United States Patent [19]

Sharp

[11] **3,920,905**

[45] **Nov. 18, 1975**

[54] **PRODUCTION OF NON-FREQUENCY PROPORTIONAL VIBRATO**

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[73] Assignee: **CBS Inc.,** New York, N.Y.

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[21] Appl. No.: **441,031**

[52] **U.S. Cl.** ..... **179/1 J;** 84/1.24

[51] **Int. Cl.²** **G10H 1/04**

[58] **Field of Search** ..... 179/1 J; 84/1.25

[56] **References Cited**

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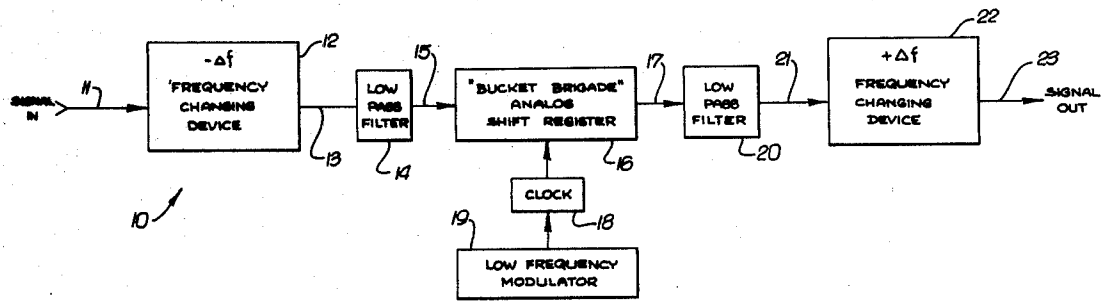
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Primary Examiner—William C. Cooper
Assistant Examiner—E. S. Kemeny
Attorney, Agent, or Firm—Flam & Flam

[57] **ABSTRACT**

Non-frequency proportional vibrato and like effects are achieved by cooperation of a device such as a modulated analog shift register that by itself produces frequency proportional modulation and other components which dynamically shift the frequency or phase of the processed signal. In one embodiment, the input signal is offset downward in frequency by $-\Delta f$, processed by a modulated bucket brigade device, and subsequently shifted back in frequency by an amount $+\Delta f$. In another embodiment, the signal is passed serially through a dynamic phase shifter and a modulated bucket brigade delay line. By driving the phase shifter and the delay line synchronously, the separately introduced modulation effects may be partially cancelled. The output signal from each embodiment exhibits vibrato or like modulation having non-frequency proportional percentage frequency deviation characteristics.

5 Claims, 8 Drawing Figures



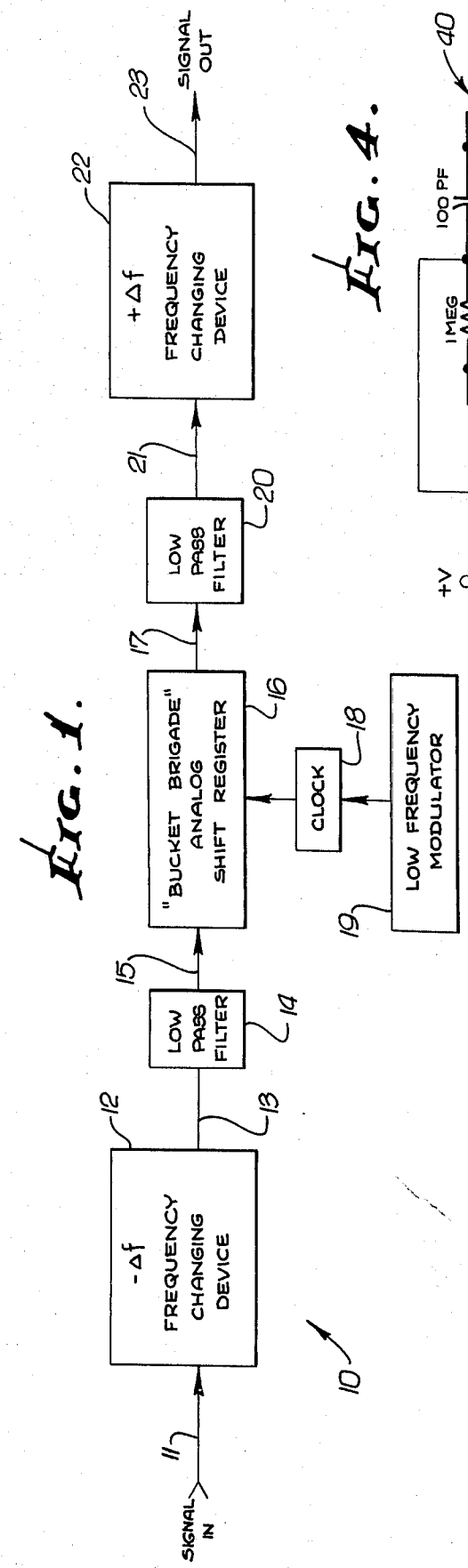


FIG. 1.

