factors for the intervals listed in column 5 will be obtained for the output on line 18b by the previously described switching. The proper outputs on lines 18c and 18d will likewise be obtained if counter 55 has countdown ratios of 30, 32, and 36 when line 57, line 58, and neither are respectively connected to the positive supply and if counter 59 has ratios of 36, 40 and 45 when line 61, line 62, and neither are respectively coupled to the positive supply.

The factors listed in columns 5 and 6 of Table B produce the exact Just Intonation ratios of each of the intervals. The factors listed in column 7 are slightly off for one of those for the fifth interval and for intervals 6, 9, and 10. If these errors can be tolerated, lower countdown factors can be used. It will be recognized that various other approximations might also be made to simplify equipment design at some sacrifice in musical quality. The countdown factors of column 7 may be effected by the apparatus of FIG. 3 if the previously listed countdown factors for counters 50, 51, 55, and 59 are changed as follows: 8 for 24, 9 for 27, 10 for 30, 11 for 32, 12 for 36, 13 for 40, and 15 for 45. The combination of factors listed in column 6 provide the proper ratios with smaller factors which may be more convenient to implement and FIGS. 9a and 9b to be described later show a modification to the apparatus of FIG. 3 for implementing these factors.

Referring now to FIG. 7 which shows a circuit that may be used for the counters of FIG. 3, the input signal to be divided is applied via line 65 through condenser 66 to the plates of diodes 67a and 67b and to the cathode of diode 74. The cathodes of diodes 67a and 67b are connected to the grids of twin triode tube 69 which is connected in a circuit similar to that of FIG. 2. Condensers 68a and 68b interconnect alternate plates and grids, one plate is connected to a positive supply through resistor 70a and the other through resistors 70b and 70c in series, diodes 72a and 72b put a positive clamp on the grids to ground, and the cathodes are connected together through resistor 73 to a negative supply. Potentiometers 70d and 70e have one side connected to the junction of resistors 70b and 70c and the other to lines 71a and 71b respectively. Diode 74 has its plate connected to the negative supply.

The input on line 65 is preferably a square wave or pulse having a relatively large amplitude. As the input swings negative condenser 66 will discharge through diode 74 so its junction with diode 74 will not go below the negative supply voltage. When the input swings positive, condenser 66 will charge through the one of diodes 67a or 67b which happens to be connected to the most negative grid of tube 69. An amount of charge depending upon the amplitude of the voltage swing and the relative sizes of condenser 66 and the respective one of condensers 68a or 68b connected to the negative grid will be transferred to the respective one of condensers 68a or 68b. The amount of charge transferred for each cycle of the input will be independent of the frequency if the time constant of condenser 66 in combination with the plate load resistance of tube 69 and the output resistance of the source is a small fraction of the positive going interval.

The voltage on the negative grid of tube 69 is thus stepped positively with each cycle of the input until the switching point is reached and the other grid goes negative to be stepped in turn. Variation of step size as the grid goes positive can be kept small by using an input signal swing considerably larger than the grid swing to the switching point. The amplifier and cathode follower of circuit 43 of FIG. 2 is capable of producing such an output and also of having a low impedance output. Where the circuit of FIG. 7 is to be cascaded, a similar circuit in its output taken from one plate via line 75 to drive the next stage may be desirable.

When used for counters 46 and 47, line 65 would connect to line 16 and line 75 would connect to the input of a circuit like circuit 43 of FIG. 2 which would in turn produce an output on line 48 or 49 capable of driving like circuits in counters 50, 51, 55, and 59. Potentiometers 70d and 70e would not be needed and resistors 70b and 70c could be replaced by a single resistor. Condenser 66 might be made adjustable in combination with one of the plate load resistors or condensers 68a or 68b to set the desired countdown ratio.

