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Chase et al.

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[45] **Dec. 11, 1973**

[54] **ELECTRONIC MUSICAL INSTRUMENT WITH PHASE SHIFT TREMULANT SYSTEM**

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[73] Assignee: **Warwick Electronics Inc.**, Chicago, Ill.

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[52] **U.S. Cl.** **84/1.25**, 84/DIG. 1

[51] **Int. Cl.** **G10h 1/04**

[58] **Field of Search** .... 84/1.01, 1.18, 1.24, 84/1.25, DIG. 4, DIG. 1, DIG. 27; 331/106, 178, 66; 332/3, 16, 17, 21, 22, 23 R; 250/199, 217 R

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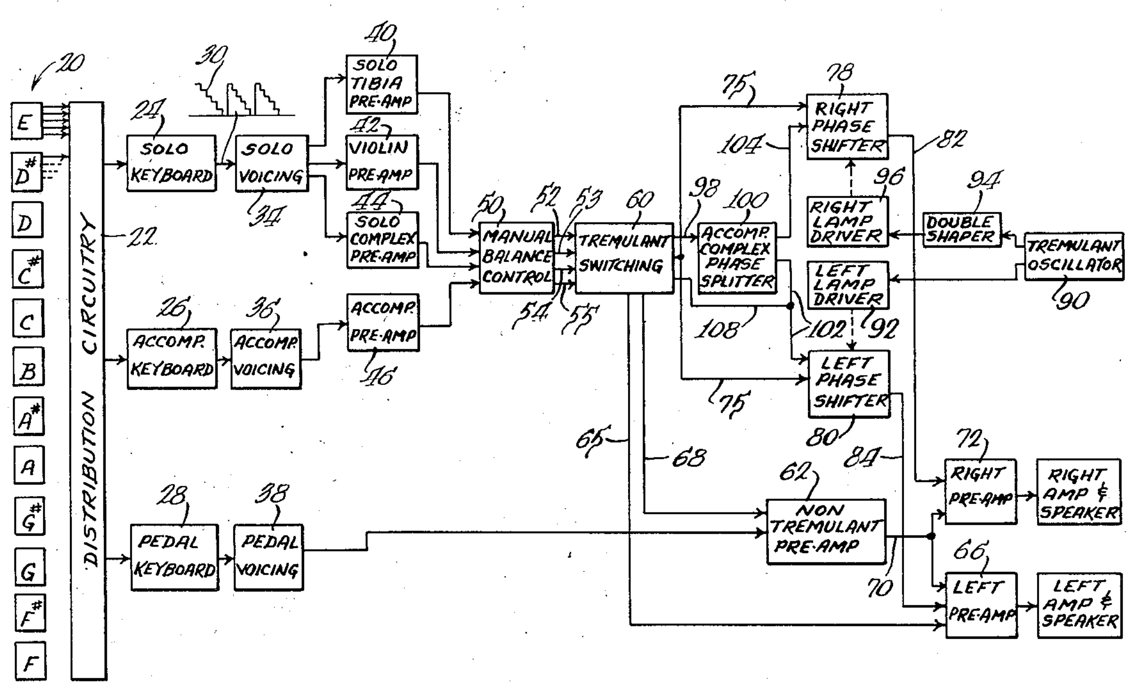
[57] **ABSTRACT**

A tremulant circuit includes cascaded phase shifting networks in right and left amplifying channels of an electronic organ. An oscillator and associated circuitry produce offset signals of different wave shape which energize lamps associated with light responsive impedances in the phase shifting networks in the right and left channels. A switching circuit interconnects the phase shifting networks in different configurations to adapt the tremulant effect to a selected organ voice in order to produce the most pleasing and realistic acoustical output.

