Nov. 26, 1968 K. D. JACOB 3,413,403

VIBRATO AND TREMOLO SYSTEM

Filed April 28, 1965 2 Sheets-Sheet 1

FIG. 1

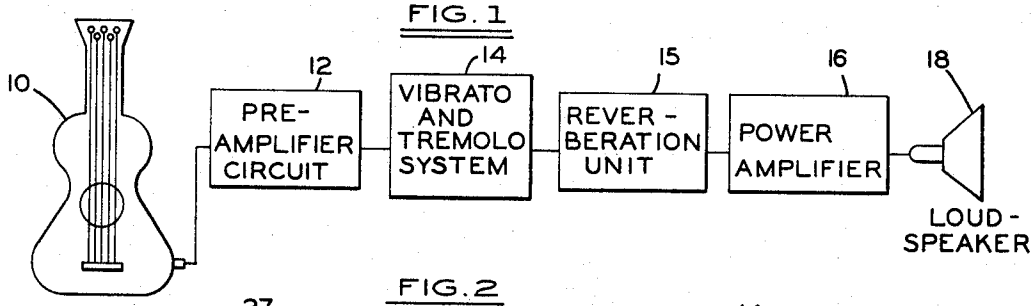


FIG. 2

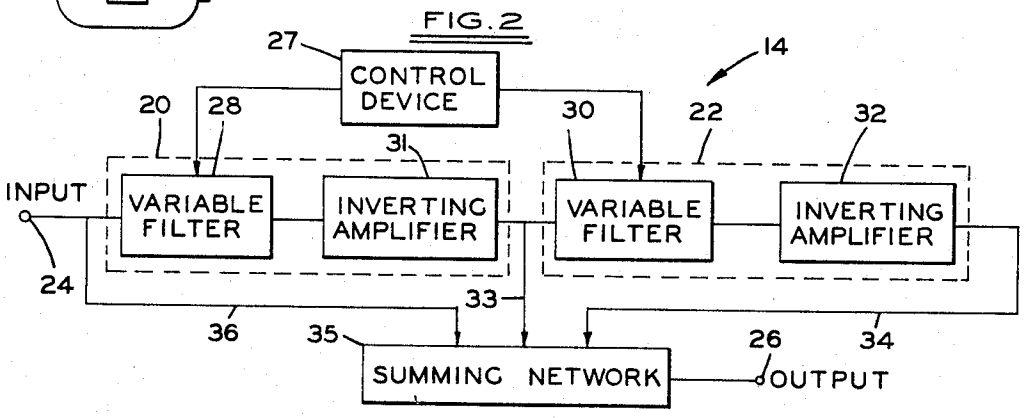


FIG. 5

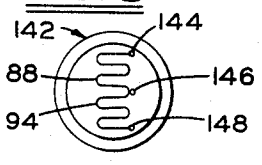


FIG. 6

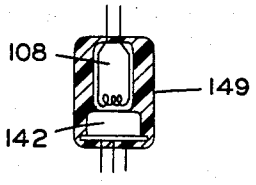


FIG. 7

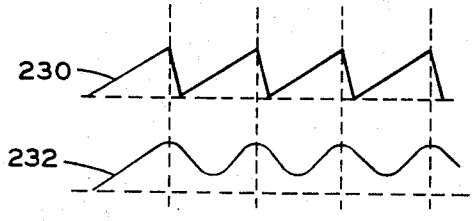


FIG. 8

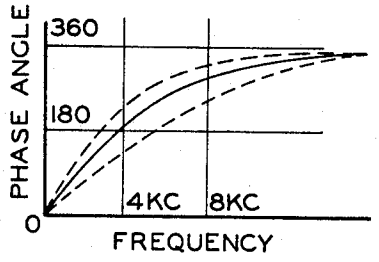
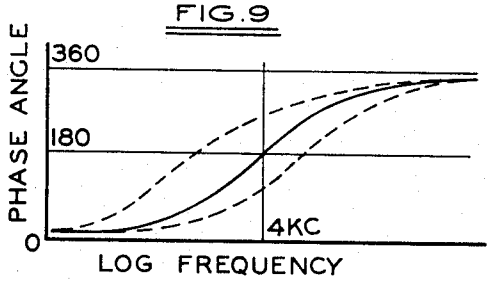