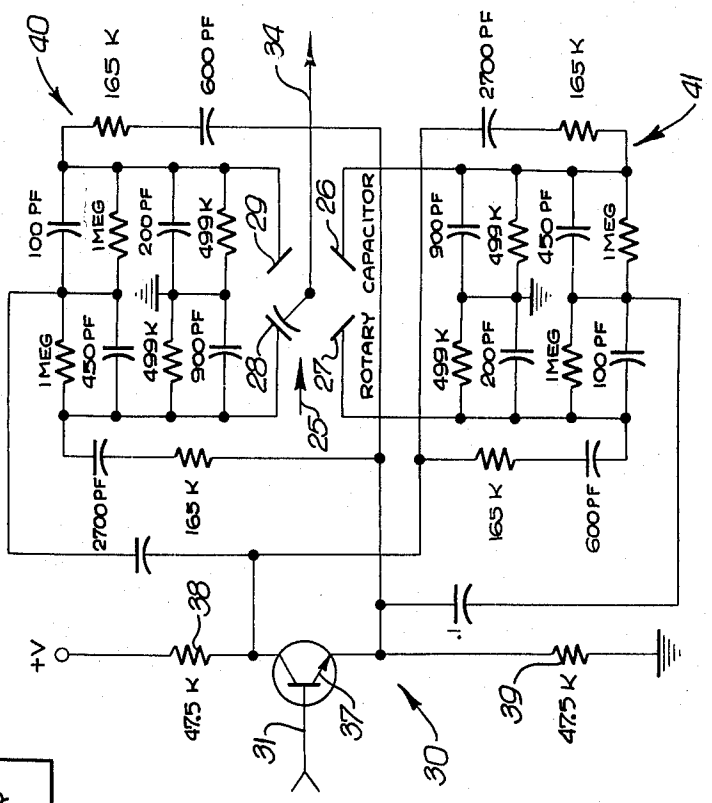


FIG. 4.

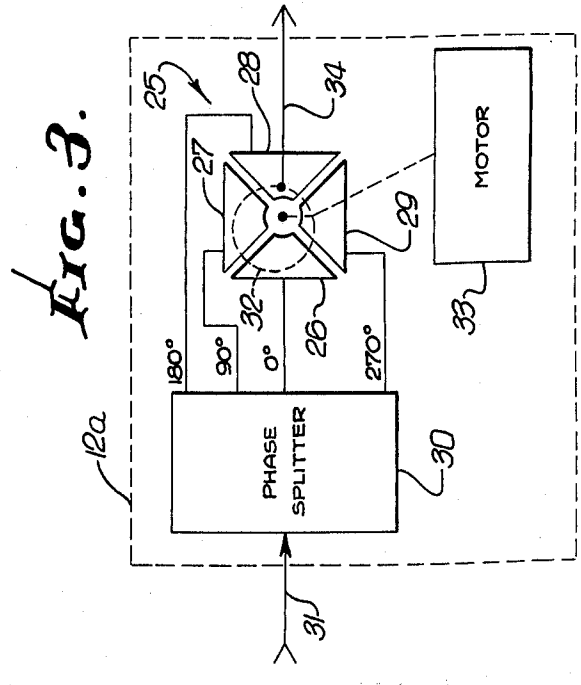


FIG. 3.

FIG. 2.

