Oct. 11, 1955 A. R. MORGAN 2,720,133

APPARATUS FOR CONTROLLING FREQUENCY CHANGE

Filed Sept. 22, 1954 2 Sheets-Sheet 1

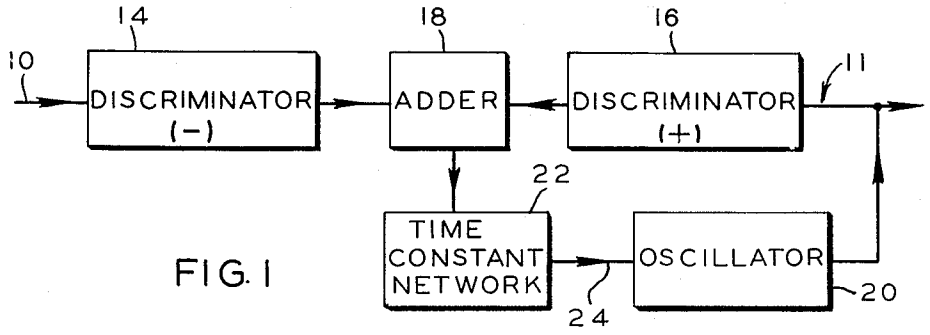



FIG. 1

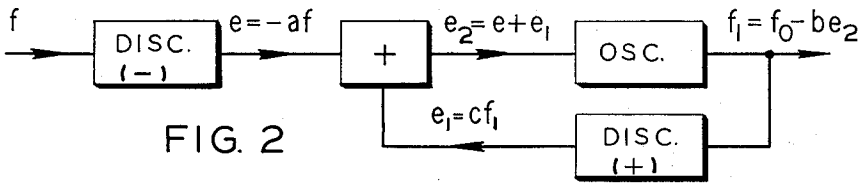



FIG. 2

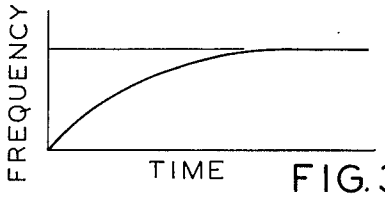



FIG. 3

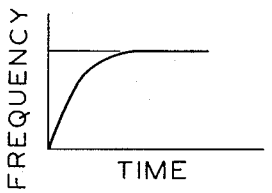



FIG. 4

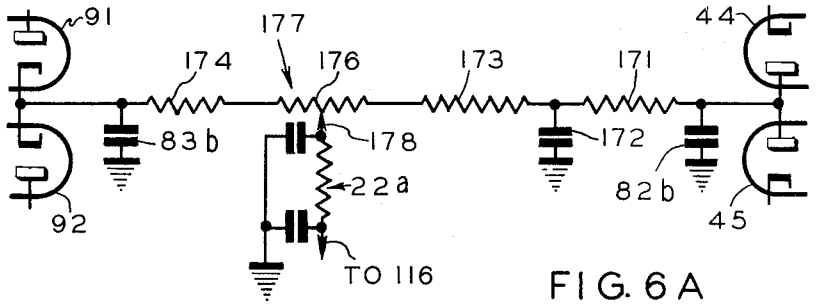



FIG. 6A

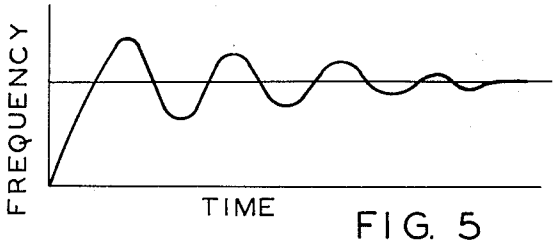



FIG. 5

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APPARATUS FOR CONTROLLING FREQUENCY CHANGE

Filed Sept. 22, 1954 2 Sheets-Sheet 2

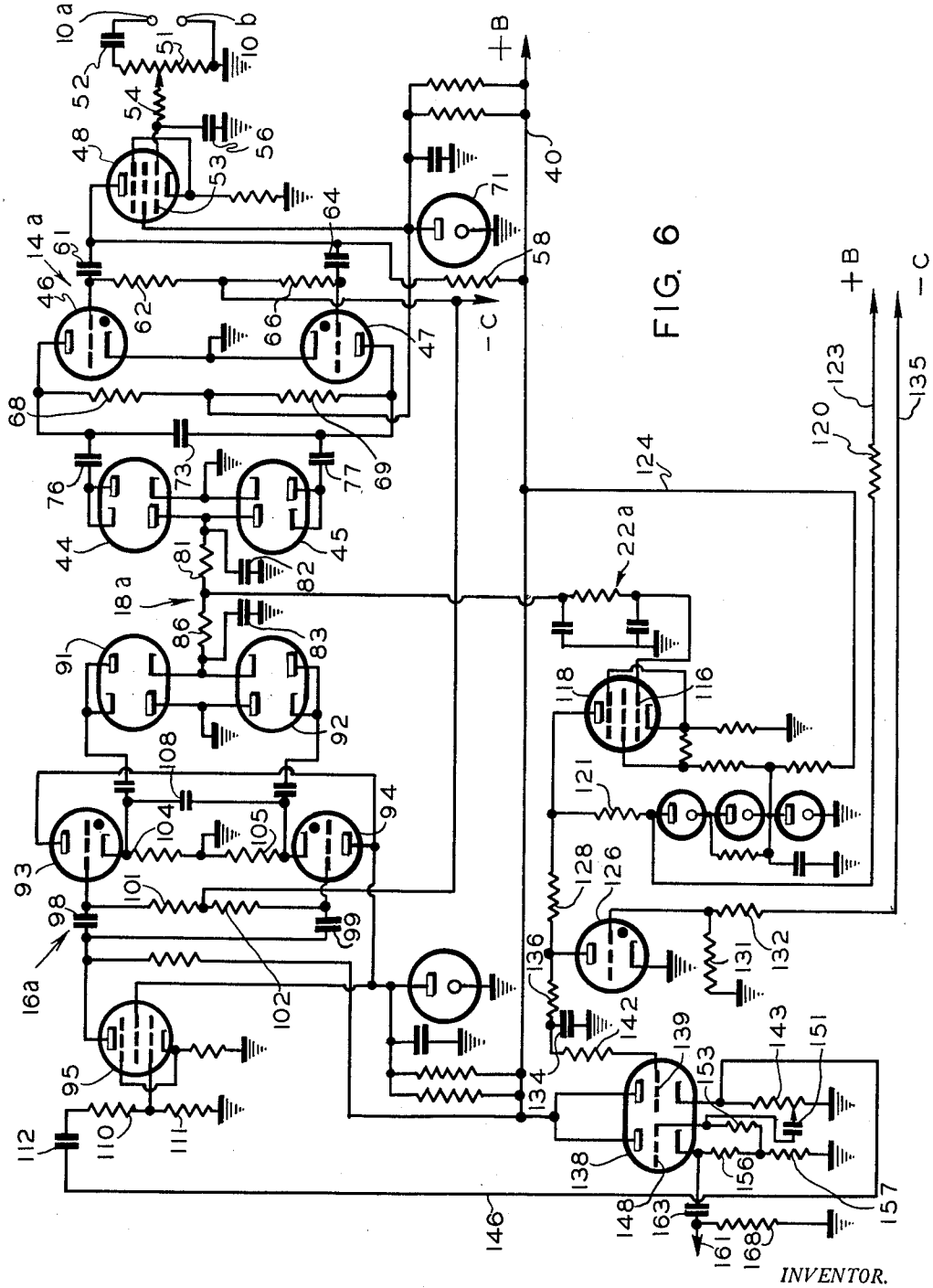



FIG. 6

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2,720,133

# APPARATUS FOR CONTROLLING FREQUENCY CHANGE

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Application September 22, 1954, Serial No. 457,709

8 Claims. (Cl. 84—1.24)

The present invention relates to apparatus for controlling frequency change, and, more particularly, but not necessarily exclusively, to novel apparatus for controlling the rate of change and the manner of change from a tone of one frequency to a tone of a different frequency.

Apparatus embodying the present invention is especially useful in providing a musical glide or portamento for changing from a produced tone to another produced tone. Each produced tone may originate in the circuits of a musical synthesizing device. However, it will be understood that apparatus embodying the present invention may be employed to insert a controllable transient between two frequencies of substantially any order of magnitude when a sudden change is made between one frequency and the other.