When used for counters 50, 51, 55, or 59, line 65 would be connected to line 48, 52, 56, or 60 and an output taken directly from line 75 to line 18a, 18b, 18c, or 18d. For counters 51, 55, and 59, line 71a would connect to line 53, 57, or 61 and line 71b would connect to line 54, 58, or 62. The circuit would be set up to produce the highest countdown ratio required with lines 71a and 71b disconnected. Line 71a would then be connected to the positive voltage supply and potentiometer 70d adjusted for the smallest countdown. Line 71b would then be connected to the positive supply and potentiometer 70e adjusted for the middle countdown value. Connection of potentiometers 79d or 70e to the positive supply changes the effective value of plate load resistance on that side and so the amount of grid swing which in turn changes the number of steps required to reach the switch point.

FIG. 8 shows a different type of countdown circuit. The input is applied via line 76 through condenser 77 to the plate of diode 78 and to the cathode of diode 85. The cathode of diode 78 connects to one side of condensers 79a, 79b, and 79c and to the emitter of unijunction transistor 81. The other side of condenser 79a and one base of transistor 81 connect to ground. The other sides of condensers 79b and 79c go to lines 80a and 80b respectively and the other base of transistor 81 connects to a positive supply through resistor 82. The cathode of diode 78 also connects to the grid of tube 83 which has its plate connected to a positive supply and its cathode to a negative supply through resistors 84a and 84b in series. An output on line 86 is taken from the cathode of tube 83 and the plate of diode 85 is connected to the junction of resistors 84a and 84b.

When the signal on the input goes positive, condenser 77 transfers a charge through diode 78 to condenser 79a 75

to produce a step rise of voltage. When the signal goes negative, the diode side of condenser 77 is clamped by diode 85 to the voltage at the junction of resistors 84a and 84b. This voltage increases with the voltage across condenser 79a so that the step sizes remain substantially constant even if the input signal swing is relatively small. Transistor 81 is of a type, such as General Electric Company type 2N489, which leaves the emitter essentially open circuited until its voltage reaches a trigger point at which a negative resistance appears between the emitter and the base connected to ground. Condenser 79a then discharges through the emitter base circuit of transistor 81 when the voltage across it reaches the trigger point. As soon as the emitter current drops upon discharge of the condenser 79a, transistor 81 recovers and the emitter again represents an open circuit. The action is similar to that which could be obtained with a thyatron except that the recovery time is much shorter.

Resistor 8a helps to stabilize the trigger point of transistor 81 against changes with variations in temperature. Tube 83, functioning as a cathode follower, minimizes the shunting of condenser 79a by any load which must be driven as well as shifting the clamp point for diode 85 to maintain a more constant step size. The latter allows the circuit to be driven by the output of a circuit such as that of FIG. 7 without amplification. Condensers 79b or 79c may be switched in parallel with condenser 79a by connecting lines 80a or 80b respectively to ground. This will change the countdown ratio as the charge transferred will not produce as large a voltage step across the increased capacitance and more steps will be required to reach the trigger point.

Referring now to FIG. 9 which shows a modification to the apparatus of FIG. 3 to use the countdown factors shown in Table B, column 6, counter 51a uses the circuit of FIG. 7 with the same connections as previously described except that the output line 75 connects to line 76 which is the input of counter 51b instead of to line 18b. The countdown ratios are changed from 24, 27, and 30 to 8, 9, and 10 respectively. Counter 51b may be the circuit of FIG. 8 counting down by a factor of three. Counter 50 may produce a countdown of 24 in one stage as previously described or by two cascaded stages with factors of 8 and 3 in an arrangement similar to that of counters 51a and 51b. The proper ratios of outputs on lines 18a and 18b will then be produced.

Counter 55a replaces counter 55 in the arrangement of FIG. 3 as previously explained for using the circuit of FIG. 7 except that the countdown factors are changed from 30, 32, and 36 to 10, 8, and 9 respectively and the output is connected to the input of counter 55b. With the contacts of the relays as shown, counter 55b, which consists of the circuit of FIG. 8, produces a countdown factor of 3. If line 80a is connected to ground by operation of relay 3b or by operation of relay 2a and b when relay 3a is not operated, the countdown factor changes to 4. The factors shown in column 6 of Table B are thus produced for the right combinations of operation of the relays.

