United States Patent

Freeman

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[45] **Aug. 29, 1972**

[54] **TONE MODULATION SYSTEM**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 835,506, June 23, 1969, abandoned.

[52] **U.S. Cl.** **84/1.11,** 84/1.19, 84/1.24, 84/1.25, 84/DIG. 9, 84/DIG. 10, 84/DIG. 18, 323/74

[51] **Int. Cl.**.....**G10h 3/00**

[58] **Field of Search**.....333/70, 80, 70 R, 80 T, 17; 84/1.14, 1.2; 323/93

[56] **References Cited**

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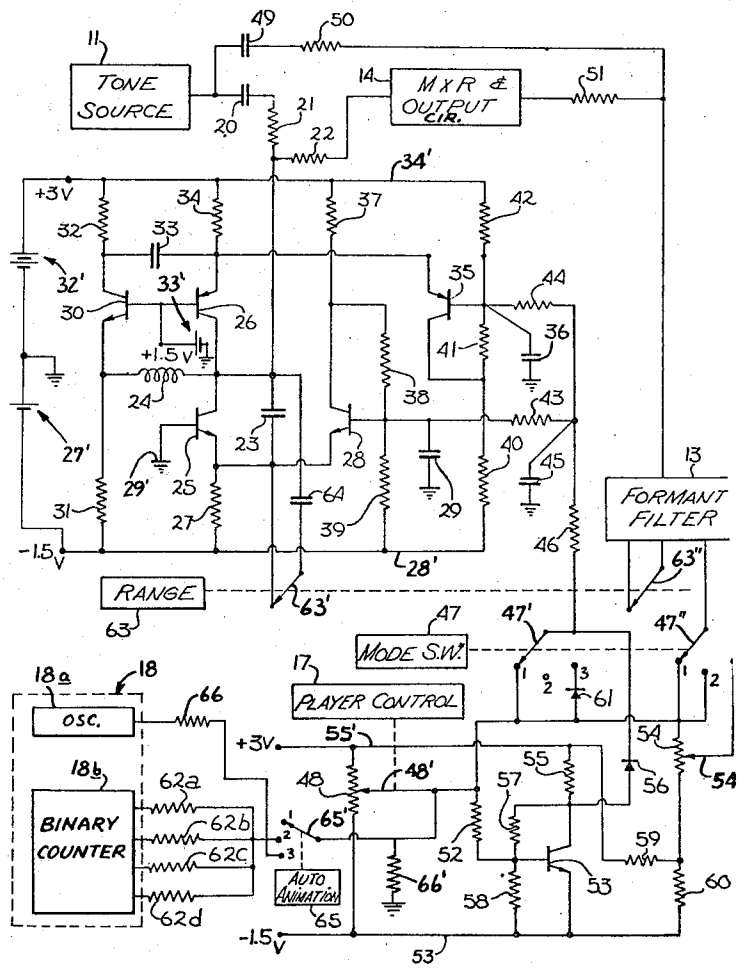
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Primary Examiner—Lewis H. Myers
Assistant Examiner—U. Weldon
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[57] **ABSTRACT**

Musical tone signals in electrical form are applied to a plurality of formant filters which are tuned dynamically by player operated controls and by electronically generated control signals. Control signal shaping networks or special potentiometer controls are switched in a number of ways to produce different formant frequency response patterns including one similar to that of the human vocal tract producing dipthongs. The disclosure includes filters which are responsive in tuning to a control voltage and filters in which both inductive and capacitive components are varied for tuning so a nearly constant Q is maintained over wide tuning ranges.