16 Claims, 10 Drawing Figures



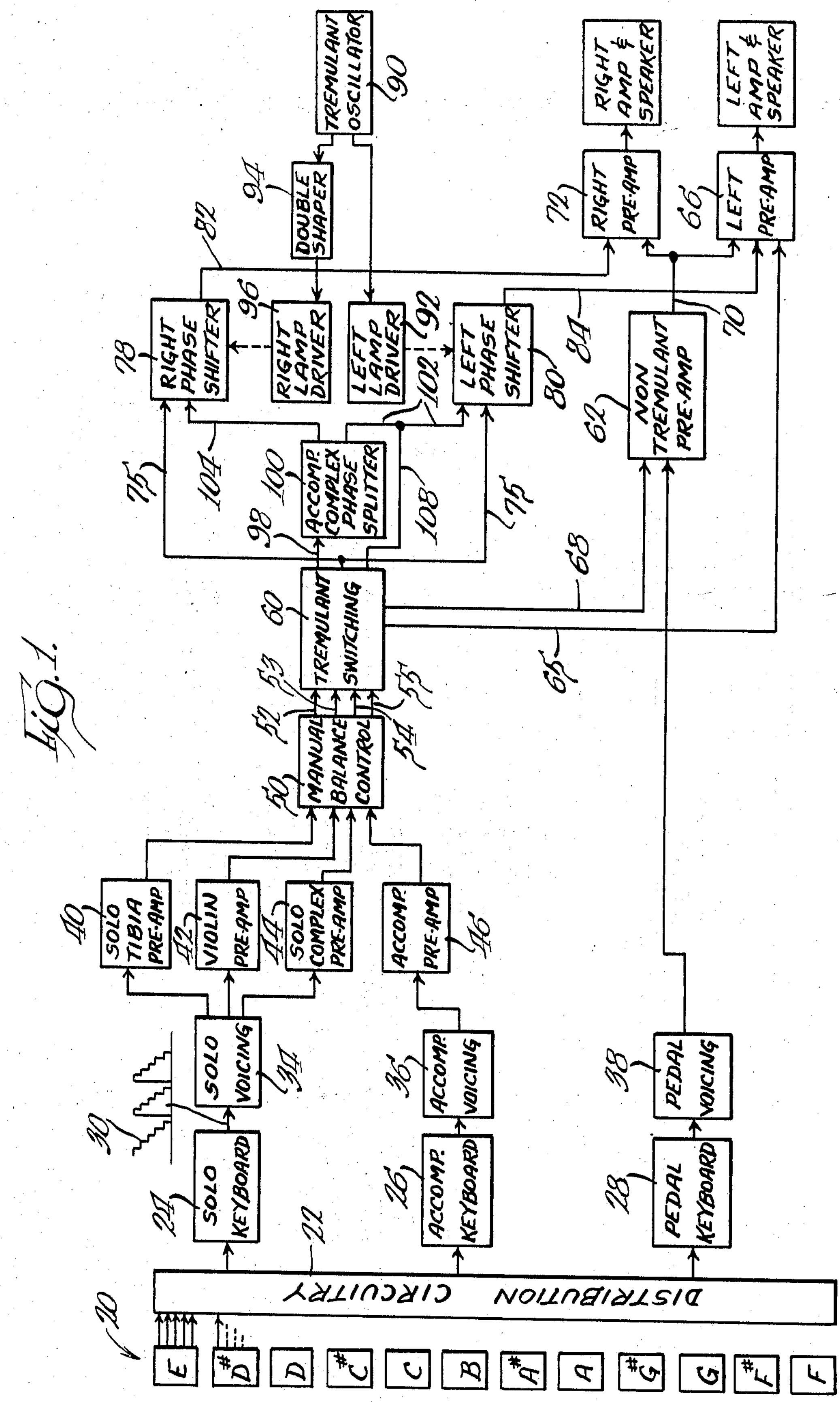

TREMULANT OSCILLATOR
RIGHT AMP & SPEAKER
LEFT AMP & SPEAKER
DOUBLE SHAPER
RIGHT PRE-AMP
LEFT PRE-AMP
RIGHT PHASE SHIFTER
RIGHT LAMP DRIVER
LEFT LAMP DRIVER
LEFT PHASE SHIFTER
NON TREMULANT PRE-AMP
ACCOMP. COMPLEX PHASE SPLITTER
TREMULANT SWITCHING
MANUAL BALANCE CONTROL
SOLO TIBIA PRE-AMP
VIOLIN PRE-AMP
SOLO COMPLEX PRE-AMP
ACCOMP. PRE-AMP
SOLO VOICING
ACCOMP. VOICING
PEDAL VOICING
SOLO KEYBOARD
ACCOMP. KEYBOARD
PEDAL KEYBOARD
DISTRIBUTION CIRCUITRY
E
#D
D
#C
C
B
#A
A
#G
G
#F
F

Fig. 1.