Counter 59a replaces counter 59 in the same way that counters 51a and 55a replaced counters 51 and 55 except that line 71a is also connected to the positive supply when both relays 4a and 4b are operated. The countdown factors of 36, 40, and 45 are changed to 9, 10, and 9 respectively to match with the second factors in column 6 of Table B. The output of counter 59a drives counter 59b, which consists of the circuit of FIG. 8 as did counters 51b and 55b, producing a countdown factor of 4 except when operation of both relays 4a and 4b changes it to 5 by grounding line 80a. Output on line 18d is thus proper.

Referring now to FIG. 10 which is a partial schematic of one of attack and decay units 23a, 23b, or 23c of the apparatus of FIG. 1, the plate of the output tube of octaver unit 19a is connected to one side of neon tube 87a. Re-

sistor 88a connects the other side of neon tube 87a to the anode of diode 89a which has its cathode connected to clamp voltage source 90 via line 91. The junction of neon tube 87a and resistor 88a is connected through the series combination of resistors 92a, 93a, and 94a to the positive voltage supply. Condenser 95a is connected between ground and the junction of resistors 92a and 93a. The junction of resistors 93a and 94a connects through condenser 96a and resistor 97a to different arms of relay 64a1 and also connects to the cathode of diode 98a. The anode of diode 98a connects via line 99 to the cathode of tube 100. Tube 100 is connected as a cathode follower with its plate connected to the positive supply and its cathode to ground through resistor 101. Resistors 102 and 103 are connected between the positive supply and ground and have their junction connected to the grid of tube 100 through resistor 104. The grid of tube 100 is also connected to an arm of relay 64a2 through condenser 105. Resistor 106a connects the junction of resistor 88a and diode 89a to another arm of relay 64a1 and resistor 107 is connected between the same arm and ground.

The plate of the output tube of octaver unit 19b connects to a network composed of neon tube 87b, resistors 88b, 92b, 93b, 94b, and 97b, condensers 95b and 96b, and diodes 89b and 98b arranged identically to the components with corresponding numbers in the network in the output of octaver unit 19a except that condenser 96b and resistor 97b connect to different arms of relay 64a1 than condenser 96a and resistor 97a. The outputs of octaver units 19c and 19d also connect in the same way with the same type of network (not shown) to complete the attack and decay unit 23a, 23b or 23c.

When relay 63a1 is unoperated, the positive voltage supply and the size of resistors 94a, 93a, 92a, 88a, 106a, and 107 are such that the anode of diode 89a tends to be held more positive than the output of clamp source 90. Diode 89a thus conducts to hold its anode at the junction of resistors 88a and 106a at substantially the same voltage as the output of source 90. The voltage at the junction of resistors 88a and 92a is such that the voltage across neon tube 87a is not sufficient to produce ionization and no signal is passed from octaver unit 19a. Any high frequency signal components leaking through neon tube 87a due to its capacitive effects are suppressed by the clamping action of diode 89a.

When relay 63a1 operates and connects one end of resistor 97a to ground, current is drawn from condenser 96a and from the positive supply through resistor 94b. The voltage at the junction of resistors 97a and 94a drops as condenser 96a discharges at a rate dependent on its size and that of the resistance network. Condenser 95a is considerably smaller in size so that the voltage drop across the rest of the network substantially follows that across condenser 96a. Neon tube 87a ionizes on the positive signal swings on the plate of the output tube of octaver unit 19a when the drop at the junction of resistors 88a and 92a produces a sufficient difference of potential across it. Neon tube 87a then conducts until the negative signal swings reduces the potential difference to the extinguishing point.