13 Claims, 6 Drawing Figures



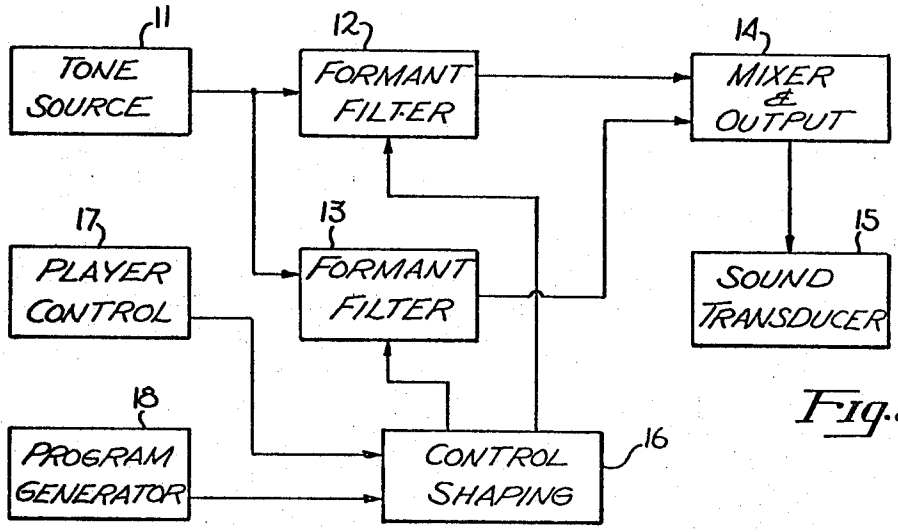


Fig. 1

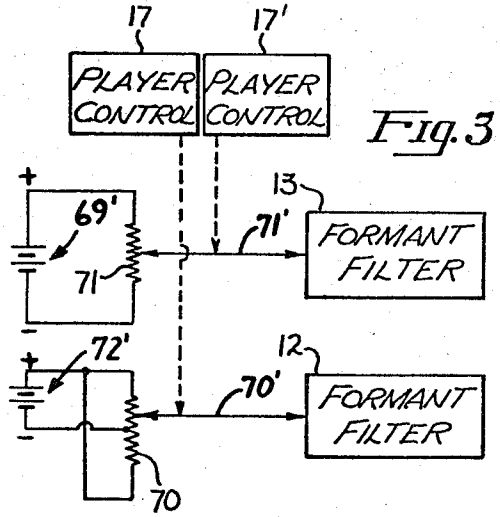


Fig. 3

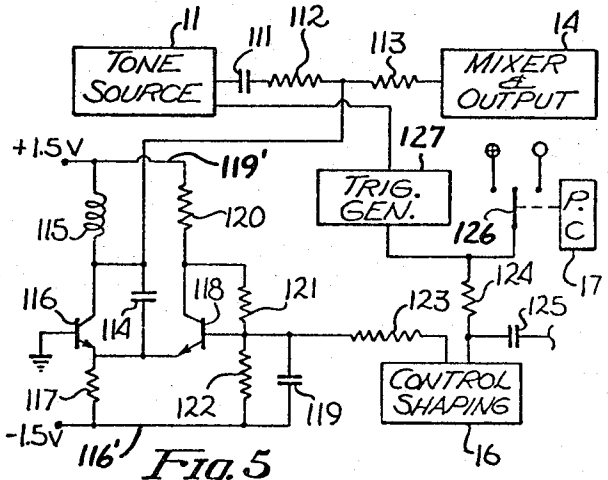


Fig. 5

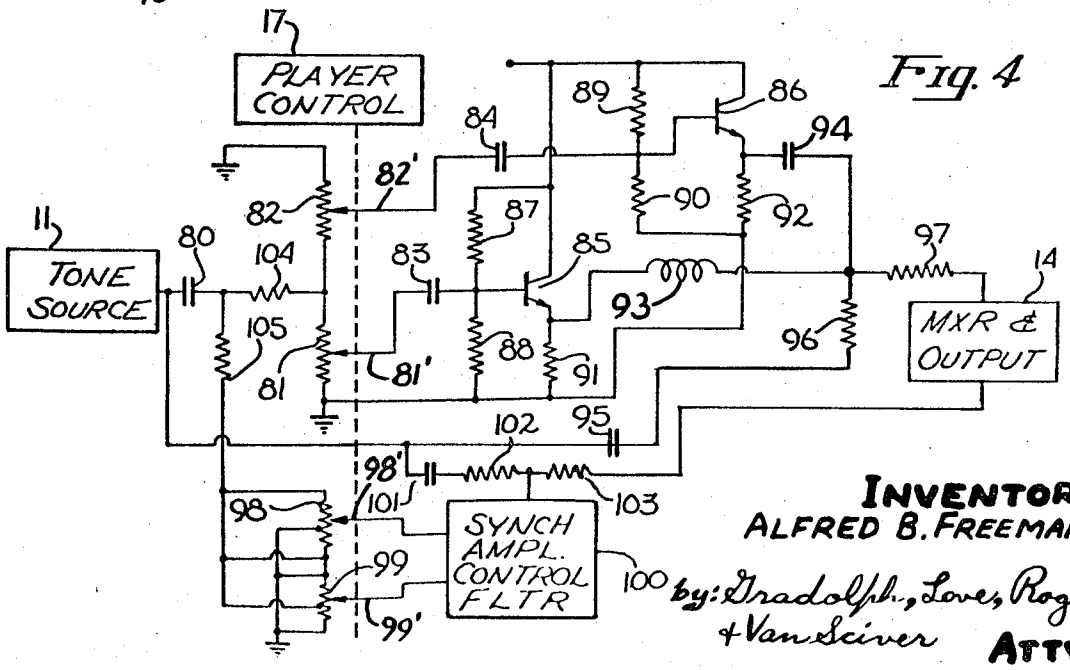


Fig. 4

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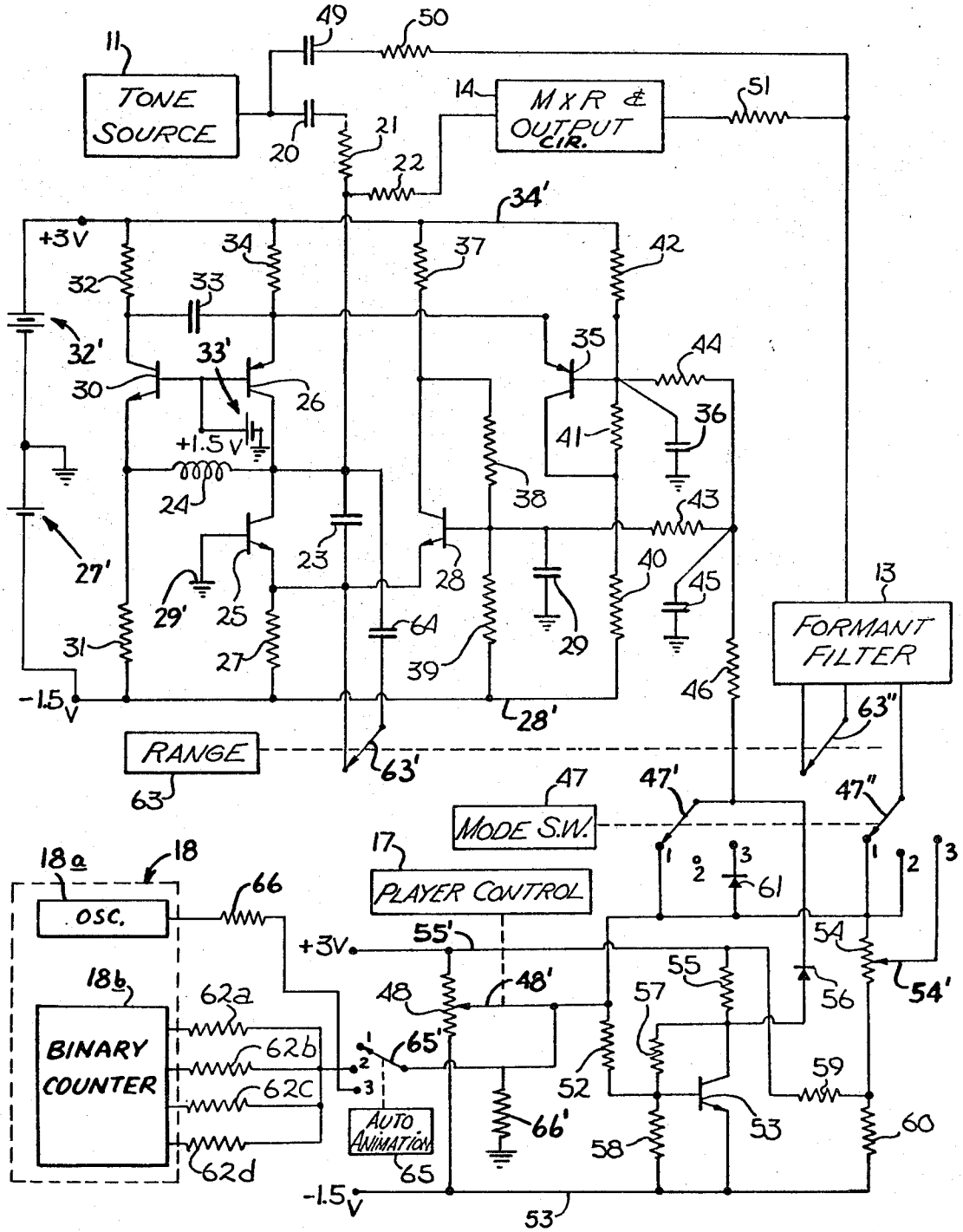
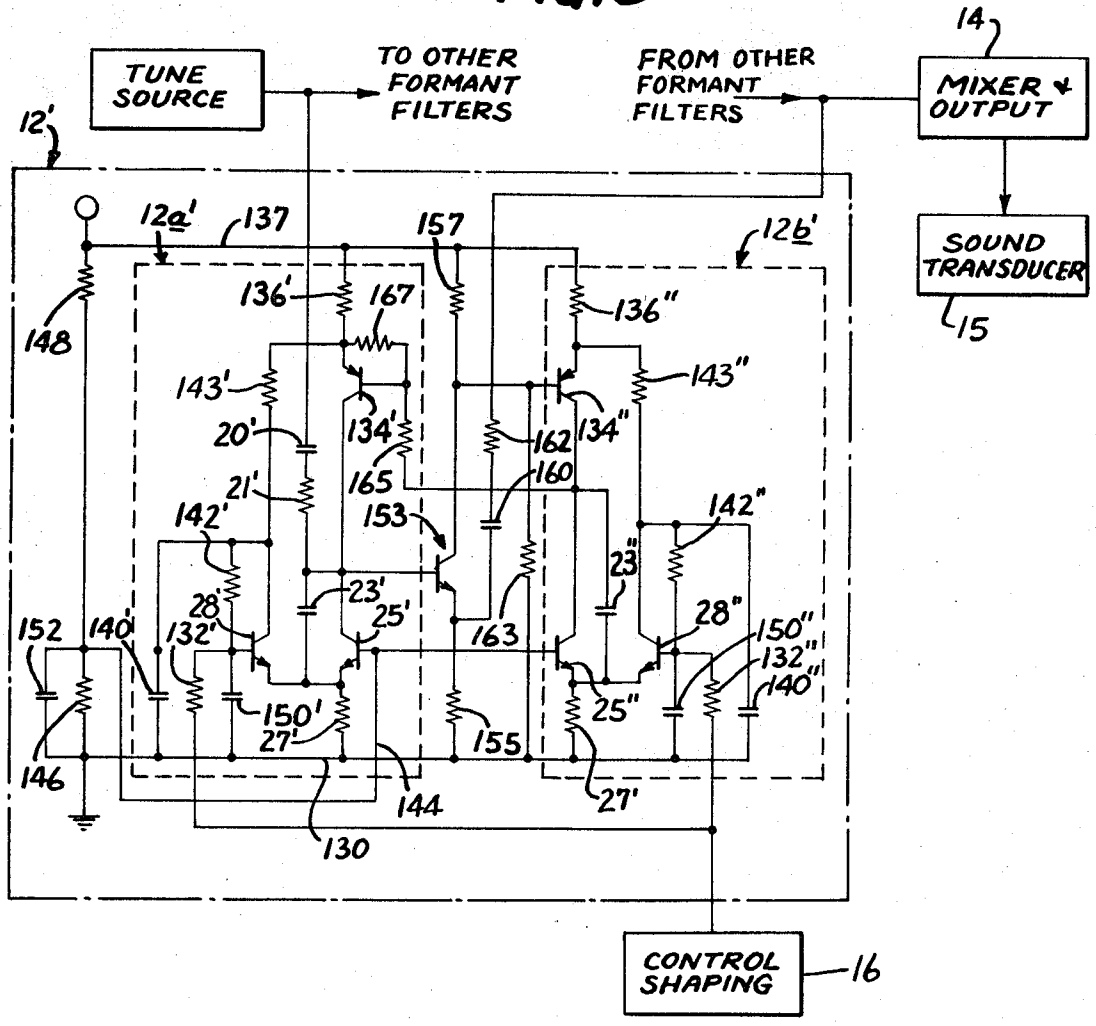