FIG. 9



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VIBRATO AND TREMOLO SYSTEM

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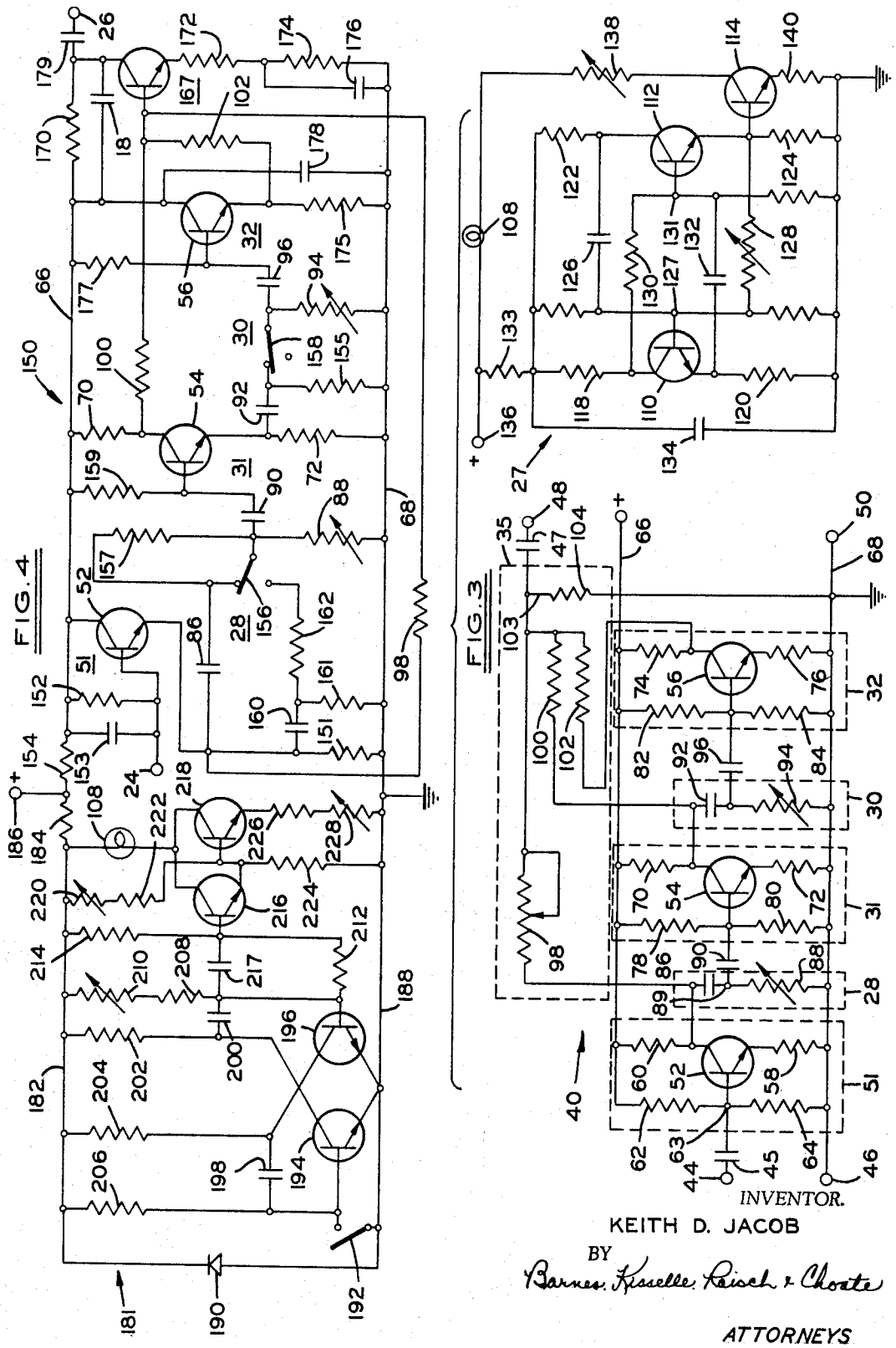


FIG. 4

FIG. 3

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VIBRATO AND TREMOLO SYSTEM

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Filed Apr. 28, 1965, Ser. No. 451,512
11 Claims. (Cl. 84—1.25)

ABSTRACT OF THE DISCLOSURE

A vibrato system for an electrical musical instrument or the like wherein an audio signal from the instrument is summed with two phase-shifted versions of the audio signal in a summing network to provide a vibrato output. One phase-shifted version of the audio signal is developed by a variable phase-shifting circuit whose input is the audio signal and the other phase-shifted version of the audio signal is developed by a second variable phase shift circuit whose input is the output of the first phase shifting circuit. A vibrato control signal varies the phase shift introduced in the first and second phase-shifting circuits substantially in unison.

This invention relates to circuits for producing vibrato and/or tremolo in electrical musical instruments.