The voltage at the junction of resistors 88a and 92a thus swings up and down with the signal output of octaver unit 19a by an amount which increases as the voltage across condenser 96a continues to drop. The initial swing with the signal is roughly proportional to the difference in ionizing and extinguishing potential of neon tube 87a and the start would produce an undesirable transient in the output such as occurs when a signal is switched on abruptly. The output of source 90 is such that diode 89a still maintains its clamping action and no signal swing of appreciable magnitude results on the anode of diode 89a until the voltage across condenser 96a drops sufficiently to permit swings more negative than the output of source 90.

When the voltage across condenser 96a drops to that

across resistor 101, diode 98a conducts and holds it at substantially that value. The signal output across resistor 107 thus increases in amplitude proportionately with the voltage drop between the points when diode 89a stops conduction on the negative swings of signal and when diode 98a starts conduction to stop the voltage drop across condenser 96a. The voltage drop and so the envelope rise, or attack, of the signal across resistor 107 can be made approximately linear by restricting the aforementioned points to a small section of the discharge curve of condenser 96a. The slope of the rise may be changed by changing the size of condenser 96a or the sizes of resistors 94a and 97a.

When relay 63a1 is released and reconnects resistor 97a to the positive supply, condenser 96a recharges toward the positive supply and the action is reversed. Reapplication of the clamping action of diode 89a before condenser 96a is fully charged restricts the decay envelope of the signal across resistor 107 to the more linear portions of the charging curve. Operation of relay 63a2 applies the output of octaver unit 19b across resistor 107 through resistor 106b in similar manner to that specified for the output of octaver unit 19a, and outputs of octaver units 19c and 19d would likewise be applied across resistor 107 by similar means (not shown).

Operation of relay 64a2 connects condenser 105 to the output of vibrato unit 14 on line 26. This voltage is coupled through condenser 105 to the grid of tube 100 and so causes the voltage on the cathode to follow that on line 26. This varies the clamp point for diodes 98a or 98b (or the corresponding components for the outputs of octaver units 19c or 19d) and amplitude modulates any signals being passed by operation of relays 63a1 or 63a2 to produce tremolo effects.

Operation of relay 64a1 switches the signal across resistor 107 from line 24a to line 24b. Both go to timbre circuits 25 but each leads to a different frequency discriminative circuit so the switching effects a change in the timbre characteristic. This switching could be ganged as shown or could be independent if desired.

Operation of relay 64a1 also connects condensers 96a, 96b, and others not shown to respective arms of relays 64a1, 63a2, etc., in place of resistors 97a, 97b, etc. Operation of relay 63a1 then switches one side of condenser 96a from the positive voltage supply to ground. This instantaneously drops the voltage at the junction of resistor 94a and diode 98a below that on line 99 as condenser 96a quickly charges through diode 98a and then more slowly through resistor 94a. Condenser 95a delays the drop of voltage at its junction with resistors 93a and 92a to the shape desired for the attack envelope which results therefrom as previously described.

It will be recognized that the buildup of voltage across condenser 96a over a given range determines the decay envelope. Release of relay 63a1 before completion of the decay will apply a positive voltage kick across resistor 94a from condenser 96a to decay the signal at a faster rate determined again by the size of condenser 95a and its associated components. This is similar to the result obtained from a percussion instrument such as a piano wherein the signal builds up rapidly and then decays slowly while the key is held down but rapidly if it is released. The clamping action of diode 89a prevents the positive kick across resistor 94a from effective in the output across resistor 107. Operation of relay 63a2 similarly controls the output of octaver unit 19b.

It will be recognized that various different arrangements of switching could be used to control the attack decay patterns applied, select the timbre characteristic, and apply tremolo effects. Independent switching of each would provide a greater number of combinations for different outputs but coordinated switching allows a particular set of instrumental characteristics to be selected by operation of a single control. The arrangement shown merely illustrates one way in which the switching might

be set up. While relays have been described, it will be understood that contacts could be operated directly by manual means.