Fig. 2

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FIG. 6



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TONE MODULATION SYSTEM

This application is a continuation-in-part of application Ser. No. 835,506, filed June 23, 1969 (Now abandoned).

FIELD OF THE INVENTION

This invention has its most important application in musical tone modulating systems using dynamically tuneable formant filters responsive to electronically generated signals and to player operations for various effects including simulation of features of the human vocal tract and further to special tunable filters for such modulating systems.

DESCRIPTION OF THE PRIOR ART

It has been heretofore proposed (e.g., see U.S. Pat. No. 3,316,341, R. H. Peterson) to use formant filters responsive to light sensitive resistors and to a player positioned potentiometer for tuning to produce special effects on musical tone signals. A mechanically moving shutter structure provides a repetitive vibrato type of modulation pattern. In such systems, one reactive component is varied for tuning so the Q of the filters change rapidly with tuning for an undesirable variation in the quality of performance. It has also been proposed to vary the response characteristics of the filters by controlling through individual transistors the amplitudes of control voltages fed from the signal input terminal of the filter to the terminals of filter capacitors remote from the signal input terminals.

SUMMARY OF THE INVENTION

One of the features of the invention most advantageously and uniquely provides coordinated control of the tuning of a plurality of formant filters to obtain unexpected musical effects from combinations including those which can simulate features of the human vocal tract. In accordance with another feature of the invention, a reasonable Q for the filters is maintained over a wide tuning range by controlling both the inductive and capacitive components of the formant filters.

In accordance with a still further feature of the invention the formant filters are tuned by unique current feedback circuits which are associated with either and preferably both the capacitive and inductance supplying components of the formant filters. A unique arrangement of emitter current sharing transistors is most advantageously provided for both the capacitive and inductance portions of each formant filter. The response of each formant filter is varied by control voltages fed to the current sharing transistors of the capacitive and inductive portions thereof. The control voltage may be derived from voltage shaping networks to obtain coordinated response patterns simply and by switching to different networks for a greater variety of effects. An oscillator or more complex voltage pattern derived from an automatic rhythm device and a resistor network may be used to drive the filters for special effects and for a special and generally pleasing animation at vibrato and tremulant rates. In electronic organs, the filters can also function as regular voicing filters to which animation and special effects can be applied.

A further aspect of the invention is the provision of an inductance supplying circuit for each formant filter which utilizes a capacitor-containing transistor circuit

or the like similar in many respects to the capacitive portion of the formant filter circuit to eliminate the necessity and disadvantages of the use of a physical inductor. The inductive portion of each formant filter circuit supplies a current to the capacitive portion of the circuit makes it appear as if an inductor were connected in parallel with it.

The above and other features of the invention together with the advantages thereof will be more fully understood upon making reference to the specification to follow, the claims and the drawings wherein:

FIG. 1 is a block diagram of an embodiment of the invention;

FIG. 2 is a partial schematic and partial block diagram of one form for the novel parts of the apparatus of FIG. 1;

FIG. 3 is a partial schematic and partial block diagram of another form for the player operated control of FIG. 1;

FIG. 4 is a partial schematic and partial block diagram of another form for parts of the apparatus of FIG. 1;

FIG. 5 is a schematic diagram of a more economical filter which can be used in the apparatus of FIG. 1 and FIG. 2; and

FIG. 6 is a schematic diagram of the most preferred form of the filter circuit of the invention.