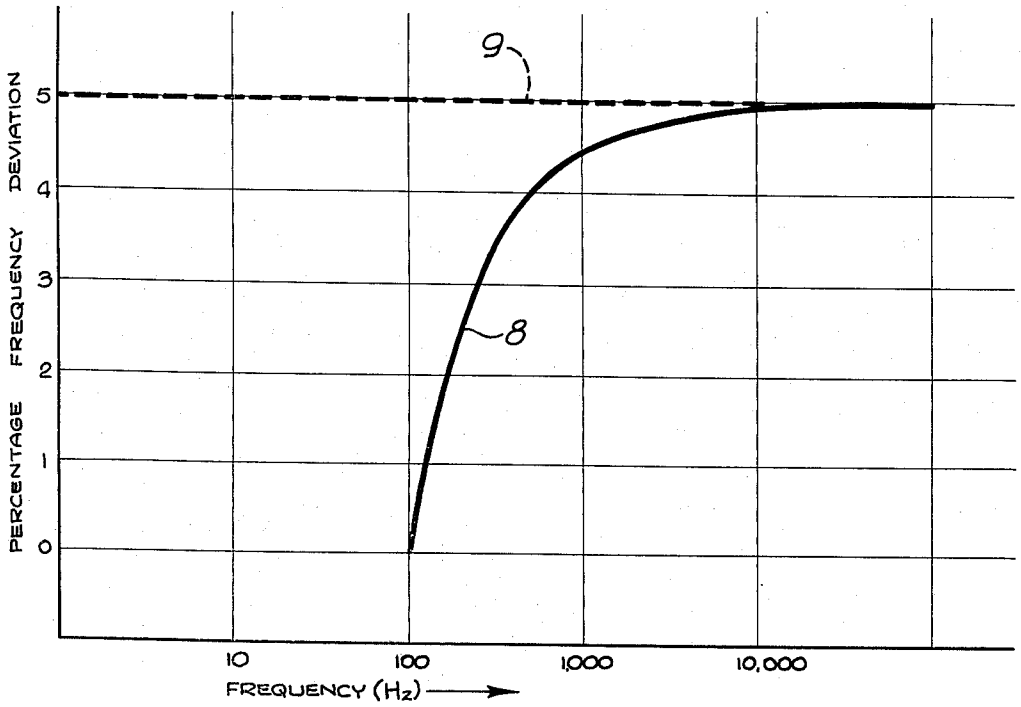
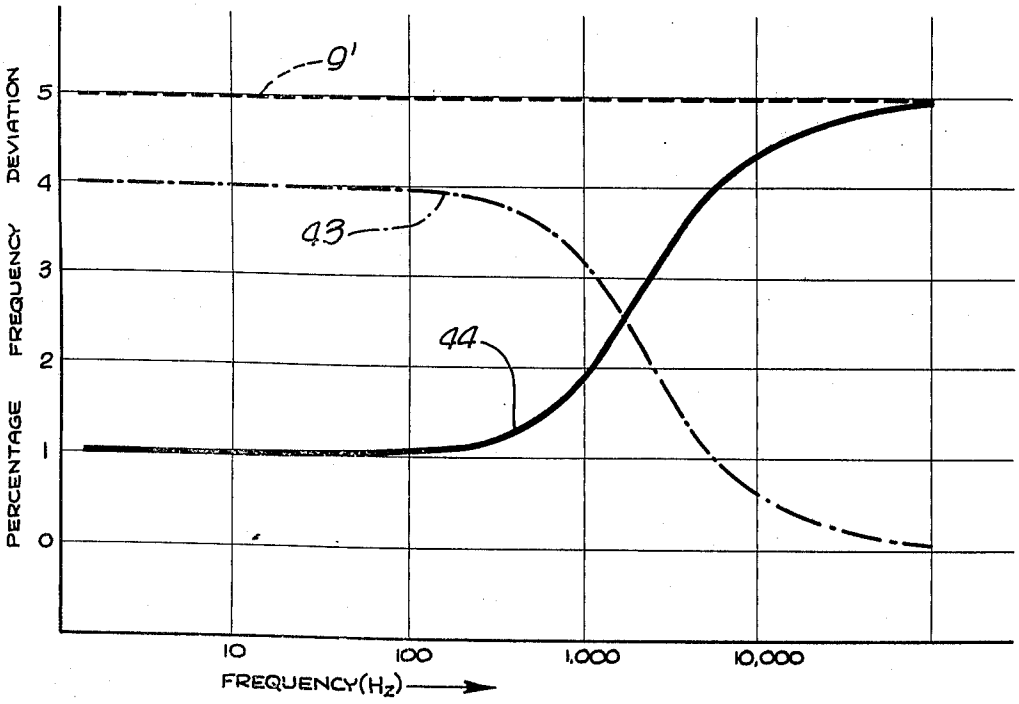

9
8
PERCENTAGE FREQUENCY DEVIATION
5
4
3
2
1
0
10
100
1,000
10,000
FREQUENCY (Hz)

FIG. 6.


9'
43
44
PERCENTAGE FREQUENCY DEVIATION
5
4
3
2
1
0
10
100
1,000
10,000
FREQUENCY(Hz)