FIG. 6 shows one possible arrangement of the controls to operate the switching of the apparatus of FIG. 10. Keys 63a1, 63a2, 63a3, and 63a4 control outputs from octaver units 19a, 19b, 19c, and 19d respectively which are all within an octave range of each other and which are all mixed to a common output point in the manner of the apparatus of FIG. 10 either by operating the relays with the corresponding designations or by positioning their contacts directly. Stops 64a1, 64a2, and 64a3 control the attack and decay, the timbre characteristic, and the application of tremolo resulting when keys 63a1, 63a2, 63a3, and 63a4 are operated.

Keys 63b1, 63b2, 63b3, and 63b4 likewise control another set of outputs of octaver units 19a, 19b, 19c, and 19d respectively with attack and decay and other instrumental characteristics selected by stops 64b1, 64b2, and 64b3. Keys 63c1, 63c2, 63c3, and 63c4 likewise mate with stops 64c1, 64c2, and 64c3 as do keys 63d1, 63d2, and 63d3 and 63d4 with stops 64d1, 64d2, and 64d3. Keys 63a1, 63b1, 63c1, and 63d1 each control a different output of octaver unit 19a spaced apart by octave intervals. The same is true for each of the other parts.

It will be noted that the keys for any part are spaced together so that one, or any two, or all can be operated at one time as desired by one finger. Four fingers can thus play up to sixteen different outputs simultaneously having four different instrumental characteristics for a full orchestral effect. The instrumental characteristics of the different groups may be changed by their individual stops and different groups than those shown could be arranged.

While the present invention has been described in conjunction with some specific embodiments, it will be recognized that various changes and modifications can be made without departing from the spirit and scope of the invention as set forth in the following claims.

What is claimed is:

1. An electronic musical instrument comprising a tone generating system, a sound reproducer, a glow tube connected to the output of said tone generating system, means for biasing the other side of said glow tube to maintain it in a normally deionized state, means for keying said biasing means to ionize said glow tube, means for connecting the junction of said biasing means and said glow tube to said sound reproducer, said biasing means being of a type which includes an internal resistance, and means for blocking passage of signals to said sound reproducer until they are greater in amplitude than those resulting when said glow tube just starts to ionize.

2. An electronic musical instrument comprising a tone generating system, a sound reproducer, a gas diode connected to the output of said tone generating system, a bias voltage source, a resistor connected between said diode and said voltage source, means for keying said voltage source to ionize said diode, and means for passing all signals from the junction of said diode and said resistor to said sound reproducer which are greater in amplitude than those occurring when said diode first ionizes.

3. A polyphonic electronic musical instrument comprising a master oscillator, a plurality of frequency dividers

driven in parallel by the output of said master oscillator, said frequency dividers being of a type which cannot free run and each having a different dividing ratio so that the plurality of outputs differ from each other by musical intervals of less than an octave, a sound reproducer, and means for gating the outputs of said dividers to the input to said sound reproducer.

4. The combination according to claim 3 including means for varying the dividing ratios of said dividers.

5. The combination according to claim 4 wherein said dividers consist of stepping circuits with means for changing the number of steps per cycle.

6. A polyphonic electronic musical instrument comprising a master oscillator, a plurality of frequency dividers driven in parallel by the output of said master oscillator to produce a plurality of outputs differing from each other by musical intervals of less than an octave, a sound reproducer, and means for gating the outputs of said dividers to the input to said sound reproducer.

7. The combination according to claim 3 including means for controlling the frequency of said master oscillator.

8. The combination according to claim 4 including means for controlling the frequency of said master oscillator, a row of melody keys coupled to said controlling means and a set of harmony bars which are coupled to said varying means and which are each positioned substantially parallel to said row of melody keys.

9. The combination according to claim 3 including a set of playing keys coupled to said gating means.

10. The combination according to claim 8 including means for restricting operation of said harmony bars and said varying means to prevent production of some combinations of fractions for said outputs.

11. The combination according to claim 4 wherein said frequency dividers each comprise a plurality of frequency divider stages having a variety of different fractional relations between input and output frequencies, and means for connecting said stages in different combinations between said master oscillator and said sound reproducer responsive to said varying means.

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