GENERAL DESCRIPTION (FIG. 1)

Referring to FIG. 1, the circuit there shown includes a source 11 of musical tone signals in electrical form applied to formant filters 12 and 13. The source 11 may consist of electrical pickups on any musical instrument, electronic oscillators, or any other tone generating means. The signal outputs from filters 12 and 13 are fed through mixer and output circuit 14 to sound transducer 15. Mixer and output circuit 14 may include such conventional apparatus as selection controls, equalizing networks, and amplifiers to drive sound transducer 15 which may also be of any suitable conventional type.

Formant filters 12 and 13 are tuneable in response to control voltages received from control shaping network 16. Filters 12 and 13 will preferably maintain a relatively high and substantially constant Q over their tuning range which should cover a 2 octave span or more. Particular forms for filters 12 and 13 will be discussed in detail later and it will be recognized that additional filters could be added in parallel for the signal with filters 12 and 13 if control shaping network 16 were adapted to provide more control outputs.

Control shaping network 16 receives inputs from player control 17 and program generator 18. Player operated control 17 may be a potentiometer whose arm is positioned by a pedal or other element and which is adapted in a circuit to produce a voltage corresponding to its position. The player operated control might further include switching means to shift voltage output levels and might use other types of transducers to produce voltage outputs. Program generator 18 may consist of a low frequency oscillator such as is used in electronic organs for vibrato and tremolo effects or a more elaborate pattern generator such as could be offered by a multistage binary counter driving a resistor network.

The control shaping network 16 includes switching means to select from its input sources and from the several possible shaping outputs and combinations which it can provide. Filters 12 and 13 can be driven in tracking relation, or contra-tracking relation or in a pattern corresponding to that of the first two formant frequencies of the human vocal tract in the production of dipthong sounds and other vowel sounds. A paper titled "Control Methods Used in a Study of the Vowels" by G. E. Peterson and H. L. Barney printed in The Journal of the Acoustical Society of America, Vol. 24, No. 2, 175–184, of Mar, 1953 illustrates the first and second formant frequency relationships for a large number of different speakers. When filters 12 and 13 are tuned along trajectories maintaining similar frequency relationships, a very effective humanlike quality is given to complex musical tone signals.

EMBODIMENT OF FIG. 2

In FIG. 2, which shows filter 12 in a possible schematic form for it and filter 13, tone source 11 applies its output through capacitor 20 and resistors 21 and 22 to mixer and output circuit 14. The junction of resistors 21 and 22 connects to the junction of a controlled capacitor 23 and controlled inductor 24 with the collectors of transistors 25 and 26. The other terminal of capacitor 23 connects to the emitter of feedback transistor 25 and through resistor 27 to a bus 28' extending to the negative terminal of a 1.5 volt D.C. supply 27' whose positive terminal is grounded. The base of feedback transistor 25 is connected to a point of fixed voltage such as ground point 29'. Transistor 25 remains conducting during normal operation so the voltage across its base emitter junction will not change appreciably. The voltage drop across resistor 27, and so the current through it, must therefore remain substantially constant. Resistor 27 could be replaced by other means for providing a constant current. Transistor 28 has its emitter connected to the emitter of feedback transistor 25 and its base connected to ground through a signal filtering capacitor 29. The base emitter junction of transistor 28 serves as a circuit element which inherently has a non-linear current-voltage relation matching the non-linear voltage-current relation of the base emitter junction of transistor 25. Control of the D.C. current drive to the base of control transistor 28, which will be described later, controls the sharing of emitter current by transistors 25 and 28 and so controls the effective size of capacitor 23 by controlling the amount of negative current fed back thereto as will be explained. Since the current passing through resistor 27 is a substantially constant D.C. current, the increase or decrease in emitter current through control transistor 28 is matched by a corresponding decrease or increase respectively of the current through the feedback transistor 25.

If transistor 28 is cut off, signal current through capacitor 23 will produce a corresponding out of phase change in the emitter current of transistor 25. The emitter current change is reflected as a collector current change of the same size less the amount of signal current drawn by the base of transistor 25. The out of phase collector current subtracts from the current through the capacitor 23 so the combination draws the same signal current from the junction as would a much smaller capacitor than capacitor 23. If transistor 28 is drawing the same current as transistor 25, the signal current through capacitor 23 will effectively share by their emitter circuits. The out of phase signal current then resulting in the collector of transistor 25 will be much less and the combination will appear to draw the same current as a capacitor half the size of capacitor 23. The effective size capacitor 23 presents to the signal is thus controlled by controlling the sharing of D.C. current between transistors 25 and 28.

The other terminal of inductor 24 connects to the emitter of transistor 30 which further connects to the negative bus 28' extending to the negative supply 27' through resistor 31. The collector of transistor 30 is shown connected to the positive terminal of a 3 volt D.C. supply 32' through resistor 32 and to the emitter of feedback transistor 26 through a large capacitor 33. The negative terminal of supply 32' is grounded. The bases of transistors 26 and 30 are shown connected to the positive terminal of a 1.5 volt D.C. supply 33' whose opposite terminal is grounded. The emitter of feedback transistor 26 further connects through a resistor 34 to a bus 34' leading to the positive terminal of the 3 volt D.C. supply 32' and to the emitter of a PNP control transistor 35. Any differences in D.C. current between transistors 25 and 26 must flow through inductor 24. The D.C. current through inductor 24 will add or subtract from the emitter current of transistor 30. Resistor 31 will be sized to allow for the D.C. current changes over the control input range without transistor 30 reaching cut off. Resistor 32 will be sized to avoid causing transistor 30 to saturate over the same control range. The signal current through inductor 24 likewise produces a corresponding change in the emitter current of transistor 30. The resulting signal voltage appearing on its collector is applied through capacitor 33 to the emitter of transistor 26 which operates in the common base mode. Capacitor 33 substantially blocks the D.C. changes. The signal current produced in the collector of transistor 26 is out of phase with the originating current through the inductor 24 and so subtracts from it. The combination of inductor 24 and the collector of transistor 26, like the combination of capacitor 23 and the collector of transistor 25, thus draws less current than inductor 24 would alone. In the case of an inductor, however, a smaller signal current means a larger apparent inductor. This arrangement therefore increases the apparent size of inductor 24.