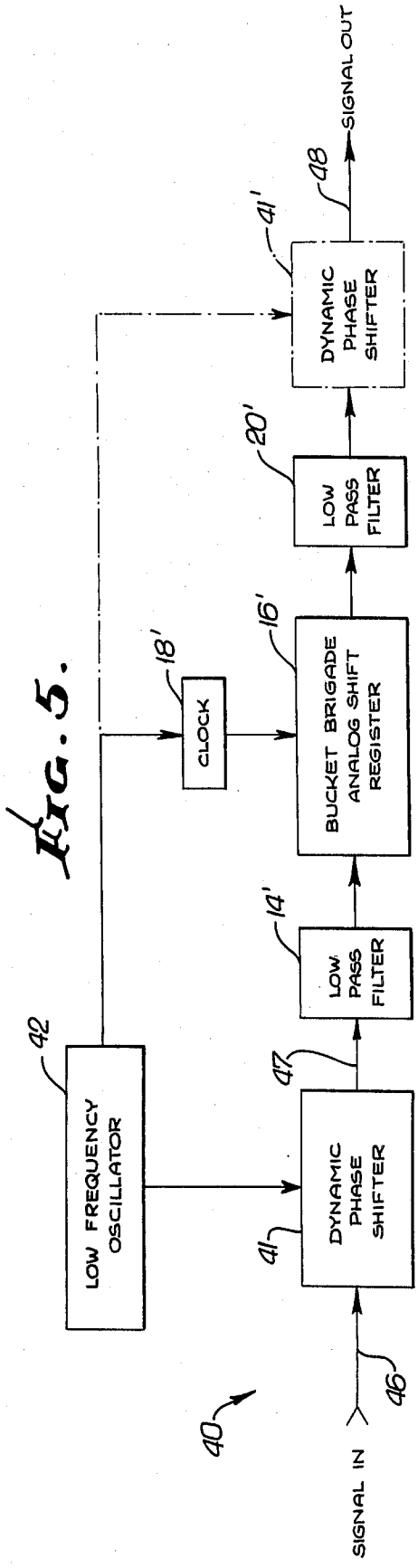


FIG. 5.

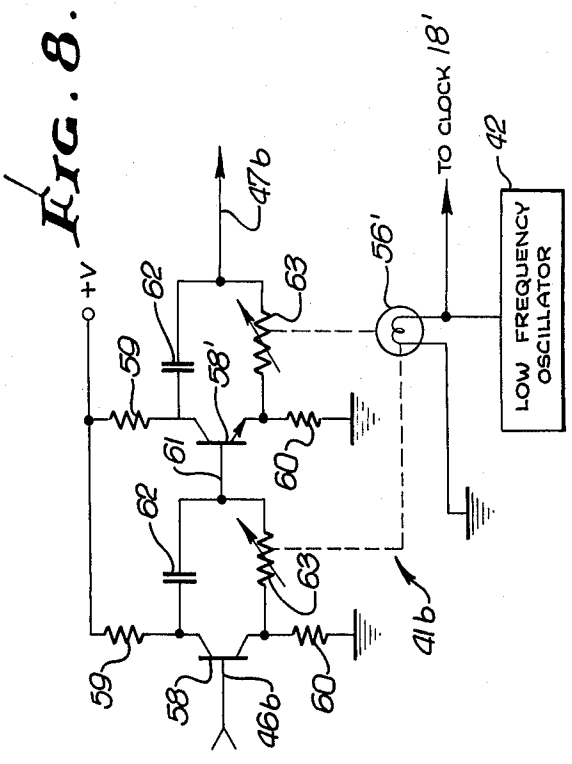


FIG. 8.

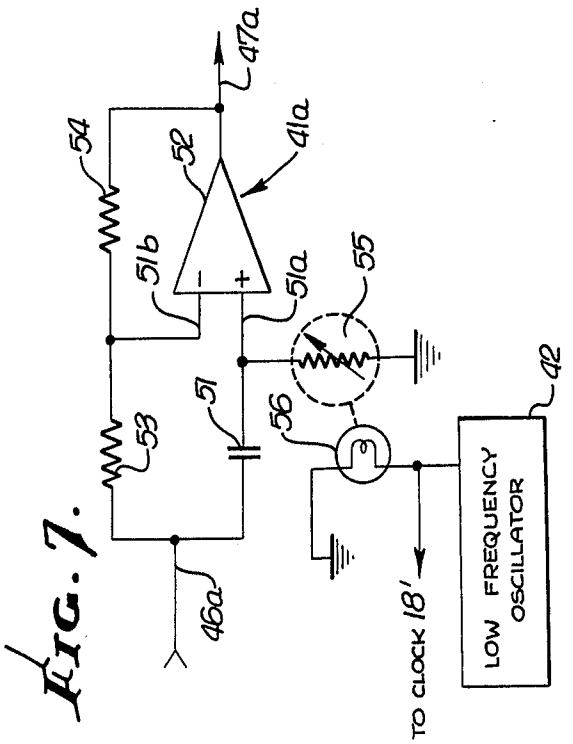


FIG. 7.

PRODUCTION OF NON-FREQUENCY PROPORTIONAL VIBRATO

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the electronic production of non-frequency-proportional vibrato.

2. Description of the Prior Art

Most musical sounds are enhanced by the addition of low frequency modulation. Numerous techniques have been devised to introduce such vibrato and tremolo effects in electronic musical instruments. Well known among these is the use of a rotating speaker or acoustical channel shown e.g., in the U.S. Pat. No. Re. 23,323 to Leslie.

The recent availability of integrated circuit analog shift registers of the "bucket brigade" type provides another tool for implementing vibrato. As taught in the recent U.S. Pat. No. 3,749,837 to Doughty, such effects can be achieved by passing the musical signal through a shift register in which the shifting rate is varied at a low frequency. The resultant periodic compression and expansion of the wave passing through the shift register results in frequency modulation of the delayed signal.

The vibrato modulation so produced is directly proportional to frequency. Thus if the shifting rate of the bucket brigade delay line is varied so as to introduce a modulation of ±2Hz for a tone of 100Hz, when a 200Hz signal is passed through the shift register, a modulation of ±4Hz will be introduced. For a signal of 1000Hz, the modulation will be ±20Hz. In other words, the vibrato frequency deviation is a constant percentage of the signal frequency.