In the synthesis of musical tones it is necessary to provide means for producing a frequency or pitch glide, sometimes referred to as portamento. In playing a succession of musical notes a musician will, with an instrument such as a trombone, sometimes produce a continuous transition from one note to another. At another time the musician will play successive notes as units of substantially constant frequency. In the latter type of performance discrete tones or notes are produced. In the former the notes are produced with portamento.

The present invention has for one of its major aims to provide an apparatus for producing a portamento type of synthesis from discrete note synthesis.

Another object of the invention is to provide a novel arrangement for controlling an oscillator so that various kinds of transition characteristics may be provided in changing from a tone of one frequency to a tone of another frequency.

A still further object is to provide novel means for controlling an oscillator upon occurrence of a change in frequency of a produced tone.

In accordance with the present invention a direct current controlled oscillator is subject to control by the output of a pair of frequency discriminators feeding a time constant network. A produced tone or signal is fed to one of the frequency discriminators while the other frequency discriminator receives signals from the direct current controlled oscillator. The algebraic sum of the frequency discriminators is employed to control the oscillator and is variable in a predetermined manner.

Other objects and advantages of the present invention, in addition to those mentioned above, will, of course, become apparent and immediately suggest themselves to those skilled in the art to which the invention is directed from a reading of the following specification in connection with the accompanying drawing in which:

Fig. 1 is a diagrammatic showing of apparatus embodying the present invention;

Fig. 2 is a diagram similar to Fig. 1 to be used hereinafter in explaining theory related to the present invention;



Figs. 3, 4 and 5 are curves showing, by way of example, the rate at which the oscillator frequency can be made to approach the input frequency;

Fig. 6 shows a detailed embodiment of the present invention; and

Fig. 6*a* discloses an arrangement which may be substituted in the showing of Fig. 6.

Referring to Fig. 1 of the drawing, an input signal connection is indicated schematically at **10**. A corresponding output signal appears at **11**. The output signal and the input signal are of substantially the same frequency in the steady state condition. A discriminator is indicated at reference character **14** which is arranged to have a negative direct current output as indicated by the minus sign. A second discriminator **16** is designed to have a positive direct current output as indicated by the positive sign. Reference character **18** designates an adder which makes an algebraic addition of the two discriminator output currents. A D. C. controlled oscillator **20** is of the type in which the frequency is substantially proportional to the D. C. input which is the output of the adder **18** supplied through a time constant network **22** and applied as indicated at reference character **24**. In the arrangement to be described more in detail in connection with Fig. 6 of the drawing the polarity of the D. C. control is such that a current of the polarity delivered by the negative discriminator will cause the oscillator frequency to increase.

Assume that the two frequency discriminators are exactly the same with the exception that the outputs are of opposite polarity as indicated. If the input frequency to the two discriminators is the same, the output currents will have the same value but will be opposite in polarity. The output of the adder **18** would then be zero. If the input frequency to the negative discriminator **14** is higher than the input frequency to the positive discriminator **16** the output of the adder **18** will have negative polarity, and vice versa. It will be assumed that the D. C. oscillator is adjusted so that its frequency for zero D. C. input is equal to some specified frequency. This frequency is applied to the positive discriminator **16**. If this same frequency is applied to the negative discriminator **14** the output of the adder will be zero to agree with the proposed adjustment or setup of the oscillator. Then if the oscillator **20** should drift to a higher frequency the output of the positive frequency discriminator **16** would predominate and the positive polarity of the adder output would be such as to lower the oscillator frequency, assuming that the oscillator is of the type mentioned above. In other words the oscillator frequency would tend to lock on the input frequency to the negative frequency discriminator **14**. This is the desired condition since the frequency at the output **11** is to be substantially equal to the frequency at the input **10** in the steady state condition.

There must be a difference between the input frequency and the oscillator frequency, for input frequencies other than the case just discussed, in order to have an adder output to control the D. C. controlled oscillator **20**. This difference can theoretically be as small as desired by making the sensitivity of the D. C. controlled oscillator as great as necessary.