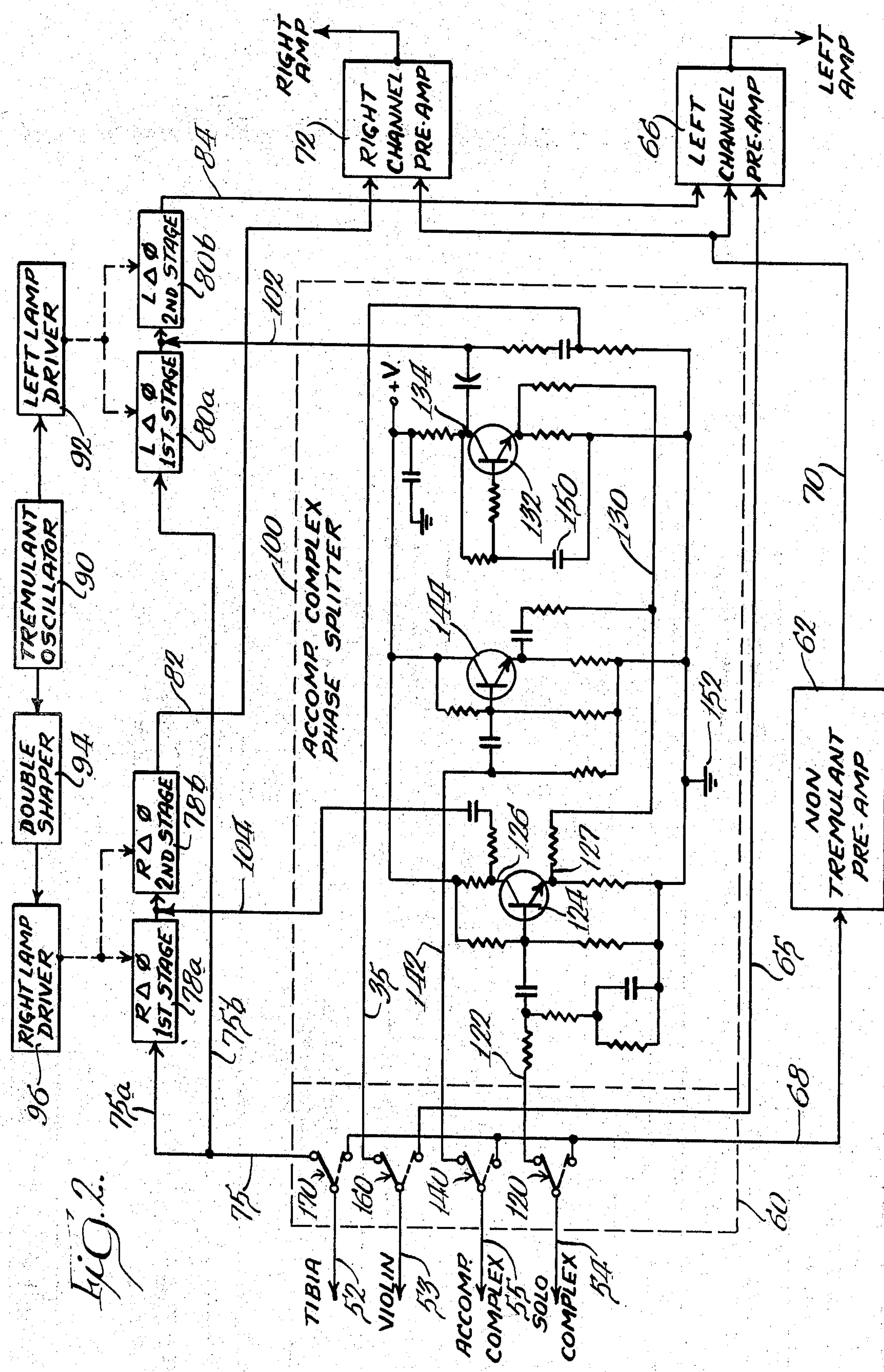

RIGHT AMP
RIGHT CHANNEL PRE-AMP
LEFT CHANNEL PRE-AMP
LEFT AMP
LEFT LAMP DRIVER
TREMULANT OSCILLATOR
DOUBLE SHAPER
RIGHT LAMP DRIVER
L Δ Φ 1ST STAGE
L Δ Φ 2ND STAGE
R Δ Φ 1ST STAGE
R Δ Φ 2ND STAGE
ACCOMP. COMPLEX PHASE SPLITTER
NON TREMULANT PRE-AMP
+V
TIBIA
VIOLIN
ACCOMP. COMPLEX
SOLO COMPLEX

Fig. 2.