As the terms vibrato and tremolo are used in the description and claims which follow, vibrato means a variation of pitch and is produced by frequency or phase modulation of signals, whereas tremolo means a variation of loudness and is produced by amplitude modulation of signals. The signals to be modulated, however, cover a wide range of frequencies, so the modulation differs from ordinary frequency or amplitude modulation where a single carrier frequency is varied in frequency or amplitude, often in proportion to the variations of an audio frequency signal.

An object of this invention is to provide an improved system for producing substantially pure vibrato in the sound from an electrical musical instrument.

Another object of the invention is to provide a circuit which can produce either vibrato or tremolo or both effects simultaneously.

Another object of the invention is to introduce vibrato by producing a dynamic phase shift in a signal over a wide range of frequencies without introducing substantial amplitude variations.

A further object of the invention is to provide an improved vibrato system having all-pass transmission characteristics; i.e., one which passes a very wide range of signal frequencies.

Another object of the invention is to isolate control signals from the audio signals in a vibrato system.

A further object of the invention is to effect modulation in a vibrato system by variations of light.

Other objects and features of the invention will be apparent from the description which follows considered with the accompanying drawings, in which:

FIG. 1 is a simplified block diagram illustrating a vibrato and tremolo system embodied in an electric guitar.

FIG. 2 is a block diagram of a vibrato and tremolo system in accordance with the invention.

FIG. 3 is a schematic diagram for a vibrato and tremolo system which constitutes one embodiment of the invention.

FIG. 4 is a schematic diagram for another embodiment of the invention.

FIG. 5 is a plan view of a light dependent resistor included in the system of FIG. 4.

FIG. 6 shows a light bulb and a light dependent resistor encapsulated with plastic.

FIG. 7 illustrates certain waveforms produced in the operation of the system of FIG. 4.

FIG. 8 is a curve showing the relationship between phase angle and frequency of signals transmitted by the circuits of FIGS. 3 and 4.

FIG. 9 is a curve similar to FIG. 8 but with frequency plotted on a logarithmic scale.

In FIG. 1, the sound system for an electric guitar **10** has been illustrated in block diagram form. It is to be understood that the utility of the vibrato and tremolo system of the invention is not limited to electric guitars, but this is a major application for the invention. Electric organs are another instrument in which the system is useful. Electrical signals are derived from vibrations of the strings of guitar **10** by a pick-up device (not shown) which ordinarily includes a coil and magnet mounted under the strings such that as a string vibrates, it varies flux linking the coil, thereby inducing voltage in the coil. Signals from the pick-up device are amplified by a pre-amplifier circuit **12** and are fed to the vibrato and tremolo system **14** where either amplitude modulation (tremolo) or frequency modulation (vibrato) may be introduced into the signals. It is sometimes desirable to introduce both vibrato and tremolo, but system **14** can produce either effect in a reasonably pure form. Reverberation may be added to the signals in unit **15**, and the output from unit **15** is amplified by a power amplifier **16** and supplied to one or more loudspeakers **18** which transduce the output to sound.

FIG. 2 is a block diagram of a vibrato and tremolo system **14** in accordance with the invention. These are two phase shifting stages **20** and **22** coupled in cascade relation between a signal input terminal **24** and a signal output terminal **26**. The filters **28** and **30** of stages **20** and **22** respectively are varied by control signals supplied from a control device **27** so as to modulate input signals fed to terminal **24**. The outputs of variable filters **28** and **30** are inverted in phase by inverting amplifiers **31** and **32**, and output signals are supplied from the inverting amplifiers via lines **33** and **34** to a summing network **35** where they are summed with the input signal which is supplied to network **35** over line **36**. The output signals which appear at terminal **26** are audio frequency signals modulated in frequency at a vibrato rate determined by control device **27**. Normal rates for either vibrato or tremolo are from four to ten cycles per second, but system **14** is not restricted to these rates. In both natural and artificial music, a vibrato rate as high as ten percent of the audio frequency can occur.

It has been found that by weighting the amplitudes of the three signals which are summed in network **35** in the ratio of one part of input signal to four parts of each of the phase-shifted signals, and by making the time constants of variable filters **28** and **30** equal, it is possible to produce pure vibrato in the output signal which appears at terminal **26**. In this case, the overall transmission characteristic of system **14** is that of an all-pass network; that is, the system passes a very wide range of frequencies without attenuating any particular frequencies more than others. If the gain of system **14** is unity, it will pass all frequencies in a wide range without attenuating any frequency. The individual filters **28** and **30** may be either high-pass or low-pass filters, but the overall system **14** nevertheless has all-pass transmission characteristics due to the 1:4:4 ratio in which the input signal and the two phase-shifted signals are summed in network **35**.