Another known system for producing frequency proportional vibrato is disclosed in the U.S. Pat. No. 3,518,354 to Lubow. Here the input signal simultaneously is recorded on opposite sides of an electrostatic storage drum that is rotated at a rate which varies above and below an average rate during each revolution. The signal is recovered from the drum by a read electrode situated between the record electrodes. The recovered signal is frequency modulated above and below the input signal frequency as a result of the varying drum rotation rate.

In practice, only a few conventional musical instruments, typically the violin and the steel guitar, exhibit frequency proportional vibrato. In most instruments, the vibrato is not proportional to frequency. Thus in certain organ pipes there is little or no vibrator at the pedal frequencies, a mild vibrato in the mid-range, and considerable frequency deviation or "warble" at the highest notes.

A principal object of the present invention is to implement non-frequency proportional vibrator electronically. A further object is to achieve such non-frequency proportional vibrato through the cooperation of (a) a first device that by itself produces frequency proportional modulation, and (b) other components which dynamically shift the frequency or phase of the signal processed by the first device.

SUMMARY OF THE INVENTION

In one embodiment these objectives are achieved by utilizing a low frequency modulated analog shift register in conjunction with circuits that dynamically shift the frequency of the signal processed through the shift register. The input signal is shifted downward in frequency by a constant amount $-\Delta f$ prior to introduction of frequency-proportional vibrator in the modulated bucket brigade device. Subsequently the signal is shifted back in frequency by an amount $+\Delta f$. The product is a vibrator having a small percentage frequency deviation at low frequencies, gradually increasing to a frequency deviation which at high frequencies asymptotically approaches that of the modulated shift register.

In another embodiment, a dynamic phase shifter is used to introduce a low frequency modulation having generally non-linear percentage frequency deviation characteristics. The signal also is modulated by passage through the bucket brigade delay line, either before or after processing by the dynamic phase shifter. By driving the phase shifter and the modulated delay line synchronously, as from the same low frequency oscillator, a partial cancellation or subtraction may occur. The resultant signal exhibits a vibrator which typically has a small percentage frequency deviation at low frequencies, and rises along an S-shaped frequency deviation curve with increasing frequency. Appropriate selection of the phase shifter characteristics permits tailoring of the resultant vibrato characteristics.

In alternative embodiments, the modulated shift register may be replaced by some other device, such as a mechanical recording medium that is driven at a varying rate, which by itself produces frequency proportional vibrato.

BRIEF DESCRIPTION OF THE DRAWINGS

A detailed description of the invention will be made with reference to the accompanying drawings wherein like numerals designate corresponding elements in the several figures.

FIG. 1 is an electrical block diagram of an embodiment of the invention in which the signal is shifted in frequency before and after processing through an analog shift register.

FIG. 2 is a graph showing typical percentage frequency deviation characteristics of the vibrator obtained using the circuit of FIG. 1.

FIG. 3 is an electrical block diagram of a frequency changing device useful in the circuit of FIG. 1.

FIG. 4 is an electrical schematic diagram of a phase splitter useful with the circuit of FIG. 3.

FIG. 5 is an electrical block diagram of another embodiment of the present invention utilizing synchronously modulated phase shifter and bucket brigade devices.

FIG. 6 is a graph showing typical percentage frequency deviation characteristics of vibrato obtained using the circuit of FIG. 5.

FIG. 7 is an electrical schematic diagram of a dynamic phase shifter applicable in the circuit of FIG. 5.

FIG. 8 is an electrical schematic diagram of a cascaded phase shifter also useful in the circuit of FIG. 5.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following detailed description is of the best presently contemplated modes of carrying out the invention. This description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention since the scope of the invention best is defined by the appended claims.

Structural and operational characteristics attributed to forms of the invention first described also shall be attributed to forms later described, unless such characteristics obviously are inapplicable or unless specific exception is made.

In the embodiment of FIG. **1**, non-frequency proportional vibrato and like effects are achieved by shifting the input signal by a constant amount $-\Delta f$, processing the resultant signal through a low frequency modulated analog shift register, and frequency shifting the output signal by a corresponding amount $+\Delta f$. As illustrated by the typical curve **8** of FIG. **2**, the resultant output signal will exhibit a vibrato effect which is proportionately less at lower input signal frequencies and greater at higher frequencies, in contrast with the constant percentage frequency deviation vibrator (see curve **9** of FIG. **2**) obtained using only the modulated bucket brigade delay line.