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SHEET 3 OF 4

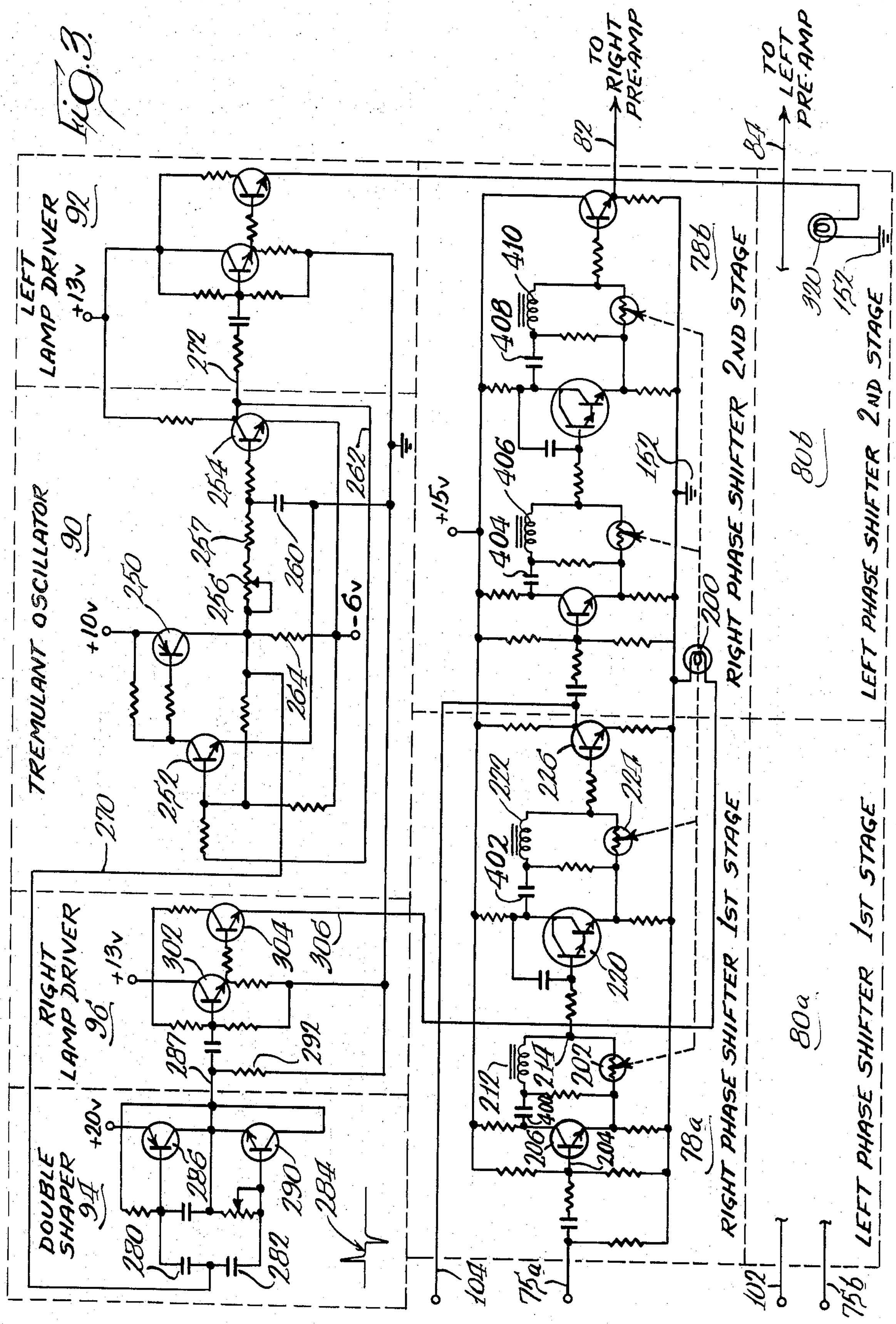


Fig. 3

Fig. 4.

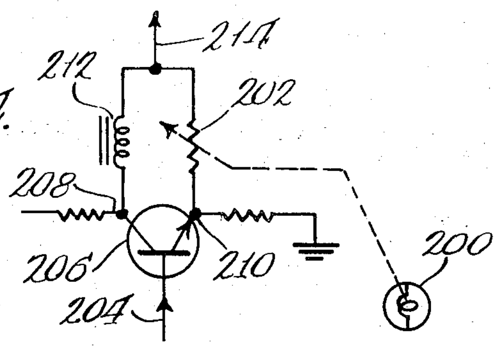


Fig. 5A.
RIGHT CHANNEL PULSE

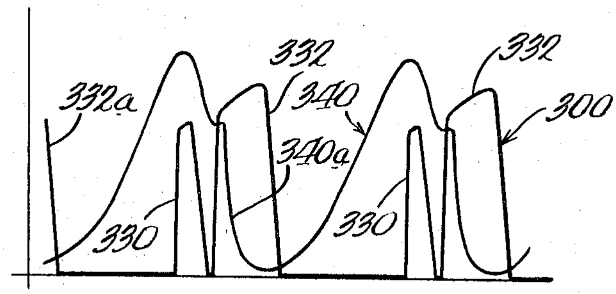


Fig. 5B.
LEFT CHANNEL PULSE

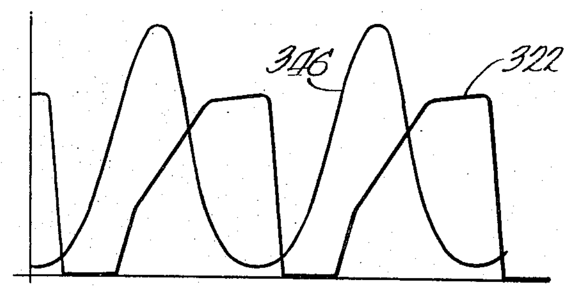


Fig. 5C.
COMPOSITE

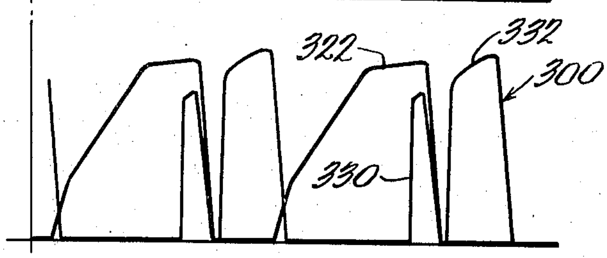


Fig. 5D.
FREQUENCY DEVIATION RIGHT CHANNEL

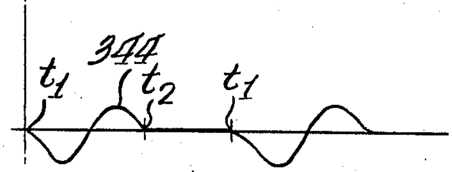


Fig. 5E.
FREQUENCY DEVIATION LEFT CHANNEL

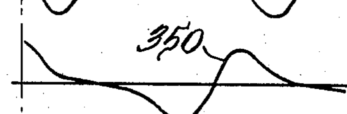
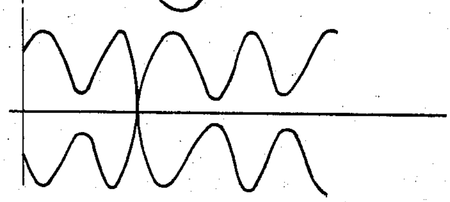


Fig. 5F.
MODULATION ENVELOPE



ELECTRONIC MUSICAL INSTRUMENT WITH PHASE SHIFT TREMULANT SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to electrical musical instruments, and more particularly to a phase shift tremulant system for an electrical musical instrument such as an electronic organ.

In an electronic organ, it has been found to be musically pleasing to vary the frequency and/or amplitude of the tones produced by the organ, at a rate of between four and eight Hertz. These cyclical variations are termed "vibrato" when they are predominately of frequency, and "tremolo" when they are predominately of amplitude (loudness). Certain more sophisticated electronic organs are capable of producing a combined vibrato-tremolo effect which, for purposes of the following description, will be termed a "tremulant" effect. The tremulant effect is one wherein both frequency and amplitude of a given tone are varied at a rate of approximately 6.7 Hertz. In prior electronic organs, several methods have been used to produce the vibrato, tremolo, and/or tremulant effects.