It will be recognized by those skilled in the art that the oscillator **20**, the positive frequency discriminator **16**, the adder **18** and the time constant network **22** constitute a closed feedback loop. Certain manipulation of the loop gain and phase characteristics is necessary to prevent instabilities such as continuous oscillation. The transient behavior of a feedback network is dependent on the gain and phase characteristics of the feedback loop. The time constant network **22** provides the means for

controlling the overall loop gain and phase characteristics so that the desired transient performance (portamento) can be obtained.

A variety of frequency approaches can be obtained depending on the complexity and adjustment of the network **22**. For example, with the network shown by way of example in Fig. 6 of the drawing, later to be described, which is a resistor-capacitor filter the results shown in Figs. 3, 4, 5 can be obtained. In the language of the transient response art these conditions would be called overdamped, critically damped and underdamped responses, respectively.

The more detailed circuit of Fig. 6 will now be described. Tubes **44** to **48** and the associated circuitry constitute the frequency discriminator having an output of negative polarity. This frequency discriminator corresponds to discriminator **14** in Fig. 1 of the drawing and is designated **14***a*. Input terminals are designated **10***a* and **10***b*. The input terminal **10***a* is connected to the potentiometer resistor **51** of a volume control potentiometer through a coupling capacitor **52**. The No. 1 grid **53** of the tube **48** is connected through a series grid resistor **54** to the slider on the potentiometer resistor **51**. The grid is shunted to ground by a small capacitor **56**. The tube **48** operates as a limiter stage and serves to shape the input signal wave to reduce the dependence on input voltage. Tube **48** may be a type 6SH7. With the tube type named, solely by way of example, the resistor **54** is 120,000 ohms and the capacitor **56** is 220 micromicrofarads. The anode of the tube **48** is connected to the +B or positive high voltage terminal of a suitable power supply (not shown) through a resistor **58**, the latter having a value of 24,000 ohms. The values of components are given herein solely by way of example. The +B lead or bus is designated **40**.

The tubes **46** and **47** constitute a flip-flop circuit which flips over and back once for each two cycles of the input frequency. The purpose of the flip-flop circuit is to provide pulses, the amplitude of which are independent of the input signal amplitude and wave-shape. The tubes **46** and **47** are gas tubes, for example type 884 Thyratrons. The output appearing at the anode of the tube **48** is differentiated and applied to the grids of the tubes **46** and **47**. One differentiating circuit is composed of a capacitor **61** and a grid resistor **62**. The other differentiating circuit is composed of a capacitor **64** and a grid resistor **66**. The capacitors **61** and **64** have a value of 51 micromicrofarads and the resistors **62** and **66** have a value of 120,000 ohms each. The anodes of the tubes **46** and **47** are connected through load resistors **68** and **69** to a regulated voltage source which includes the voltage regulator tube **71**. Illustratively, the value of resistors **68** and **69** is 10,000 ohms. The anodes of the tubes **46** and **47** are bridged by a capacitor **73** which serves to extinguish conduction in the conducting tube. In the illustrative example this capacitor has a value of .01 microfarad. The square wave output of the flip-flop which is composed of tubes **46** and **47** is applied by capacitors **76** and **77** to the previously mentioned double diodes **44** and **45** in the manner illustrated by the drawing. In the illustrative example the capacitors **76** and **77** each have a value of 510 micromicrofarads. The tubes **44** and **45** may, for example, be type 6H6 tubes.

The interconnected cathodes of one-half of the tubes **44** and **45** are connected to ground. The interconnected anodes of the other half of these tubes are connected to one end of a resistor **81** which is a part of the adder **18***a*. An integrating capacitor **82** is connected between the anodes of the tubes **44** and **45** and ground. In the illustrative example the capacitor **82** has a value of 5,100 micromicrofarads. In view of the described circuit arrangement, the tubes **44** and **45** serve to select the negative pulses generated by the flip-flop circuit and to inject these pulses to the integrating capacitor **82**.

The positive discriminator, indicated generally by reference character **16***a*, is similar to the discriminator **14***a* except that it delivers positive pulses to an integrating capacitor **83** having the same value as the capacitor **82**. A resistor **86** is combined with the resistor **81** in the adder **18***a*.