A capacitor 36 connects the base of control transistor 35 to signal ground so its emitter can share signal current with that of transistor 26. Control of the D.C. drive to the base of control transistor 35 then controls the sharing ratio of signal current between its emitter and that of feedback transistor 26. This is the same as the situation with transistors 25 and 28 for control of feedback current except that an increase in current flow through transistor 35 decreases the effective size of inductor 24 whereas an increase in the current flow through transistor 28 increases the effective size of capacitor 23.

Control transistor 28 has its collector connected to the positive bus 34' through a resistor 37 and to its base through a resistor 38. A resistor 39 connects the base of control transistor 28 to the negative bus 28' extending to the negative terminal of the 1.5 volt D.C. supply 27'

so it is biased at or near cut off with no further drive applied. Negative feedback is provided by resistor **38** from the collector to the base of control transistor **28** to provide a response to input current drive which is substantially independent of the gain of control transistor **28**. The collector of control transistor **35** is likewise connected to the negative bus **28'** through a resistor **40** and to its base through a resistor **41**. A resistor **42** connects the base of control transistor **35** to the positive terminal of the positive 3 volt D.C. supply **32'** so it is at or near cutoff with no additional drive provided.

Resistors **43** and **44** connect from the bases of control transistor **28** and **35** respectively to a terminal of a capacitor **45** and through resistor **46** to arm **47'** of a switch **47**. Capacitor **45** has its other terminal connected to ground so it smoothes any voltage transients appearing on the arm **47'** of switch **47**. A control voltage appearing on the arm **47'** of switch **47** is thus applied to the bases of control transistors **28** and **35** through resistors **43** and **44** respectively and through resistor **46**. A change in the control voltage in a positive direction increases current through transistor **28** and decreases that through transistor **35** and so increases the effective sizes of both capacitor **23** and inductor **24** to thereby tune to a lower frequency. A control voltage change in the opposite direction decreases the current through control transistor **28** and increases the current through control transistor **35** to decrease the effective size of capacitor **23** and inductor **24** and so tune the circuit for a higher frequency.

With mode switch **47** in the position shown, the arm **47'** to which resistor **46** connects is connected to the arm **48'** of a potentiometer **48** which is positioned by player control **17**. The other arm **47''** of mode switch **47** also connects the arm **48'** of potentiometer **48** to a similar control input for filter **13**. Formant filter **13** may consist of the same type of circuit as that just described for filter **12** with different sizes for its respective capacitor **23** and inductor **24** so it covers a different frequency range. A capacitor **49** and resistors **50** and **51** provide another signal path from tone source **11** to mixer and output **14** with the junction of resistors **50** and **51** connected to a point in filter **13** corresponding to the point at which the junction of resistors **21** and **22** is connected in the circuit for filter **12**. Filters **12** and **13** are then controlled in tracking relation by the positioning of the arm of potentiometer **48** by player control **17**.

Arm **48'** of potentiometer **48** also connects to one side of a potentiometer **54**, to the mid contact of switch **47** for arm **48'** connecting to filter **13**, and through a resistor **52** to the base of a NPN transistor **53**. Transistor **53** has its emitter connected to a negative bus **53'** extending to the negative terminal of the negative D.C. supply **27'** and its collector connected to a positive bus **55'** leading to the positive terminal of the 3 volt supply **32'** through resistor **55** and to the junction of arm **47'** of switch **47** and resistor **46** through a diode **56**. A resistor **57** from the collector of transistor **53** to its base provides negative feedback to obtain a linear and predetermined output response to input drive through resistor **52**. Resistor **58** connected from the base to the negative bus **53'** causes transistor **53** to be biased at or near cutoff with no drive received through resistor **52**. The other side of potentiometer **54** connects to a voltage divider formed by resistors **59** and **60** connected between the positive bus **55'** and the negative bus **53'**.

With mode switch **47** in its mid position, filter **13** is connected by the arm **47''** of mode switch **47** to the arm **48'** of potentiometer **48** as before, and resistor **46** is connected only to the collector of transistor **53** through diode **56**. The voltage on the collector of transistor **53** moves in the opposite direction to the voltage from the arm **48'** of potentiometer **48** so the tuning of filters **12** and **13** move in opposite directions also. (The resistence of potentiometer **48** is much smaller than resistor **55** so its output was not appreciably affected by the connection of diode **56** when mode switch **47** was in the position shown and previously described.)

When mode switch **47** is in its third position, resistor **46** is connected to the arm **48'** of potentiometer **48** through a diode **61** as well as to the collector of transistor **53** through diode **56**. The voltage on the arm **47'** then follows the most positive of the two less the offset voltage of the forward biased diode **56** or **61**. The control input to filter **13** is connected to the wiper **54'** of potentiometer **54** so the voltage swing is only a fraction of that on the wiper **48'** of potentiometer **48**. As potentiometer **48** is rotated through its range, the voltage to resistor **46** will first move in one direction through a fraction of the voltage swing and then in the other direction through the same range while the input to filter **13** moves in only one direction at a slower rate.

The prior referenced paper of Peterson and Barney show that as the second formant frequency goes from a high to a low value for the production of different vowel sounds, the first formant frequency goes from a low value to a high value and then changes direction going from high back to low frequency. In the production of dipthong sounds, the formant frequencies move generally over similar patterns from the values for the initial vowel sound of the dipthong the values for the final one. If the frequency range of filter **13** made to conform to that of the second formant and that of the circuit for filter **12** to the frequency range of the first formant, the frequencies approximate those for human vowel sounds as potentiometer **48** is movedthrough its range while mode switch **47** is in its third position.

Peterson and Barney also show variations in formant amplitude with formant frequency and the frequencies for a third formant. Equalization networks in mixer and output **14** can provide a frequency response to approximate the formant amplitudes for particular musical tone signal inputs. Design of such networks is well known to those skilled in the art. As previously mentioned, mixer and output **14** may include various networks and selection control to better serve musical purposes under various conditions. While less important than the first two, the third formant could be provided for deluxe models by adding a third filter in parallel with filters **12** and **13** and another potentiometer in parallel with potentiometer **54** to drive the third filter.

The frequency ranges of the formants for men, women and children vary generally from low to high. Range switch **63** has an arm **63'** which connects a capacitor **65** in parallel with capacitor **23** to shift the frequency range lower and an arm **63''** which accomplishes a similar change in filter **13**. Switch **63** can thus select ranges for men's or women's voices and a third

position could be added for children's voices if desired. The ranges could further be displaced for novel effects in the same way by proper selection of component sizes. The proper formant frequency trajectories impart a humanlike quality even with wide displacements.