If a pure vibrato is desired, the usual prior method has been to vary the frequencies of the master oscillators by a predetermined amount at a rate of about 6.7 Hertz. This causes the pitch of the note produced to vary above and below the nominal frequency at the desired rate of 6.7 Hertz.

If a pure tremolo effect is desired, the usual prior method has been to vary the gain of the organ amplifier circuitry at the desired rate of approximately 6.7 Hertz. This, of course, results in a variation in the amplitude of the tone produced, which cyclic variation occurs at the 6.7 Hertz rate.

In order to achieve the more sophisticated tremulant effect, most organs have relied on the so-called Leslie speaker system wherein a tremulant effect is produced by mechanical means utilizing the doppler principle. In such a system, the acoustical sound source is cyclically moved, as by rotating a loudspeaker and a deflector.

To avoid certain problems and limitations inherent in mechanical tremulant systems, the phase shift system of the present invention has been developed. Briefly, a signal having a waveshape corresponding to a given musical tone is fed into a phase spliter. In the phase spliter, the signal is broken into two output signals; one of which is in-phase with and the second of which is 180° out of phase with the incoming signal. One output signal is then fed to a first phase shifter where it is cyclically retarded and advanced in phase at a rate of approximately 6.7 Hertz. The second signal from the phase spliter is fed to a second phase shifter, wherein it is likewise cyclically retarded and advanced in phase at the 6.7 Hertz rate. The outputs of the two phase shifters are then fed through separate amplifier channels to separate speakers.

Due to the cyclical advancement and retardation in phase of the signals reproduced by each speaker, the acoustical effect is that of a frequency deviation. This frequency deviation arises because of the increasing and decreasing number of waveforms in transit between the speaker and the listener. The magnitude of frequency deviation is proportional to the rate of change of phase and the amount of phase shift. When both right and left speakers are listened to simultaneously, their signals will acoustically mix to produce a periodic cancellation and reinforcement of sound. Thus, it is seen that not only is the frequency of sound reaching the listener varied in a cyclical manner, but also the amplitude of the sound is varied.

Although known phase shift methods of producing the tremulant effect are relatively satisfactory, a number of problems have arisen, especially when the most pleasing and accurate reproductions are desired. The different voices produced by the electronic organ differ in harmonic content. When a given voice is processed by known phase shift methods, the resulting acoustical effect may not be the most pleasing for such a voice due to the difference in phase shift between the harmonic and primary signals forming the voice. In fact, the use of two reproduction channels, which is generally desirable for most tremulant effects, tends to produce an unpleasant sound for a violin voice.

SUMMARY OF THE INVENTION

In the present invention, a two channel phase shift method of producing tremulant is utilized. In both the right and left channels, a plurality of phase shift networks are cascaded. Each network includes a light responsive resistor and an associated lamp coupled to a tremulant oscillator via appropriate circuitry.

A plurality of different tremulant effects are possible, each tailored to a particular organ voice, by switching circuitry which interconnects the phase shifting networks in different configurations. For example, the phase shift applied to a tibia voice approaches 720° in both the right and left channels, whereas a violin voice is shifted slightly less than 360° in only one channel. Each different voice is phase shifted to produce the most pleasing acoustical output effect.

The lamps in the two channels are driven by separate oscillator waveforms which differ in shape and are phase offset. As a result, the phase shift produced in the right channel is not a duplication of, nor simply related, to the phase shift produced in the left channel. When voices processed by the two channels are acoustically combined, the resulting effect is most pleasing and has been empirically found to be superior to prior tremulant effects. Various other modifications have been made to enhance the operation and resulting effect of the tremulant circuits, as will be explained.

One object of this invention is the provision of an improved tremulant circuit which selectively combines phase shifting networks in different configurations in order to tailor the tremulant effect to the instrument voice then being processed.

Another object of this invention is the provision of an improved two channel tremulant circuit, in which an oscillator and associated circuitry produce different waveforms for controlling the variable impedance elements in the two channels.

A further object of this invention is the provision of an improved tremulant circuit which produces a more pleasing tonal quality for a variety of organ voices than has heretofore been possible.

Other objects and features of the invention will be apparent from the following description and from the drawings.

While an illustrative embodiment of the invention is shown in the drawings and will be described in detail herein, the invention is susceptible of embodiment in many different forms and it should be understood that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the embodiment illustrated.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of an electronic organ incorporating the applicant's tremulant system;

FIG. 2 is a partly block and partly schematic diagram of the tremulant system shown in block form in FIG. 1, and illustrating the phase spliter in detail;

FIG. 3 is a schematic diagram of the portion of the tremulant system which is shown in block form in FIG. 2;

FIG. 4 is a simplified schematic diagram of a single stage of the phase shifter used in FIG. 3; and

FIGS. 5A, 5B, 5C, 5D, 5E and 5F depict waveforms illustrating the signals produced by the electronic organ shown in the remaining figures.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning now to FIG. 1, the applicant's phase shift tremulant system is illustrated in block diagram form as incorporated in an electronic organ. A plurality of organ tone generators **20**, designated E through F, each include a master oscillator which generates a square wave having a frequency corresponding to its respective note in the highest octave on the organ keyboard. Each tone generator **20** also includes divider circuits which divide the master oscillator frequency by multiples of 2, and typically provide outputs corresponding to divisions by 2, 4, 8, and 16. Thus, each tone generator **20** produces frequencies corresponding to the indicated note in all five octaves on the organ keyboard.