Vibrato is introduced by varying the time constants of filters **28** and **30** at the desired vibrato rate. This can be accomplished by varying a resistance, a capacitance or an inductance in filters **28** and **30**, and in the case of

a resistance variation, it can be accomplished advantageously by the use of a light dependent resistor illuminated by light which is varied at the vibrato rate by the control device **27**. If desired, both tremolo and vibrato can be added to the signals, and it is possible to adjust system **14** so that it produces tremolo with little or no vibrato.

The circuitry of one embodiment of the invention is illustrated in FIG. 3. The sections of the circuit corresponding to the blocks in FIG. 2 have been enclosed in dashed lines in FIG. 3. The input signal is supplied to terminals **44** and **46** and the output signal appears across terminals **48** and **50**. Coupling capacitors **45** and **47** are connected respectively to terminals **44** and **48**. In this embodiment, circuit **40** is isolated from the control device **27**. Operating potential for circuit **40** is applied to busses **66** and **68**. Bus **68** may be grounded and bus **66** may be at plus 18 volts. Transistors **54** and **56** and the associated resistors are the inverting amplifiers **31** and **32** of FIG. 3. There is a third amplifier **51** including a transistor **52** at the input of circuit **40** which provides a constant input impedance and makes the input impedance of circuit **40** high enough so that it does not adversely load down the circuitry from which the input signals are supplied. Transistor **52** has a split load constituted by resistors **58** and **60** connected respectively in the collector and emitter paths of the transistor. Positive bias for the base of transistor **52** is derived from the junction **63** between resistors **62** and **64** connected in series as a voltage divider across the power supply busses **66** and **68**. Similarly, transistor **54** has split load resistors **70** and **72** and transistor **56** has split load resistors **74** and **76**, positive bias being applied to the bases of the latter transistors by resistors **78** and **80** which form one voltage divider and resistors **82** and **84** which form another voltage divider.

Variable filter **28** includes a single capacitor **86** and a resistor **88** connected in series between the collector of transistor **52** and grounded bus **68**. Filtered voltage appearing at the junction **89** between capacitor **86** and resistor **88** is applied to the base of transistor **54** by a coupling capacitor **90**. The other variable filter **30** includes capacitor **92** and resistor **94** connected in series between the collector of transistor **54** and grounded bus **68**, the junction **95** between capacitor **92** and resistor **94** being coupled to the base of transistor **54** by capacitor **96**.

Filters **28** and **30** are of the high-pass type, but it is to be understood that low-pass filters may be used as an alternative merely by reversing the resistance and capacitance elements. Such filters may also be constructed with an inductor and a resistor, or an inductor and a capacitor. Inductors have been avoided in practice because for audio frequency filters they are too large and weighty. An advantage of resistance-capacitance filters is that the variable element, either the resistor or the capacitor may be grounded at one end. Where the variable elements are resistances like **88** and **94** in FIG. 3, they have a grounded connection (bus **68**) between them and this makes it especially convenient to use a single integrated resistor which has two resistance arms (**88** and **94**) with a central tap which can be grounded. If low-pass filters are used in which the variable elements are ganged capacitors with a common plate, the common plate may be grounded.

The three signals to be summed are derived from the collectors of transistors **52**, **54** and **56** by resistors **98**, **100** and **102**. The latter resistors are connected together at one end thereof and their common junction **103** is connected to an output summing resistor **104**. The other ends of resistors **98**, **100** and **102** are connected respectively to the collectors of transistors **52**, **54** and **56**. As mentioned previously, the three signals which are summed in the summing network **35** should be weighted in amplitude according to the ratio of one part of input signal to four parts of the filtered signals in order to produce pure vibrato in the output signals appearing across terminals **48** and **50**. By making the overall gain of circuit **40** unity, the desired summing ratio can be obtained by simply adjusting the resistance values of resistors **98**, **100** and **102** to the ratio of 1:4:4. If the overall gain of circuit **40** is other than unity, the values of resistors **98**, **100** and **102** may be adjusted accordingly to obtain the desired amplitude ratio.

If the three signals fed to summing network **35** are weighted in some ratio other than 1:4:4, or if the time constants of the two filters **28** and **30** are not equal, the tremolo is produced as well as vibrato; i.e., the output signal across resistor **104** will vary both in frequency and amplitude. In FIG. 3, resistor **98** has been made variable to provide a control for adjusting the summing ratio to thereby determine the vibrato and tremolo content of the output signal.

The variable resistors **88** and **94** in filters **28** and **30** are light dependent resistors which can be modulated by illumination from a lamp **108** operated by the control device **27**. As the intensity of lamp **108** varies, the values of resistors **88** and **94** vary to alter the time constants of filters **28** and **30** and thereby vary the phase of the signals appearing across resistors **100** and **102** relative to the signal across resistor **98**. This dynamic phase variation produces vibrato in the output signal appearing across resistor **104**.