Tubes **91**, **92**, **93**, **94** and **95** correspond in function to tubes **44**, **45**, **46**, **47** and **48**, respectively. The tube **95** serves as a limiter to provide signals to the grids of the gas tubes **93** and **94** by way of differentiating circuits composed of capacitors **98** and **99** and resistors **101** and **102**. Each of the flip-flop tubes **93** and **94** has its cathode connected to ground by way of a resistor **104** and **105**, respectively. The resistors **104** and **105** each have a value in the illustrative example of 10,000 ohms. The cathodes are shunted by a capacitor **108** having a value in the illustrative example of .01 microfarad. The cathodes of one-half of the tubes **91** and **92** are connected, as stated previously, to one end of the resistor **86**. The input to the grid of the tube **95** is derived from a voltage divider made up of resistors **110** and **111** fed by way of a coupling capacitor **112** from the oscillator to be described.

The output from the adder **18***a* is supplied by way of the time constant network **22***a* to the grid **116** of a D. C. amplifier tube **118**. A resistor **121** in the illustrative example has a value of 75,000 ohms and serves as the load resistor for the tube **118**. As indicated in Fig. 6 of the drawing, regulated voltages are applied to appropriate electrodes of the tube **118** by way of a conductor **123** and a resistor **120** which is connected to the power supply previously mentioned (not shown) or to a separate source (not shown) of +B voltage having its negative terminal grounded. Screen voltage for the tube **118** is derived as shown by way of a conductor **124** connected to the conductor **40**.

Tube **126** serves as a gas tube relaxation oscillator. This tube is or may be a type 884 Thyratron. The anode of the tube **126** is connected to the output of the tube **118** by way of a resistor **128**. In the illustrative example this resistor has a value of 510,000 ohms. The grid of the tube **126** is connected by way of a voltage divider composed of resistors **131** and **132** to the negative terminal of a power supply (not shown) by way of a conductor **135**. A charge receiving capacitor is indicated by reference character **134**. The charging circuit of the capacitor **134** may be traced to conductor **123** through the resistor **120**, the resistor **121**, the resistor **128** and an additional current limiting resistor **136**. The resistor **136** protects the tube **126**. The resistor **136**, in the illustrative example, has a value of 390 ohms and the capacitor **134** has a value of .033 microfarad.

The charge applied to the condenser **134** is under control of the output of the tube **118** as applied between the resistors **128** and **121**. As stated previously, the oscillator frequency is lowered when the adder output goes positive. The tube **118**, among other things, accomplishes this by its normal phase inversion characteristic.

A double cathode follower is provided by the tube **138** which may be a type 6SN7 tube. The grid **139** of the right hand half of the tube **138** is connected to the high voltage terminal of the capacitor **134** by way of a resistor **142** which has a value of 9,100 ohms in the illustrative example. The output of the right hand half of the tube is taken across a cathode resistor **143** and applied by way of a conductor **146** to the previously mentioned coupling capacitor **112**. The grid **148** is coupled to a point on the resistor **143**, which serves as a potentiometer, by way of a coupling condenser **151**. The grid **148** is returned through a grid resistor **153** to a point between cathode resistors **156** and **157**. The left hand section of the tube **138** supplies the output of the apparatus to the output terminal **161** by way of a coupling condenser **163**. In the illustrative example a 5 megohm resistor **168** is connected between the output terminal **161** and ground.

In all of the foregoing, it will be understood that com-

ponent values and tube types are given solely by way of example. One skilled in the art may, in view of the teachings given herein, use other tube types and correspondingly suitable component values. Hard tubes may be used in place of gas tubes and other types of D. C. controlled oscillators may be used.

A better understanding of the action of the apparatus may be had from a brief mathematical examination of the overall action. Consider Fig. 2 which is substantially the same as Fig. 1 except that the ideal functioning of each block is indicated. The time constant network is omitted, for the moment, since it does not enter into the steady state operation of the apparatus.

The function of each block should be clear if it is realized that a discriminator converts frequency to a D. C. voltage and the D. C. controlled oscillator converts a D. C. voltage to frequency.

The adder, oscillator and (+) discriminator constitute a feedback loop that functions in accordance with the following equations:

$$f_1=f_0-be_2 \quad (1)$$
$$e_2=e+e_1 \quad (2)$$
$$e_1=cf_1 \quad (3)$$

In Equations 1, 2 and 3:

$f_0$ is the oscillator frequency with zero D. C. input.
$c$ is the sensitivity of the positive discriminator.
$b$ is the oscillator sensitivity.