In the circuit **10** of FIG. **1**, an input audio frequency signal is supplied via line **11** to a frequency changing device **12** which shifts the input signal downward in frequency by an amount $-\Delta f$. Preferably the shift $-\Delta f$ is constant over the entire input signal frequency range. For example, the device **12** may shift the frequency downward by Δf=100 Hz. In such instance, an input signal of 300 Hz on the line **11** will result in an output of 200 Hz on a line **13** from the device **12.** An input signal of 4000 Hz will be decreased in frequency to 3900 Hz by the device **12.**

The signal on the line **13** is supplied via a low pass filter **14** and a line **15** to a low frequency modulated analog shift register **16.** This bucket brigade device periodically samples the amplitude of the input signal on the line **15** and shifts this amplitude value from stage to stage to the register output line **17.** The shift rate, and hence the delay time through the register **16** is established by a clock **18.** The clock **18** is modulated at a low frequency by a modulator **19.** Thus the clock **18** and the modulator **19** cooperate to vary the effective delay time through the bucket brigade **16** at a low frequency, vibrato or chorus rate.

The signal on the line **17** is supplied via another low pass filter **20** and a line **21** to a second frequency changing device **22.** Here the signal is shifted upward in frequency by an amount $+\Delta f$. The resultant output signal is supplied via a line **23.** The following Table I illustrates operation of the circuit **10** for a value $\Delta f = 100$ Hz, and with the clock **18** and modulator **19** selected so that the bucket brigade device **16** by itself introduces a 2 percent frequency modulation of a signal supplied to that device.

TABLE I

FREQUENCY OF INPUT SIGNAL	FREQUENCY OF OUTPUT SIGNAL	
	USING ONLY "BUCKET BRIGADE"	"BUCKET BRIGADE" WITH FREQUENCY SHIFTED INPUT AND OUTPUT
100 Hz	100 Hz ±2 Hz	100 Hz ±0 Hz
200	200 ±4	200 Hz ±2 Hz
400	400 ±8	400 ±6
1,000	1,000 ±20	1,000 ±18
2,000	2,000 ±40	2,000 ±38
4,000	4,000 ±80	4,000 ±78

The middle column of Table I indicates the type of frequency proportional vibrato which is achieved using only a modulated shift register, such as disclosed in the above mentioned U.S. Pat. No. 3,749,837 to Doughty. An input signal of 100 Hz will have a modulation of ±2 Hz, while a signal at 2000 Hz will have a modulation of ±40 Hz. In contrast, using the inventive system of FIG. **1** a non-frequency proportional vibrato is obtained. Thus with the typical values given above, an input signal on the line **11** of 100 Hz will have no frequency deviation introduced. An input at 200 Hz will result in a signal output on the line **23** of 200 Hz ±2 Hz. This modulation is one percent of the input frequency, which is half of the percentage frequency deviation that would be introduced using only the bucket brigade device **16.** An input signal of 2000 Hz is modulated by ± 38 Hz which approaches two percent modulation. It is readily apparent that different non-frequency proportional effects can be achieved using the circuit of FIG. **1** with different values of Δf and/or different effective modulation frequencies through the bucket brigade device **16.**

The analog shift register **16** advantageously, but not necessarily, may be implemented using a conventional integrated circuit bucket brigade delay line such as the ITT Intermetall type TCA 350 or the Amperex type M31 device. The operation of such bucket brigade delay lines is described, e.g., in the article entitled "Bucket-brigade Electronics— New Possibilities for Delay, Time-Axis Conversion, and Scanning" by Sangster and Teer, *Journal of Solid-State Circuits*, Volume SC–4, No. 3, June 1969 and in the article "Bucket Brigade Devices Pass from Principle to Prototype" in the Feb. 28, 1972 issue of *Electronics* magazine. The low pass filter **14** is used to insure that the signal supplied to the bucket brigade device **16** contains no components at or near the shift frequency of that device. Thus typically the filter **14** will pass signals in the audio range of up to say 20,000 Hz but will attenuate frequency components above that range. The low pass filter **20** is used to eliminate from the output signal any components which might be introduced by the device **16** at the bucket brigade shift frequency.

Each frequency changing device **12** and **22** may be of the type disclosed in the U.S. Pat. Nos. 3,251,924 or 3,372,225 to Donald J. Leslie. Such a frequency changing device **12***a* is shown in FIGS. **3** and **4**, and utilizes a rotary capacitor **25** having four equiangularly arrayed stationary plates **26, 27, 28** and **29** driven respectively by signals differing in phase by 0°, 90°, 180° and 270° with respect to each other. These signals are supplied by a phase splitter **30** (FIG. **4**) receiving an input via a line **31.** The capacitor **25** also includes a rotor plate **32** eccentrically mounted with respect to the center of the plates **26** through **29.** A motor **33** rotates the plate **32** at a constant rate.

The output from the capacitor **25,** present on a line **34** from the rotor plate **32,** will differ in frequency from the input signal on the line **31** by an amount established by the rate and direction of rotation of the plate **32.** If the plate **32** is rotated counterclockwise as viewed in FIG. **3,** a negative frequency shift is obtained, as preferred for the changing device **12.** Clockwise rotation of the plate **32** results in a positive frequency shift, as preferred for the changing device **22.** The rate of rotation establishes the amount of frequency change. Thus when the motor **33** rotates the plate **32** at 100 revolutions per second, a frequency shift Δf of 100 Hz results.