The rate of the modulation is determined by component values in the control device **27**. In the embodiment of FIG. 3, the control device is a phase shift oscillator including three transistors **110**, **112** and **114** each having a split load. The split load of transistor **110** consists of resistors **118** and **120**, and the split load of transistor **112** consists of resistors **122** and **124**. Capacitor **126** and resistor **128** are connected in series from the collector of transistor **112** to its emitter, and the junction **127** between capacitor **126** and resistor **128** is connected to the base of transistor **110**. At the frequency where the reactance of capacitor **126** equals the resistance of resistor **128**, the phase shift from the collector of transistor **112** to the base of transistor **110** is minus 90°. Resistor **130** and capacitor **132** are connected in series from the collector of transistor **110** to its emitter, and the junction **131** is connected to the base of transistor **112**. At the frequency where the resistance of resistor **130** equals the reactance of capacitor **132**, the phase shift from the collector of transistor **110** to the base of transistor **112** is plus 90°.

Transistors **110** and **112** each produce a phase shift of 180°. Due to the opposite direction of the phase shifts produced by the two resistance-capacitance networks which cross couple the transistors, the total loop phase shift is 360° which is the condition necessary to sustain oscillations. Thus, the circuit will oscillate only at the frequency where the capacitance reactance of capacitors **126** and **132** is equal to the resistance of resistors **128** and **130**.

Two signals taken from the amplifiers formed by transistors **110** and **112** with their split loads are combined by a resistor **133** and a capacitor **134** connected from the junction between resistors **116** and **118** to ground. The other end of resistor **133** is connected to a positive power supply terminal **136**. A circuit branch connected from the power supply terminal **136** to ground includes a transistor **114** with its base connected to the emitter of transistor **112**, a lamp **108** and resistors **138** and **140**. The oscillating wave appearing at the emitter of transistor **112** drives the base of transistor **114** to vary the illumination of the lamp **108**. The varying light from lamp **108** in turn varies the resistance of resistors **88** and **94** to modulate the frequency of the signals passed by circuit **40**.

The two light dependent reistances **88** and **94** may be integrated in a single light dependent resistor **142** as shown in FIG. 5. Light dependent resistor **142** has one arm **88** between terminals **144** and **146** and another arm **94** between terminals **146** and **148**. Terminal **146** is a

center tap which may be connected to grounded bus **68** in FIG. 3. The resistance element consisting of arms **88** and **94** is made of a photoconductive material such as cadmium sulphide. By using a single light dependent resistor having two arms and a center tap, the values of the two arms may be made equal and will track each other accurately as their resistance values are varied by light from a single source.

FIG. 6 illustrates a simple manner of mounting a lamp **108** on the transparent face of light dependent resistor **142** and encapsulating this assembly with opaque plastic material **149** so as to keep ambient light from affecting the light dependent resistor **142**.

FIG. 4 shows the circuitry of another embodiment of the invention. Like components in FIGS. 3 and 4 have the same reference numerals. In circuit **150**, there is an input amplifier **51**, two intermediate amplifiers **31** and **32** and an output amplifier **167** which is part of the summing network **35**. The first high-pass filter **28** between amplifiers **51** and **31** consists of a capacitor **86** and a light dependent resistor arm **88** connected in series from the emitter of transistor **52** to grounded bus **68**. The second high-pass filter **30** consists of capacitor **92** and light dependent resistor arm **94** connected in series from the emitter of transistors **54** to grounded bus **68**. Filters **28** and **30** are coupled to the bases of transistors **54** and **56** respectively by capacitors **90** and **96**.

There is a switch having two ganged movable contacts **156** and **158** in filters **28** and **30** respectively. When movable contacts **156** and **158** are in the upper position as shown, the high-pass vibrato filters **28** and **30** are in circuit with the inverting amplifiers **31** and **32** and may be varied by cyclically illuminating resistance arms **88** and **94** to produce vibrato in the output signals. When movable contacts **156** and **158** are in their lower positions, filter **30** is disconnected from amplifier **32**, so filter **30** and amplifier **32** have no effect on the signals passing through circuit **150**. Resistor **155** remains in circuit with capacitor **92** and serves to hold that capacitor at the same potential so that there will be no clicking noise in the sound from the system (FIG. 1) when contact **158** is switched back to the upper position. Resistors **157** and **161** likewise hold capacitors **86** and **160** at a given potential to prevent clicking when contact **156** is switched.