Solving for $f_1$ in terms of $e$ we find:

$$f_1=\frac{f_0-be}{1+bc} \quad (4)$$

Inserting the functioning of the (—) discriminator $e=-af$, where $a$ is the sensitivity of the negative discriminator, we have for the overall action of the apparatus:

$$f_1=\frac{f_0+baf}{1+bc} \quad (5)$$

If, as stated previously, the oscillator is adjusted so that its frequency for zero D. C. input is equal to some specified frequency ($f_0$ in Equation 5), and it is assumed that the two discriminators have the same sensitivity ($a$ equals c in Equation 5); then it will be seen that $f_1$ will equal $f$ only when $f$ is equal to $f_0$. It may also be seen that if the oscillator sensitivity ($b$ in Equation 5) is made very large, Equation 5 will reduce to approximately:

$$f_1\cong\frac{baf}{bc}\cong f$$

The larger $b$, the better the approximation.

Further examination of Equation 5 can result in an adjustment procedure that is superior to the one just described. Suppose that $f_0$ be set to zero, which means that the oscillator is adjusted to give zero frequency for $e_2$ equal zero. Then Equation 5 reduces to:

$$f_1=\frac{baf}{1+bc} \quad (6)$$

Satisfactory operation is obtained when

$$\frac{ba}{1+bc}=1 \quad (7)$$

which can be approximated by making $a$ equal $c$ and the product $bc$ much greater than unity.

Another solution is seen by solving (7) for $a$ in terms of $b$ and $c$ as:

$$a=\frac{1+bc}{b}=\frac{1}{b}+c \quad (8)$$

If this value of $a$ is put in (6) then: $f_1=f$, which is indeed a very satisfactory solution.

There remains to discuss the effect of changes of $a$, $b$ and $c$ with time and with input levels. From the similiarity that is inherent between the (+) and (—) discriminators it is to be expected that the changes in $a$ and $c$ will be similar with signal and with time. In other words the ratio $a/c$ should be substantially constant under practical circumstances. The quantity $b$ can be expected to have an appreciable amount of variation with time and with signal level. Now consider again Equations 7 and 8. The best operation is obtained when the products $ba$ and $bc$ are large compared with unity. It is desirable to make $bc$ as large as stability will allow and then adjust $a$ to satisfy Equation 8.

The control of the rate at which the D. C. controlled oscillator approaches the input frequency can be affected by placing the time constant network between the adder and the oscillator in the showing of Fig. 1. In this case consideration must be taken of the feedback loop gain and phase as stated previously. It may be that the desired approach rate cannot be obtained without instability in the feedback circuit. The time constant network can also be placed between the (—) discriminator and the adder and thus be free of feedback limitations. It is possible that a combination of networks in both positions would be desirable.

Fig. 6*a* of the drawing discloses a modification which may be incorporated in the showing of Fig. 6 to obtain operation with a time constant network placed between the negative discriminator and the adder. In Fig. 6*a* the tubes **44** and **45** correspond to the tubes **44** and **45** of Fig. 6. Also, the tubes **91** and **92** correspond to the tubes **91** and **92** of Fig. 6. The time constant network **22***a* is the same as the time constant network **22***a* in Fig. 6 and the remaining tubes and circuits of Fig. 6 are undisturbed. The integrating capacitors connected to the discriminator tubes are designated by reference characters **82***b* and **83***b*. An additional time constant network is provided by a resistor **171** together with a capacitor **172** which is connected to ground as indicated. An additional resistor **173** together with the resistor **171** corresponds somewhat in function to the resistor **81** of Fig. 6. The resistors **171** and **173** are of equal value and may, for example, each have a value of one-half megohm. A resistor **174** corresponds in function to the resistor **86** of Fig. 6 and may also have a value of 1 megohm. The resistor **176** of a potentiometer **177** is bridged between the resistor **173** and the resistor **174**. In the illustrative example of Fig. 6*a*, the resistor **176** may have a value of 100,000 ohms. The sliding contact **178** of the potentiometer is connected to the time constant network **22***a* which is the same network that appears in Fig. 6 by way of example. The sliding contact **178** is adjustable to set the ratio $a/c$, the significance of which is described in the foregoing.