The program generator **18** may consist of an oscillator **18***a* driving a binary counter **18***b* and may serve other purposes such as a time pattern generator for an automatic rhythm device. An auto-animation switch **65** is provided which has an arm **65'** which in the second position of the switch connects a network of resistors **62***a* through **62***d* to the wiper **48'** of potentiometer **48**. Each resistor **62***a* through **62***d* connects to a different stage of the binary counter **18***b* and may be of a different size. The switch arm **65'** is connected to a voltage divider-forming resistor **66'** so the voltage on arm **65'** changes in steps for each position of the counter to produce a voltage pattern output which adds or subtracts from the voltage normally on the arm of potentiometer **48**. This produces corresponding steps in the frequencies of filters **12** and **13** about the frequencies for the setting of potentiometer **48**. Thus, when mode switch **47** is in its third position, the steps can change successively to different vowel sounds for a sort of yodeling effect and moving potentiometer **48** shifts the steps to a new set of sounds.

As previously mentioned, program generator **18** can also be simply an oscillator operating at a tremolo or vibrato rate. This effect can be obtained by moving auto-animation switch **65** to its third position to connect the arm **48'** of potentiometer **48** to a resistor **66** which is driven by the oscillator **18***a*. The voltage on the arm **48'** of potentiometer **48** then swings between two values. Adjusting the frequency of the oscillator can provide a range of different effects from steps at syllabic rates to rapid vibrato rates. The animation provided by formant frequency modulation at tremolo and vibrato rates is musically pleasing and varied as the musical tone input changes and far less monotonous and fatiguing than pitch vibrato and many tremolo systems. Additional resistor networks similar to that of resistors **62***a* through **62***d* could be coupled to the different outputs of program generator **18** in different combinations and more positions added to auto-animation switch **65** to select them for an even greater variety of effects.

EMBODIMENT OF FIG. 3

FIG. **3** shows a simplified arrangement which can get vowel sound effects similar to those of the apparatus of FIG. **2** when mode switch **47** is in its third position. Player controls **17** and **17'** respectively positions the wipers **70'** and **71'** of two potentiometers **70** and **71** in ganged relation to provide control voltage inputs to formant filters **12** and **13** respectively. Potentiometer **71** has its opposite ends connected respectively to the positive and negative terminals of a source **69'** of D.C. voltage. Potentiometer **70** is of a special type in that a source **72'** of D.C. voltage is connected between the midpoint thereof and end thereof which are tied together. The positive terminal of the source **72'** is applied to the two ends of the potentiometer and the negative terminal thereof is applied to the midpoint thereof so the voltage output on arm **70'** moves from positive to negative and then back to positive as the arm is moved through its range. Potentiometer **71** is conventional to provide a control for the second formant filter at the same time.

Player controls **17** and **17'** are individually coupled to potentiometer wipers **70'** and **71'** but the two controls are positioned in close proximity so they may easily be moved together by placing foot, or hand, on both to maintain potentiometer wipers **70'** and **71'** in ganged relation. If the player has a second foot, or other member available, he can also operate potentiometer wipers **70'** and **71'** more independently for a greater variety and precision of effects. Potentiometers **70** and **71** may have their resistances tapered for optimum control response and optimum matching for first and second formant frequencies to a model vocal tract pattern.

EMBODIMENT OF FIG. 4

FIG. **4** shows an alternative type of filter and control arrangement for obtaining vowel sound effects. The output of tone source **11** is applied through a capacitor **80** to one of the ends of potentiometer pair **81** and **82** whose opposite ends are grounded. The arms **81'** and **82'** of potentiometers **81** and **82** are coupled through capacitors **83** and **84** to the bases of NPN transistors **85** and **86** respectively. Circuit elements are connected to transistors **85** and **86** to form emitter follower circuits with base biasing resistors **87** and **88** respectively connected between the collectors and bases thereof, resistors **89** and **90** connected between the bases thereof and ground respectively and load resistors **91** and **92** respectively connected between the emitters thereof and ground. An inductor **93** has one terminal connected to the emitter of transistor **85** and the other to capacitor **94**. The other terminal of capacitor **94** connects to the emitter of a NPN transistor **86**. Tone source **11** also connects through the series combination of capacitors **95** and resistors **96** and **97** to mixer and output **14**. The junctions of inductor **93** and capacitor **94** connects to the junction of resistors **96** and **97**.

With their signal inputs removed, the emitter follower circuit transistors **85** and **86** are inoperative and inductor **93** and capacitor **94** function as a conventional formant filter circuit including resistors **91** and **96**. With an in phase signal applied to the buses of transistors **85** and **96**, the signal voltage across the filter circuits is reduced and the current therethrough is reduced. This causes inductor **93** to appear larger to the junction of resistors **96** and **97** and capacitor **94** to appear smaller. Potentiometers **81** and **82** are arranged oppositely so that when they are driven in ganged relation the signal to one emitter follower increases while that to the other decreases. Inductor **93** and capacitor **94** thus increase or decrease in effective size together as player control **17** is moved. As in the circuit of FIG. **3**, the tuning actions then add and the Q remains more nearly constant than would be the case if only one element were varied.

A synchronous amplitude control filter **100** is provided which may be similar to the circuit just described with inputs to its two emitter follower circuit supplied from potentiometers **98** and **99**. The output of tone source **11** is also applied through capacitor **101** and resistors **102** and **103** to mixer and output **14** and the junction of resistors **102** and **103** is connected to the

junction of the reactive elements in filter **100**. Potentiometers **98** and **99** are similar to potentiometer **70** in FIG. **3** in that they have a stationary tap on their midpoints and their ends tied together. Potentiometer **98** has its center tap grounded and the signal applied to its ends while potentiometer **99** has its ends grounded and the signal applied to its center tap.

As the wipers **98'** and **99'** of potentiometers **98** and **99** are moved from one extreme to the other, the signal on the arm **98'** of potentiometer **98** goes from a maximum to zero and then back to a maximum while that of the arm **99'** of potentiometer **99** goes from zero to a maximum and then back to zero. The output from potentiometer **98** drives the emitter follower connected to the inductive element and that from potentiometer **99** drives the emitter follower connected to the capacitive element of filter **100**. The tuning of filter **100** thus follows the trajectory for the first filter frequency while the filter circuit connected to potentiometers **81** and **82** follow that for the second filter. Resistors **104** and **105** in series with the signal input to potentiometers **81** and **82** and potentiometers **98** and **99** respectively limit the adjustment ranges and are of different sizes so the proper frequency ranges are obtained for both formants.