Each of the five frequency outputs from all 12 tone generators **20** is fed to a distribution circuit **22.** The distribution circuit thus receives as inputs 60 signals, each signal having a frequency corresponding to the basic frequency of one note which can be played on the organ. Distribution circuit **22** cooperates with keying circuitry actuated by a solo keyboard **24**, an accompaniment keyboard **26,** and a pedal keyboard **28**, each of which pass signals having basic frequencies corresponding to the notes played by the organist. For example, if the key corresponding to the note E in the top octave of the solo keyboard is depressed, the circuit associated with keyboard **24** cooperates with distribution circuit **22** to pass a waveform having the appropriate basic frequency and harmonic content. The operation of accompaniment keyboard **26** and pedal keyboard **28** is similar, as is well known.

Typically, the signal passed by solo keyboard **24** is a sawtooth wave, as shown at **30.** The sawtooth wave is simulated by adding together appropriate square wave signals produced by the tone generators **20** to form a stair-step waveform. It is desirable to pass a sawtooth wave at this point since such a waveform contains not only the basic frequency desired, but also all harmonics of that frequency. Thus, it is a waveform well suited for the further wave shaping which must be performed to simulate various voices to be produced by the organ.

A solo voicing circuit **34** is used to process the sawtooth wave passed by solo keyboard **24** such that a tone having a desired timbre may be produced. Voicing circuit **34** is a passive network having appropriate filter circuitry to selectively attenuate the basic and harmonic frequencies included in the sawtooth wave so as to produce various preselected timbres. For example, if the violin tab for the solo manual is depressed, appropriate filter circuitry will act on the basic and harmonic frequency content of the sawtooth wave such that amplification and reproduction of the resultant waveform will generate a sound having the timbre of a violin.

Illustratively, voicing circuit **34** is capable of acting on the incoming waveform such that tibia, violin, or complex voicing can be produced. An accompaniment voicing circuit **36** and a pedal voicing circuit **38** perform corresponding functions for signals transmitted by the accompaniment keyboard **26** and the pedal keyboard **28,** respectively.

Returning to the solo voicing circuit **34,** the three signals emanating therefrom are individually fed to a corresponding solo tibia preamplifier **40**, a violin preamplifier **42,** and a solo complex preamplifier **44.** The signal which has been shaped by the accompaniment voicing circuit **36** is fed to accompaniment preamplifier **46.** These preamplifiers act to amplify the signals prior to further signal processing.

The appropriately shaped and amplified signals from circuits **40, 42, 44** and **46** are passed to a manual balance control **50.** In balance control **50,** a resistive network including various potentiometers is used to balance the signal strength of the incoming signals, such that the outgoing signals are of the proper amplitude in relationship to each other. The four signals corresponding to the tibia, violin, complex and accompaniment voicings are now passed over individual lines **52, 53, 54,** and **55,** respectively, to a tremulant switching circuit **60,** forming part of the present invention. Switching circuit **60** is controlled by conventional rocker switches located on the cheek block of the organ. By appropriately presetting such switches, the organist can determine whether the notes produced by the solo and/or accompaniment manual will be passed through the phase shift tremulant circuitry of the present invention. If switching circuit **60** is preset to give a tremulant effect to the solo voicing signal, for example, such signal will be fed into the the phase shift tremulant circuitry of the subject invention prior to further amplification by the organ amplifier circuitry. If the organist desires not to subject a given voicing to the tremulant effect, appropriate setting of the switches associated with circuit **60** will pass the signal directly to the nontremulant preamplifier **62** prior to further processing by the organ amplifier circuitry.

The various paths for the voicings connected through switching circuit **60** are as follows. First, it will be assumed that circuit **60** is set to produce a violin timbre in a non-tremulant mode. In such a case, the signal is transmitted out along a line **65** and is delivered only to a left channel preamplifier **66.** Thus, the signal is produced only by the left speaker of the organ. This result has been empirically determined to be musically desirable when a violin voicing is preselected.

Secondly, assume that voicing circuit **60** has been preset to give either a tibia or a complex voicing in response to playing of the solo manual, and that such voicing is to be produced without a tremulant effect. In such a case, the switching circuit **60** is preset to pass the signal waveform corresponding to the tibia or complex voicing along a line **68** to the nontremulant preamplifier **62.** It will then be passed via a line **70** to both the left channel preamplifier **66** and a right channel preamplifier **72.** Thus, the desired voicing will appear in both the left and right speakers, without the tremulant effect. If it is desired to pass the accompaniment signal without a tremulant effect, proper presetting of switching circuit **60** will also pass the accompaniment complex signal along line **68** to the nontremulant preamplifier **62.**