FIG. **4** shows a phase splitter **30** which may be used in the frequency changing device **12***a* of FIG. **3.** In this circuit, the input signal on the line **31** is directed to the base of a transistor **37** the collector of which is con-

nected to a positive voltage source via a resistor **38** and the emitter of which is connected to ground via a resistor **39.** Driven by the emitter and collector of the transistor **37** is a symmetric pair of capacitor-resistor networks **40, 41** which provide the appropriately phased signals at the capacitor plates **26** through **29.**

Frequency changing devices other than that shown in FIGS. **3** and **4** may be used in the circuit **10** of FIG. **1.** For example, a single sideband modulation-demodulation system could be used. The input signal is used to modulate a carrier at a certain frequency. The modulated carrier is passed through a single sideband filter and then demodulated. By utilizing a demodulation carrier frequency separated by Δf from that of the modulation carrier, the resultant signal will be shifted in frequency by a like amount Δf with respect to the original audio input.

In the illustrated circuit **10** (FIG. **1**) the input frequency changing device **12** introduces a negative frequency shift $-\Delta f$ and the output device **22** introduces a positive frequency shift $+\Delta f$. This arrangement generally is preferred since it results in a lower vibrato rate at the lower input frequencies and a greater vibrato effect at higher frequencies. However, for certain unusual vibrato effects it may be desirable to interchange these devices, so that an upward frequency shift is introduced prior to passage through the shift register **16,** with a compensating downward shift in frequency being introduced into the output signal. Unusual chorus effects may be achieved by using different values of Δf in the two frequency changing devices **12** and **22.**

In the embodiment **40** of FIG. **5,** non-frequency proportional vibrato effects are obtained by using a dynamic phase shifter **41** in conjunction with a modulated bucket brigade device **16'.** A common low frequency oscillator **42** is used synchronously to modulate both the shift register clock **18'** and the phase shifter **41** in opposite senses. With this arrangement, phase shift vibrato modulation introduced by the phase shifter **41** (see the typical curve **43** of FIG. **6**) subtractively cancels out some of the constant frequency deviation vibrato (see curve **9'** of FIG. **6**) produced by the bucket brigade device itself. The resultant vibrato modulation (curve **44** of FIG. **6**) exhibits non-linear percentage frequency deviation characteristics that cannot be obtained using phase-shifters alone, and which can be tailored to desired values.

The input signal supplied on a line **46** (FIG. **5**) is dynamically shifted in phase by the device **41.** This causes frequency modulation of the input signal by an amount dependent on the rate of change of the phase shift. For example, a phase shift of +180° in one-twelfth of a second is equivalent to adding 6 Hz to the frequency of the input signal. In typical phase shift circuits the net phase shift is a non-linear function of frequency. Thus, if the circuit employs a resistance-reactance bridge, the phase shift may exhibit a characteristic S-curve, as shown, e.g., in the U.S. Pat. No. 3,146,292 to Bonham.

The phase shift modulated signal from the device **41** is supplied via a line **47** and a low pass filter **14'** to the analog shift register **16'.** As noted above, this bucket brigade delay line device **16'** is modulated synchronously with the phase shifter **41,** so that the frequency modulation introduced by the bucket brigade **16'** will partly cancel or "buck-out" the modulation produced by the phase shifter **41.** The resultant signal from the device **16'** is supplied via a low pass filter **20'** to the output line **48.** In an alternative configuration, the phase shifter **41** may be omitted and a like phase shifter **41'** (shown in phantom in FIG. **5**) placed in the output line **48.** Similar results are achieved.

The constant amplitude phase shifter circuit **41***a* shown in FIG. **7** and described on page **63** of the January, **1971** issue of *EEE Magazine,* is useful as the device **41** or **41'.** The circuit produces an output voltage on the line **47***a* equal in magnitude to the input voltage on the line **46***a* but shifted in phase. The input signal is supplied via a capacitor **51** to one input terminal **52***a* of an operational amplifier **52,** and via a resistor **53** to the other complementary input terminal **52***b* of the amplifier. A feedback resistor **54** connects the output line **47***a* to the amplifier input terminal **51***b.* For unity gain the resistors **53** and **54** are of equal value.

A variable resistor **55** is connectd between the amplifier input terminal **51***a* and ground. As the value of this resistor is varied from a very high value (open circuit) to a very low value (short circuit), the phase shift introduced by the circuit **41***a* varies concomitantly between 0° and 180°. A resistance variation over a smaller range will correspondingly reduce the range of phase shift variation.