EMBODIMENT OF FIG. 5

The filter circuit of FIG. **5** can be used in place of the circuit of FIG. **2** where a wider variation of Q can be permitted or the desired animation or other effects can be obtained with a smaller frequency range. The signal from tone source **11** is applied through a capacitor **111** and resistors **112** and **113** to mixer and output **14** and the junction of resistors **112** and **113** is connected to the junction of capacitor **114** and inductor **115**. The other terminal of capacitor **114** is connected to the emitter of an NPN transistor **116** which in turn connects to the negative bus **116'** through resistor **117**. The base of transistor **116** connects to ground and its collector to the junction of capacitor **114** with inductor **115**. Transistor **118** has its emitter connected to the emitter of transistor **116**, its base to capacitor **119**, and has its collector connected to a positive 1.5 volt D.C. supply bus **119'** through resistor **120**. Resistors **121** and **122** provide feedback from collector to base of the transistor **118** and bias the base thereof at or near cutoff with no additional drive provided.

It will be recognized that the circuitry associated with capacitor **114** is similar to the circuitry associated with capacitor **23** in the circuit of FIG. **2** except that the other terminal of inductor **115** is connected to the positive bus **119'** rather than to additional circuitry. Control of the drive to the base of transistor **118** is through a resistor **123** from control shaping circuit **16** which controls the effective size of capacitor **114** just as the effective size of capacitor **23** is controlled in FIG. **2**. Accordingly, the reduction of current through transistor **116** will increase the effective size of capacitor **114** and also reduces the D.C. current through inductor **115**. If inductor **115** has a core whose permeability decreases with increasing magnitization, as is the case for most commercially available inductors, its effective inductance will increase as the D.C. current through it is reduced and shifts the operating point on the magnetization curve for the signal current. This change will aid the change in effective size of the capacitor **114** for an increase in turning range and a more constant Q. The change in effective inductance will not, however, be as great as in the circuit of FIG. **2** and so the tuning range will be less and the change in Q will be greater. The circuit is, of course, lower in cost then that of FIG. **2**.

Player control **17** is shown coupled to a switch **126** to apply a positive or negative voltage to the control shaping circuit **16** through a resistor **124** which voltage is smoothed by a capacitor **125**. Such action can produce a formant frequency glide in either direction with the rate of the glide being determined by the time constant of resistor **124** and capacitor **125**. A trigger generator circuit **127** is provided which receives a signal from tone source **11** and responds to an envelope increases to produce a transient voltage coupled through resistor **124** to the control shaping circuit **16**. It will be recognized that switch **126** and trigger generator circuit **127** could be used with the apparatus of FIG. **2** as well and that various other transient or signal voltages could be applied for control of format frequency for various special effects.

EMBODIMENT OF FIG. 6

The use of a physical inductor in a format filter circuit has a number of disadvantages. In the first place, the use of inductors poses a problem of cost and of quality control since it is difficult to make inductors with consistent characteristics. Also, the elimination of physical inductors in format filter circuits like that shown in FIGS. **2**, **4** and **5** make the circuits more independent of transistor parameters and provides for easier matching of controls so the effective capacitive and inductive reactances will track better over a larger tuning range.

The formant filter circuit shown in FIG. **6** identified by reference numeral **12'** includes a variable capacitance supplying circuit **12***a'* and a variable inductance supplying circuit **12***b'*. The capacitance and inductance supplying circuit **12***a'* and **12***b'* of the formant filter circuit **12'** have many circuit components in common with the formant filter circuit shown in FIG. **2**, are enclosed by dashed lines and corresponding elements have been similarly numbered except for the addition of a single (') or double prime ('), respectively, in the case of the circuits **12***a'* and **12***b'*. Accordingly, circuits **12***a'* and **12***b'* respectively have controlled capacitors **23'** and **23''** respectively which are connected between the emitter and collectors of NPN feedback transistors **25'** and **25''** respectively. Resistors **27'** and **27''** are respectively connected between the emitters of the feedback transistors **25'** and **25''** and a ground bus **130**. The emitters of respective NPN control transistors **28'** and **28''** are connected to the emitters of the feedback transistors **25'** and **25''** respectively to share emitter current flow therebetween in accordance with the control signal on the bases of the control transistors **28'** and **28''**. The effective capacitance at the collectors of the feedback transistors **25'** and **25''** and capacitors **23'** and **23''** is a function of the relative emitter currents of the transistor pairs **25'–28'** and **25''–28''** just as in the case of the previously described embodiment of the invention shown in FIG. **1**. The output of the aforementioned

control shaping circuit 16 is coupled respectively through resistors 132' and 132'' to the bases of the control transistors 28' and 28'' to effect the sharing of emitter current between the aforementioned transistor pairs.

Current source PNP transistors 134' and 134'' and resistors 136' and 136'' are respectively connected between the collectors of feedback transistors 25' and 25'' and a positive D.C. bus 137. The collectors of control transistors 28' and 28'' are coupled through resistors 143' and 143'' respectively to the emitters of the associated current source transistors 134' and 134'' respectively. The currents through transistors 28' and 28'' thus subtract substantially the same current from transistors 134' and 134'' respectively as they do from transistors 25' and 25'' respectively so current balances are maintained between transistors 25' and 134' and transistors 25'' and 134'' with changes in control current. Small signal current variations are imposed on the transistors 28' and 28'' collector currents. Large electrolytic capacitors 140' and 140'' connected between the collectors of control transistors 28' and 28'' respectively and the ground bus 130 bypass the signal current on the collectors of the control transistors. Resistors 142' and 142'' respectively connected between the base and collectors of control transistors 28' and 28'', resistors 143' and 143'' respectively connected between the collectors of the control transistors 28' and 28'' and the emitters of transistors 134' and 134'' and a connection between the bases of feedback transistor 25' and 25'' and the juncture of voltage divider resistors 146 and 148 extending between busses 130 and 137 establish the proper bias conditions for the control and feedback transistors 28'–28'' and 25'–25''. Resistors 142' and 142'' also stablize the D.C. current gain of the control transistor circuitry so the gain is independent of the transistor parameters. Capacitors 150', 150'' and 152 are connected to the latter resistors for signal bypassing purposes.

The input signal is applied through capacitor 20' and resistor 21' to the terminal of controlled capacitor 23' of the capacitance producing circuit 12*a'* connected to the collector of the associated feedback transistor 25'. The same point is also connected to the input of an emitter follower circuit including an NPN transistor 153. The transistor 153 has its base connected to the latter capacitor terminal, its emitter connected through a resistor 155 to the ground bus 130 and its collector connected through resistor 157 to the positive bus 137. The emitter of transistor 153 which constitutes the output terminal of the entire formant filter circuit 12' is coupled through capacitor 160 and resistor 162 to the input of the aforesaid mixer and output circuit 14.