With movable contact **156** in its lower position filter **28** produces no phase shift because of the large value of resistor **157** in series with capacitor **86**. Resistor **162** is connected in series with light dependent resistor arm **88** forming a resistive voltage divider which is varied by cyclically illuminating resistance arm **88**. Capacitor **160** couples the emitter of transistor **52** to resistor **162** and has a sufficiently large value that there is no phase shift in this signal path. Thus, the signals passing through the circuit are varied only in amplitude producing a tremolo effect in the output. Note that in this case, only two signals are combined in the summing network formed by resistors **98**, **100** and **102** together with transistor **168** and its emitter resistors **172** and **174**. The first signal is the amplified input signal supplied through resistor **98**, and the second signal is a further amplified version of the input signal supplied through resistor **100**. These signals are out-of-phase and the sum varies in amplitude at a rate determined by the control device **181**.

The remainder of circuit **150** is similar to circuit **40** of FIG. 3, but some of the interconnections differ slightly. The input terminal **24** is connected to the base of transistor **52** which in this embodiment is connected as an emitter follower, the emitter resistor **151** being connected to grounded bus **68** and the collector of transistor **52** being connected directly to the positive power supply bus **66**. Resistor **152** connected from the base of transistor **52** to positive bus **66** biases the base positively, and capacitor **153** connected to the base of transistor **52** together with capacitor **180** connected to the collector of transistor **168** limit the high frequency response of circuit **150** to four kilocycles. The latter capacitors are not essential, but since there are no signal frequencies above four kilocycles except noise, they are useful for minimizing noise in the output. Resistor **154** simply drops the supply voltage appearing at terminal **186** to an appropriate level.

Transistor **54** has split-load resistors **70** and **72** as in FIG. 3 and a base bias resistor **159**. Transistor **56** is connected as an emitter follower and has an emitter resistor **175** and a base biasing resistor **177**. Transistor **168** has resistors **172** and **174** in its emitter path and resistor **170** in its collector path, and its base is connected to the three summing resistors **98**, **100** and **102**. Capacitor **176** bypasses resistor **174** for audio frequencies. Capacitor **178** decouples the collector of transistor **56** from power supply bus **66** for audio frequencies to keep audio signals out of the power supply. Output signals are supplied to terminal **26** through coupling capacitor **179** connected to the collector of transistor **168**.

The control device **181** for the embodiment of FIG. 4 is of a type which provides a sawtooth wave for energizing the lamp **108**. Control device **181** includes a positive power supplying bus **182** connected through resistor **184** to the power supply terminal **186**. Supply bus **188** is grounded. The operating voltage is regulated by a Zener diode **190** connected between busses **182** and **188**. The control device is turned off by closing a switch **192** to connect the base of transistor **194** to ground potential.

Transistors **194** and **196** are interconnected so as to form a multivibrator circuit which is free-running when switch **192** is open. The collector of transistor **196** is cross-coupled to the base of transistor **194** by capacitor **198** and the collector of transistor **194** is cross-coupled to the base of transistor **196** by capacitor **200**. Resistors **202** and **204** are connected respectively from the collectors of transistors **194** and **196** to the positive bus **182** and provide load resistors for the transistors. Resistor **206** connected from the base of transistor **194** to bus **182** polarizes the base of the transistor positively, and series resistors **208** and **210** connected from the base of transistor **196** to bus **182** polarizes the base of the latter transistor positively.

Transistors **194** and **196** alternate between on and off conditions providing a substantially sawtooth voltage at the base of transistor **196**. The latter voltage is modified by capacitor **217** and resistors **212** and **214** to provide a sawtooth driving voltage at the base of transistor **216**. The emitter portion of the latter transistor clamps the base of the output transistor **218** at a positive potential which provides a threshold voltage. Specifically, transistor **218** does not respond until the sawtooth wave applied to transistor **216** rises above the threshold voltage. This threshold, then, determines the minimum light level produced by lamp **108**.

Operating potentials for transistor **218** are furnished by resistors **220**, **222**, **224**, **226** and **228**. Resistor **210** connected to transistor **196** may be varied to control the repetition rate of device **181**. This in turn controls the rate of vibrato or tremolo. Resistor **220** may be varied to control the depth of vibrato or tremolo.

The reason for energizing lamp **108** with a sawtooth wave is to allow for a difference between the rise time and fall time of the lamp. The lamp lights up to its maximum brightness at a rate determined by the leading edge of the sawtooth wave, but the rate at which it dims is independent of the trailing edge of the wave. In FIG. 7, the sawtooth waveform **230** represents the energizing signal for lamp **108**, and the more nearly sinusoidal waveform **232** represents the illumination of the lamp which in turn corresponds to the resistance variation of the light dependent resistor arms **88** and **94**. Thus, by using a sawtooth drive for the lamp, it is possible to obtain a fair approximation to a sinusoidal variation of the light dependent resistor which produces a desirable vibrato effect in the output signals from the vibrato circuit.