Several examples will now be given when it is desired to produce preselected voicings with the tremulant effect. For example, if the tibia voicing on the solo manual is selected and switching circuit **60** is set to produce tremulant, the tibia waveform is transmitted on a line **75** directly to a right channel phase shifter **78** and a left channel phase shifter **80.** As will be explained, the right and left phase shifters **78** and **80** effectuate a cyclic advancement and retardation of the phase of the signal passing therethrough at a rate of about 6.7 Hertz. Thus, the signal passing through the right phase shifter **78** is continuously advanced and retarded in phase as it is transmitted along an output line **82** to the right channel preamplifier **72.** Likewise, the signal on line **75,** which is supplied to the left phase shifter **80,** is subjected to a similar continuous cyclical retardation and advancement in phase. The resulting output signal on a line **84** is then separately coupled to the left preamplifier **66.** The output from the right preamplifier **72** and the left preamplifier **66** is independently amplified and coupled to separate right and left speakers. When one listens to the right and left speakers, the resulting acoustical effect is a cyclical variation in both frequency and amplitude, which, of course, constitutes the tremulant effect.

The cyclical variation in phase in the pair of phase shifters **78** and **80** is produced by a master tremulant oscillator **90** generating a left control signal which is coupled to a left channel lamp driver **92,** associated with left channel phase shifter **80.** A second signal is transmitted through a double shaper **94** to produce a different right control signal coupled to a right lamp driver **96** associated with right phase shifter **78.** The lamp drivers energize lamps which control the impedance of light sensitive variable impedance elements in each of the phase shifters, which variable impedance elements are connected to effect a phase shift in accordance with the impedance thereof. The control signals are different in offset and wave shape in order to produce different phase shifts in the right and left channels, creating a pleasing acoustical effect as will be explained.

Assume now that a complex voicing has been selected for the solo manual by proper presetting of the tabs associated with voicing circuit **34.** If such voicing is to be subjected to the tremulant effect, switching circuit **60** passes the signal corresponding to the complex voicing to a line **98,** forming one input of an accompaniment complex phase splitter **100.** In phase splitter **100,** the complex voicing signal is broken down into two signals, one in phase with the incoming signal and having a wave shape identical thereto, and another 180° out of phase with the incoming signal, but otherwise having an identical wave shape. The in phase signal is coupled along an output line **102** to the left channel phase splitter **80.** The phase inverted signal is coupled along an output line **104** to the right channel phase shifter **78.** Thereafter, the operation is the same as previously described, except that the input waveform to the pair of phase shifters is **180** degress out of phase.

Assuming now that it is desired to subject the accompaniment complex voicing to a tremulant effect, the switching circuit **60** is set appropriately to pass the accompaniment signal via lines **98** to a phase splitter **100.** In phase splitter **100,** the accompaniment signal is split into two isolated signals having waveforms similar to the input waveform. Unlike the complex signal, the phase splitter **100** does not invert the phase of one of the output signals. Hence, the signals transmitted via lines **102** and **104** to their respective phase shifters are both in phase with the input signal representing the accompaniment voice.

Lastly, it will be assumed that the violin voicing has been selected for the upper solo manual and is to be subjected to the tremulant effect. In such a case, the switching circuit **60** is set appropriately to pass the violin signal along a line **108** and then via line **102** to only the left channel phase shifter **80.** As previously noted, the violin voicing is isolated and confined to only the left channel. The left channel phase shifter **80** then processes the incoming violin voicing signal in the same manner as previously described.

With the present invention, a variety of tremulant effects can be obtained, as described above. Unlike the mechanical Leslie speaker system, wherein all organ voicings are subject to the same type of tremulant effect, the applicant's system allows a tremulant effect tailored to the particular voicing. Furthermore, this tailoring or custom tremulant effect has not been possible with prior tremulant systems of the phase shift type, due to the inability to interconnect the phase shifting networks in a variety of configurations of the type described above. Since the tibia voicing, for example, is close to being a pure sine wave having little harmonic content, it can be subjected to more phase shift without production of an unpleasant sound. The phase inversion of the complex signal in the accompaniment splitter **100** prior to introduction into the respective right and left channel phase shifters **78** and **80,** results in a different tremulant effect being applied to results in a different tremulant effect being applied to this voice as compared with the accompaniment voice, which is not phase inverted prior to phase shifting. The violin voicing is processed with phase shifting in only the left channel, creating still another tremulant effect. This versatility of creating a plurality of tremulant effects in a single system is a significant advancement over prior tremulant systems.

Turning now to FIG. **2,** the switching circuit **60** and the accompaniment complex phase splitter **100** are shown in detail. The right phase shifter **78** and the left phase shifter **80** and the circuitry associated therewith, are illustrated in more detail but in block diagram form.

In order to explain the operation of phase splitter **100,** it will be assumed that the voicing circuit **34** of FIG. **1** has been set to pass a complex voicing on the solo manual. In such a case, a signal is present on line **54.** For simplicity, it will be assumed that no signals are present on lines **52, 53** and **55.** Also, it will be assumed that a switch **120** in circuit **60** is preset as shown in the solid line, such that the complex voicing signal is transmitted to a line **122.** The signal then passes through an appropriate input network to the base of a transistor **124.** The transistor **124** has a pair of outputs, one output occurring at its collector electrode **126** and the other at its emitter electrode **127.** The output at collector **126** is 180° out of phase with the input applied to the base of transistor **124;** that is, it is phase inverted. This phase inverted output is then coupled through an