This emitter follower circuit also functions as an inverter for the input of the signal to be filtered to the variable inductance producing circuit 12*b'*. Accordingly, the collector of transistor 153 is connected to the base of current source transistor 134''. The base of current source transistor 134'' is shown connected by a resistor 163 to ground bus 130.

The collector current of current source transistor 134'' thus varies with the input signal and this collector current charges and discharges the effective capacitance of the inductance producing circuit 12*b'*. This current is not affected by the voltage on the controlled capacitor 23'' so long as it remains within the normal operating limits of the circuit and so the circuit associated with controlled capacitor 23'' functions as a nearly perfect integrator with a 90° phase lag.

The voltage appearing at the collector of feedback transistor 25'' is applied to the base of the current source transistor 134' of the capacitance producing circuit 12*a'* through a D.C. voltage shifting network. This voltage shifting network comprises a resistor 165 connected between the base of current source transistor 134' and the collector of feedback transistor 25'', and a resistor 167 connected between the base and emitter of current source supplied through resistor 165. As the base current required is relatively small, the voltage drop across resistor 165, which corresponds to the voltage shift, depends on the relative sizes of resistors 165 and 167. The current drawn from circuit 12*b'* changes only slightly with signal voltage as little change in base current is needed to cause the emitter of transistor 134' to follow the signal. This means that the signal load imposed on circuit 12*b* by the network is small. The D.C. voltage shifting network described and the symmetry of circuits 12*a'* and 12*b'* also enables these circuits to operate at the same voltage and current values to simplify power supply and control parameters. The signal voltage appearing across capacitor 23' thus produces a corresponding signal current through transistor 134'' which in turn produces a corresponding signal voltage across capacitor 23'' which lags that across capacitor 23' by approximately 90°. The voltage across capacitor 23'' in turn produces a corresponding current through transistor 134'. This current lags the voltage across capacitor 23' by approximately 90° and so has the same effect as an inductive component would have. To check phase relations, consider a positive going voltage peak across capacitor 23'. The resulting negative going peak on the base of transistor 134'' increases the current through it to charge capacitor 23'' more positively. The voltage across capacitor 23'' reaches a positive peak 90° later in the cycle and this decreases the current through transistor 134' which has the same effect as an increase in current through a component in parallel with capacitor 23' would have.

It is thus apparent that the effective controlled capacitance seen at the collector of feedback transistor 25'' of circuit 12*b'* appears as an effective inductance in circuit 12*a'* proportional to the size of the effective capacitance involved and in a manner to maintain a substantially constant Q. As the circuits 12*a'* and 12*b'* are substantially identical, the capacitive and inductive components will track quite well in response to a common control input and the Q of the circuit will then remain substantially constant as it is tuned over a wide range.

It should be understood that numerous modifications may be made in the most preferred forms of the invention described without deviating from the broader aspects of the invention. For example, some of the aspects of the invention are applicable to filter circuits having a variety of applications in addition to the disclosed application in a musical amplifier system.

I claim:

1. In an electrical musical apparatus including a source of musical tone signals in electrical form, a

signal utilizing device, and a network interconnecting said source and said utilizing device and including the combination of:

a. a first capacitive reactance,

b. a second capacitive reactance,

c. first means for producing a signal current to said second capacitive reactance which is proportional to the signal voltage across said first capacitive reactance, and

d. second means for producing a signal current to said first capacitive reactance which is proportional to the signal voltage across said second capacitive reactance.

2. The combination according to claim 1 including means for controlling the effective sizes of said first and second capacitive reactances.

3. The combination according to claim 2 wherein said first and second capacitive reactances each include a feedback circuit and said controlling means controls the effective gain of said feedback circuits.

4. In an electrical musical apparatus including a source of musical tone signals in electrical form, a signal utilizing device, and a network interconnecting said source and said utilizing device which includes the combination of:

a. a capacitor,

b. a transistor having its collector and emitter terminals connected to opposite terminals of said capacitor,

c. a source of fixed potential connected to the base of said transistor,

d. a constant current source connected to the emitter of said transistor,

e. a control current source having a low signal impedance,

f. a circuit element having a non-linear current voltage relation connected between the emitter of said transistor and said control current source, and

g. means for applying operating and signal voltages to the collector of said transistor.

5. The combination according to claim 4 wherein said circuit element comprises the base emitter junction of a second transistor.

6. The combination according to claim 4 wherein said applying means includes a high impedance current source.

7. The combination according to claim 6 wherein said high impedance current source consists of a potential source and an inductor connected between said source and the collector of said transistor.

8. In an electrical musical apparatus including a source of musical tone signals in electrical form, a signal utilizing device, and a network interconnecting said source and said utilizing device which includes the combination of:

a. a capacitor to render the network frequency discriminative including first and second terminals;

b. a feedback circuit including a transistor having its emitter connected to said first terminal, its collector to said second terminal, and its base to a fixed potential point;

c. control means responsive to an electrical control signal connected to said feedback circuit to control the amount of current feedback to said second terminal by the collector of said transistor and thereby control the effective size of said capacitor; and

d. an electrical control signal source connected to said control means.

9. The combination according to claim 8 wherein said control means robs a portion of the signal current from the emitter of said transistor with the variation in the output from said control signal source.

10. The combination of claim 8 wherein said control means include a transistor whose emitter is connected to the emitter of the transistor in said feedback circuit and to a source of D.C. voltage through a constant current D.C. path so the constant current in the D.C. path is shared by the emitters thereof in accordance with the base to emitter drive on said control means.

11. The combination according to claim 8 wherein said control signal source consists of a low frequency oscillator.

12. The combination according to claim 11 wherein said control signal source further includes:

a. an electronic counter driven by said oscillator; and

b. a set of resistors connected between the stages of said counter and a control input to said control means.

13. In an electrical apparatus including a source of signals in electrical form, a signal utilizing device, and a network interconnecting said source and said utilizing device which includes the combination of:

a. a capacitor,

b. a transistor having its collector and emitter terminals connected to opposite terminals of said capacitor,

c. a source of fixed potential connected to the base of said transistor,

d. a constant current source connected to the emitter of said transistor,

e. a control current source having a low signal impedance,

f. a circuit element having a non-linear current voltage relation connected between the emitter of said transistor and said control current source, and

g. and means for applying operating and signal voltages to the collector of said transistor.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,688,010 Dated August 29, 1972

Inventor(s) Alfred B. Freeman

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 10, lines 23, 26 and 32, "format" should be --formant--.

Column 12, line 14, after "source" insert --transister 134'. Current for base drive to transistor 134' and current to maintain the voltage drop across resistor 167 equal to the base emitter voltage is --

Signed and sealed this 6th day of March 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
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ROBERT GOTTSCHALK
Commissioner of Patents

FORM PO-1050 (10-69)

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