The following values and type identification for the

components used in the circuit of FIG. 4 are given by way of example only and are not to be construed as a limitation on the scope of the invention:

All transistors	2N2926.
Resistors:	
152, 155, 157, 159, 161, 177	220 kilohms.
70, 72. 151, 175	390 ohms.
162	10 kilohms.
88 and 94	Dual L.D.R. (Clairex).
98	16 kilohms.
100, 102	3.9 kilohms.
172	68 ohms.
170	1.8 kilohms.
174	3.3 kilohms.
206	220 kilohms.
202, 204	10 kilohms.
208	100 kilohms.
212	430 kilohms.
214	560 kilohms.
222	4.7 kilohms.
224	10 kilohms.
226	47 ohms.
184	390 ohms.
154	1 kilohm.
Capacitors:	
198, 200, 217	1.0 microfarad.
153	.001 microfarad.
86, 92, 179	.22 microfarad.
160	10 microfarads.
90, 96	.1 microfarad.
180	.02 microfarad.
176	20 microfarads, 50 v.
178	100 microfarads, 25 v.
Diode **190**	1 watt Zener, 12 v.
B-plus voltage	39±5 v.

FIGS. 8 and 9 illustrate graphically the relationship between phase angle and frequency produced by the circuits of FIGS. 3 and 4 when operating in the pure vibrato mode. In FIG. 8, frequency is plotted against phase angle and in FIG. 9, log frequency is plotted against phase angle. The formula corresponding to these curves is:

$$\phi=4\tan^{-1}\omega RC$$

From the formula it is apparent that by varying either R or C, it is possible to vary the phase angle of a signal passing through the network. The effect of the resistance or capacitance variation is to shift the curves as shown by the dashed lines in FIGS. 8 and 9. The amount of vibrato corresponds to the slope of the curve of FIG. 8 at any given frequency. From the curve, it is evident that vibrato is a maximum at lower frequencies and decreases with increasing frequency. The decrease is fairly gradual, however, and there is sufficient vibrato at relatively high frequencies to produce a proper vibrato effect.

The all-pass characteristics of the circuits of FIGS. 3 and 4 may be explained mathematically as follows. The transfer function for an all-pass filter is given by the formula:

$$\frac{TS-1}{TS+1}$$

where

$$T=RC$$
$$S=J\omega$$

Where two stages are cascaded as in the circuits of FIGS. 3 and 4, the transfer function is given by:

$$\frac{(TS-1)^2}{(TS+1)^2}$$

The latter transfer function can be expanded to:

$$-\frac{4}{TS+1}+\frac{4}{(TS+1)^2} \text{ or } 1-\frac{4TS}{TS+1}+4\left(\frac{TS}{TS+1}\right)^2$$

Referring to FIG. 2, the first term of this formula determines the amount of the input signal fed to summing network **35**. The second term in the formula shows that a second signal, which is shifted in phase relative to the input signal, is summed with the input signal. The subtraction indicated by the minus sign is accomplished in FIG. 3 by the phase inversion from base to collector of transistor **54** and in FIG. 4 by taking the second signal to be summed from the collector of transistor **54** whereas the signal fed to transistor **56** is taken from the emitter of transistor **54**. The third term in the formula corresponds to the second filtering and amplifying stage. The summing ratio is determined by the numerators of the terms of the formula; i.e., 1, 4 and 4.

The invention provides an all-pass system capable of introducing vibrato into signals varying over a very wide range of frequencies without attenuating any frequency or with some constant attenuation of all frequencies. The system has a flat frequency response at least over the entire range of signal frequencies and can vary the phase of the signals in any amount up to 360°. Tremolo may be added to the vibrato if desired, or the system can be set by means of switches to produce pure tremolo. From FIGS. 3 and 4, it is apparent that by using a light dependent resistor as the variable element for introducing a dynamic phase shift, the control signals may be completely isolated from the filtering and amplifying circuit. If such control signals were allowed to pass to the output system of the musical instrument they would cause an objectionable rumbling sound, and filtering would be necessary to remove them from the output.

I claim:

1. A vibrato system for an electrical musical instrument comprising first and second phase-shifting stages each having an input and an output, means coupling the output of said first phase-shifting stage to said input of said second phase-shifting stage to interconnect said stages in cascade relation, a signal input coupled to said input of said first phase-shifting stage, each of said phase-shifting stages including a filter network having a variable impedance means therein, summing circuit means having an output and at least three inputs connected respectively to said signal input and to said outputs of said first and said second phase-shifting stages for combining signals supplied therefrom in a predetermined ratio to produce an output signal at said output of said summing network, and means for cyclically varying said variable impedance means in unison at a predetermined vibrato rate to thereby vary said output signal in frequency at said vibrato rate.