The resistance value of the resistor **55** is varied at the low frequency rate established by the oscillator **42.** This may be accomplished in any conventional manner. Thus in the circuit of FIG. **7,** a light-sensitive resistor **55** is illuminated by the changing intensity of a lamp **56** driven by the oscillator **42.** The shape of the vibrato percentage frequency deviation curve **44** (FIG. **6**) can be altered by appropriate selection of the phase shift characteristics introduced by the dynamic phase shifter **41.** For example, the linear region **43'** of the curve **43** may be displaced upward in frequency by increasing the total effective phase shift introduced by the phase shifter **41.** This will cause a corresponding change in the frequency deviation versus frequency characteristics (curve **44**) of the circuit **40.**

Such tailoring of the vibrato characteristics can be achieved e.g., by employing cascaded phase shift networks as the phase shifter **41.** Such cascaded phase shift vibrato circuits are known per se, as described in the U.S. Pat. No. 3,418,418 to Wilder.

A useful cascaded phase shift network **41***b* is shown in FIG. **8.** Each stage consists of a transistor **58** receiving an input signal at its base. The transistor output signals across the collector and emitter resistors **59, 60** are of opposite phase. These are fed to a common terminal **61** respectively via a capacitor **62** and a variable resistor **63.** Variation of the resistance **63** causes a concomitant phase change at the output terminal **61.** The resistance change conveniently is achieved by using a light sensitive resistor illuminated by a lamp **56'** driven by the low frequency oscillator **42.** The output terminal **61** is connected to the base of the transistor **58'** associated with the next like, cascaded phase shift circuit. The net phase shift introduced to a signal between the input terminal **46***b* and the output terminal **47***b* will be the sum of the individual phase shifts introduced by each of the cascaded networks.

For producing vibrato effects, the frequency of the modulator **19** (FIG. **1**) or the oscillator **42** (FIG. **5**) preferably is in the range of from about 3 Hz to about 10 Hz. However, the invention is not so limited. Chorus-like effect are produced by using a lower frequency, which may be less than 1 Hz. Other unique effects are produced with frequencies above 10 Hz.

Although the systems of FIGS. 1 and 5 each utilize a bucket brigade analog shift register, the invention is not so restricted. This component may be replaced in either system with another device that by itself produces frequency proportional vibrato. For example, the present invention may be implemented by processing the input signal first through a frequency changing device 12 like that of FIG. 1, than through a variable speed storage disc of the type shown in U.S. Pat. No. 3,518,354, and finally through another frequency changing device 22 (FIG. 1). As another example, a dynamic phase shifter like that of FIG. 7 or 8 may be combined with a device which itself produces frequency proportional modulation, in a manner analogous to that shown herein in FIG. 5.

Other variations will be apparent to those skilled in the art. For example, in the circuit of FIG. 5, the relative phase of the drive signals to the bucket brigade device and the dynamic phase shifter may be altered to introduce different amounts of vibrato addition or subtraction as a function of frequency. Further, amplitude modulation effects easily may be imparted to the inventive system, as for example by making the resistors 53 and 54 in the dynamic phase shift circuit of FIG. 7 of different values.

Intending to claim all novel, useful and unobvious features shown or described, the applicant claims:

1. In apparatus for electronic superposition of vibrato upon electrical impulses having a spectrum extending throughout a substantial frequency range:

a. means forming an electrical input and and electrical output for said apparatus;

b. a first modulator for superimposing vibrato upon said electrical impulses with a depth of swing or frequency deviation substantially proportional to the frequency of the impulses;

c. a second modulator for superimposing vibrato upon said electrical impulses with a substantially constant frequency deviation;

d. means serially connecting said modulators between said electrical input and electrical output; and

e. common means for controlling said vibrato modulators in synchronism at a selected vibrato rate whereby the frequency swing of the superimposed vibrato of said modulators is algebraically additive controllably to change the characteristics of the vibrato spectrum from a linear frequency relationship.

2. The apparatus as set forth in claim 1 in which said modulators are connected in opposition whereby frequency shift is proportionately more greatly reduced at the lower spectrum.

3. The apparatus as set forth in claim 1 in which said first modulator is an analog shift register having a clocking means and in which said second modulator includes an impedance element that is dynamically changed, said common means being a low frequency oscillator in control both of said clocking means and said dynamically changed impedance.

4. The apparatus as set forth in claim 1 in which said first modulator is an analog shift register having a clocking means and in which said second modulator comprises a series of networks each including an impedance element dynamically changed, said common means being a low frequency oscillator in control both of said clocking means and all of the dynamically changed impedances of said networks.

5. In apparatus for electronic superposition of vibrato upon electrical impulses having a spectral range extending throughout a substantial frequency range:

a. a modulator for superimposing vibrato upon said electrical impulses with a depth of swing or frequency deviation substantially proportional to the frequency of the impulses;

b. a first device for superimposing a substantially constant frequency shift upon said electrical impulses;

c. a second device for superimposing a substantially constant frequency shift upon said electrical impulses;

d. the frequency deviations imposed by said devices being substantially equal and opposite; and,

e. means serially connecting the devices and modulator with the modulator interposed between the devices whereby the characteristics of the vibrato is not a direct linear function of frequency.

* * * * *