What is claimed is:

1. In combination, a channel through which tone signals are to be passed in succession and means in said channel for causing a tone signal to glide in frequency to the next successive tone signal in response to the application of said next successive tone signal to said means, said means comprising an adder, a discriminator having a negative going output connected to said adder, means to apply said tone to said discriminator, a second discriminator having a positive going output connected to said adder, means to supply a signal related in frequency to said tone signal to said second discriminator, an oscillator, and means for controlling the frequency of said oscillator as a function of the output of said adder.

2. In combination, a channel through which tone signals are to be passed in succession and means in said channel for causing a tone signal to glide in frequency to the next successive tone signal in response to the application of said next successive tone signal to said means, said means comprising an adder, a discriminator having a negative going output connected to said adder, means to apply said tone to said discriminator, a second dis-

criminator having a positive going output connected to said adder, an oscillator, means to supply a signal from said oscillator to said second discriminator, and means for controlling the frequency of said oscillator as a function of the output of said adder.

3. In combination, a channel through which tone signals are to be passed in succession and means in said channel for causing a tone signal to glide in frequency to the next successive tone signal in response to the application of said next successive tone signal to said means, said means comprising an adder, a discriminator having a negative going output connected to said adder, means to apply said tone to said discriminator, a second discriminator having a positive going output connected to said adder, means to supply a signal related in frequency to said tone signal to said second discriminator, an oscillator, and means including a filter circuit for controlling the frequency of said oscillator as a function of the output of said adder.

4. In combination, a channel through which input tone signals are to be passed in succession having a signal source therein for producing an output tone signal having a glide approach to the next successive input tone signal, an adder, a discriminator having a negative going output connected to said adder, means to apply said input tone signals to said discriminator, a second discriminator having a positive going output connected to said adder, means to supply a signal from said signal source to said second discriminator, and means for controlling the frequency of said signal source as a function of the output of said adder.

5. In combination, a channel through which input tone signals are to be passed in succession having a signal source therein for producing an output tone signal having a glide approach to the next successive input tone signal, an adder, a discriminator having a negative going output connected to said adder, means to apply said input tone signals to said discriminator, a second discriminator having a positive going output connected to said adder, means to supply a signal from said signal source to said second discriminator, means for controlling the frequency of said signal source as a function of the output of said adder, and a filter circuit included in said last named means.

6. In combination, a channel through which tone signals are to be passed in succession and means in said channel for causing a tone signal to glide in frequency to the next successive tone signal in response to the application of said next successive tone signal to said means, said means comprising an adder and cooperating discriminators connected to said adder for producing a control voltage, a filter, an oscillator, and means for applying said control voltage to said oscillator through said filter to control the frequency of said oscillator as a function of said control voltage.

7. Frequency change control apparatus comprising a frequency discriminator having a negative going direct current output, a second frequency discriminator having a positive going D. C. output, an adder, means to supply an input signal to said first named discriminator, a connection from said first named discriminator to said adder, a connection from said second named discriminator to said adder, an oscillator, a connection from said adder to said oscillator including a filter, said oscillator, said second named frequency discriminator, said adder and said filter constituting a feedback loop, and an output connection from said oscillator.

8. In combination a channel through which tone signals are to be passed in succession having a signal source therein for producing an output tone signal having a glide approach to the next successive input tone signal, said channel having input terminals for receiving input tone signals, means for shaping the waveform of said signals, means for differentiating said signals, a flip-flop circuit, means for applying said differentiated signals to said flip-flop circuit, pulse integrating means for integrating negative going signals from said flip-flop circuit, said signal source comprising an oscillator, means for deriving and shaping signals from said oscillator, means for differentiating said derived and shaped signals, a second flip-flop circuit, means for applying said derived and shaped signals to said second flip-flop circuit, second pulse integrating means for integrating positive going signals from said second named flip-flop circuit, an adder comprising a resistor connected between said first and second integrating means, a filter circuit, a connection including said filter circuit from a point on said resistor to said oscillator, and an output connection from said oscillator.

No references cited.