2. A vibrato system for an electrical musical instrument comprising first and second phase shifting stages each having an input and an output, means coupling the output of said first phase shifting stage to the input of said second phase shifting stage, a signal input coupled to the input of said first phase shifting stage, each of said phase shifting stages including variable impedance means for varying the phase angle of a signal in said stage, a summing network having an output and including impedances connected respectively to said signal input and to the outputs of said first and second phase shifting stages for combining signals supplied therefrom in the amplitude ratio of about one part of input signal to about four parts of each of the signals from said phase shifting stages to produce an output signal at the output of said summing network, and means for cyclically varying said variable impedance means at a predetermined vibrato rate to thereby modulate said output signal in frequency at said vibrato rate without introducing substantial amplitude modulation therein.

3. A vibrato system for an electrical musical instrument comprising first and second phase shifting stages each having an input and an output, means coupling the output of said first phase shifting stage to the input of said second phase shifting stage and interconnecting said stages in cascade relation, a signal input coupled to the input of

said first phase shifting stage, each of said phase shifting stages including a filter network and an amplifier serially connected between the input and output of said stage, said filter networks each having variable impedance means therein, a summing network having an output and including impedances connected respectively to said signal input and to the outputs of said first and second phase shifting stages for combining signals supplied therefrom in a predetermined ratio to produce an output signal at the output of said summing network, and means for cyclically varying said variable impedance means in unison at a predetermined vibrato rate to thereby vary said output signal in frequency at said vibrato rate.

4. The vibrato system of claim **3** in which said variable impedance means comprises a light dependent resistor, and said varying means comprises a lamp for illuminating said light dependent resistor and control circuit means for cyclically varying the intensity of light from said lamp.

5. The vibrato system of claim **4** in which said light dependent resistor has a first resistance arm in the filter network of said first phase shifting stage and has a second resistance arm in the filter network of said second phase shifting stage.

6. The vibrato system of claim **5** in which said filter networks are of the resistance-capacitance type.

7. The vibrato system of claim **3** in which said control circuit means includes a multivibrator circuit, and means coupled to said lamp and to said multivibrator circuit and energized by said multivibrator circuit to drive said lamp with a sawtooth wave to light and dim said lamp at substantially the same rate.

8. The vibrato system of claim **3** further including switching means for disconnecting said filter networks and for connecting at least one of said variable impedance means in circuit between the input and output of the respective phase shifting stage, thereby converting said vibrato system into a tremolo system.

9. The vibrato system of claim **3** in which at least one of the impedances of said summing network is variable to change said summing ratio and thereby produce tremolo as well as vibrato in the output signal.

10. A vibrato system for an electrical musical instrument having a source of audio frequency signals comprising first and second variable phase-shifting stages each having an input and an output, a signal input adapted for connection to said source of audio frequency signals and being coupled to said input of said first phase-shifting stage, first circuit means coupling said output of said first phase-shifting stage to said input of said second phase-shifting stage, summing circuit means having an output and at least first, second and third inputs and adapted to provide an output signal representing a predetermined summing ratio between signals applied to said first, second and third inputs, second circuit means coupling said signal input to a first input of said summing circuit means, third circuit means coupling said output of said first phase-shifting stage to a second input of said summing circuit means, and fourth circuit means coupling said output of said second phase-shifting stage to a third input of said summing circuit means, said summing circuit means having its predetermined summing ratio correlated to the amplitudes of signals at said first, second and third inputs such that said output signal represents substantially one part of said audio frequency signal to four parts of said audio signal as modified by said first phase-shifting stage and four parts of said audio signal as further modified by said second phase-shifting stage, and control means for varying said phase-shifting stages substantially in unison to produce a dynamic phase shift in said stages and thereby frequency modulate said output signal.

11. The vibrato system set forth in claim **10** wherein each of said phase-shifting stages comprises phase inversion circuit means and a variable filter network having a variable impedance means therein and wherein said control means is operatively coupled to each of said variable impedance means in said first and said second phase-shifting stages to vary said impedance means in each stage substantially in unison.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,413,403 November 26, 1968

Keith D. Jacob

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

Column 2, line 31, "These" should read -- There --. Column 7, lines 72 to 74, at the beginning of the formula and before the minus sign insert the numeral -- 1 --. Column 9, line 27, the claim reference numeral "3" should read -- 4 --.

Signed and sealed this 17th day of March 1970.

(SEAL)
Attest:

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