RC network to line **104** which injects the signal at the input of the second stage **78***b* of the right phase shifter formed by cascaded stages **78***a* and **78***b*. The signal appearing at emitter **127** is in phase with the input signal applied to line **122**. This signal is coupled via a line **130** to the emitter of a transistor **132**. Since the signal on line **130** is emitter coupled to transistor **132**, the signal appearing at a collector electrode **134** of transistor **132** is in phase with the signal on line **122**. This in phase signal appearing at collector **134** is capacitor coupled to line **102** for transmission to the input of a second stage **80***b* of the left phase shifter, consisting of cascaded stages **80***a* and **80***b*. Thus, when a solo complex signal is passed through splitter **100**, two output signals are produced on lines **104** and **102**. The signal on line **102** is in phase and identical with the input signal (except for amplification), and the other signal on line **104** is 180° out of phase with the input signal, but otherwise identical thereto (except for amplification).

The reason for splitting the solo complex voicing signal into two signals 180° out of phase, prior to coupling to a single stage of a phase shift network for each channel, is that such signal processing has been found empirically to produce the most desirable tremulant effect with regard to the solo complex voice. If it was not desired to subject the solo complex signal on input line **54** to the tremulant effect, switch **120** would be flipped to the dotted line position, such that the signal would be passed to line **68**. The signal would then go directly to the nontremulant preamplifier **62**, and then to both the right and left preamplifiers **72** and **66**.

It will now be assumed that the accompaniment complex voicing, as well as the solo complex voicing on the solo manual, are to be subjected to tremulant. In such a case, both the switch **120** and a switch **140** will be in the solid line positions shown in FIG. 2. The signal on line **122** is processed exactly as previously described. The accompaniment signal is transmitted along a line **142** to a base electrode of a transistor **144**. The transistor stage **144** is used in the case of the accompaniment signal to lower its impedance in order to make it possible to drive the emitter input of transistor **126** (right output stage) and the emitter input of transistor **132** (left output stage). Following amplification by transistor **144**, the accompaniment signal is RC coupled to the line **130**, and then injected into emitter **127** of transistor **124**. The accompaniment signal mixes with the solo complex signal in transistor **124** to give the right channel output. Similarly, the accompaniment voicing signal is fed to the emitter of transistor **132** wherein it mixes with the solo complex signal to give the left channel output. It should be noted that for the accompaniment signal, both the right channel and left channel outputs are in phase with the input. This is because, unlike the solo complex voice, it has been determined empirically that the most pleasing tremulant effect to which the accompaniment complex voice can be subjected results if both right and left channel outputs are fed in phase to the phase shifters.

Each phase shifter circuit **78** and **80** comprises two stages, labeled *a* and *b*. Each stage is capable of producing a dynamic phase shift of almost 360°. Hence, the maximum obtainable phase shift using both stages is about 720°. Both the solo complex and accompaniment complex voices are coupled to only the final stage of each phase shifting circuit, and thus are subjected to slightly less than 360° of dynamic phase shift. The reason is as follows. Any complex voice contains a large harmonic content. In the phase shift circuitry, higher frequencies are subject to greater phase shifts, due to the RL circuit being utilized. When a complex voice is processed by the phase shift circuit, the higher harmonics receive more phase shift than the lower harmonics. This results in a rather unpleasant musical tone if the complex signal is subjected to too much phase shift. It has been found empirically that a 360° phase shift gives a good tremulant to complex tones, without producing discordinant effects due to more extreme shifting of higher harmonics.

The base of transistor **132** is AC coupled by a capacitor **150** to a source of reference potential or ground **152**, making it a common base configuration. This configuration has good output to input isolation characteristics, and thus prevents channel cross-talk between the left and right channels. The tremulant effect produced by the present invention would be substantially destroyed if these channels were not properly isolated. Failure to electrically isolate lines **102** and **104** from each other would result in a signal path connecting the outputs of the first stages of the left and right phase shifters. If such were the case, any output from the two stages would be electrically mixed. This would destroy the intended effect of these two stages, since the tremulant effect of the present invention is realized when the output of two separate channels are acoustically mixed in space.

If the accompaniment complex voicing is not to be subjected to tremulant, switch **140** is placed in the dotted line position and the signal on line **55** will be passed via line **68** to preamplifier **62**.

It will now be assumed that the violin voicing is selected for the solo manual, instead of the solo complex voicing. In such a case, a switch **160** is set as shown by the solid line in FIG. 2. The violin voicing signal is then transmitted along line **35** where it is injected via an RC network directly into line **102**. As previously noted, violin voices are preferred in only the left channel. Should it be desired not to use tremulant on the violin voicing, the switch **160** is set to the dotted line position which transmits the signal on line **53** to the line **65**. Again, since violin voices are musically preferred only in the left channel, the violin voicing signal is transmitted directly via line **65** to the left channel preamplifier **66**.

If it is desired to subject the tibia voicing selected on the solo manual to tremulant, the switch **170** is set as shown in solid lines. The tibia voicing signal is then translated to line **75** and along lines **75***a* and **75***b* into the first phase shift stage **78***a* of the right channel and the first phase shift stage **80***a* of the left channel. It should be noted that the tibia voicing signal is not processed by the complex phase splitter **100**. With the tibia voicing signal, it is not necessary to split the signal into two isolated channels to prevent cross coupling, since the signal is injected at the first stage of each phase shifter, rather than the final stage as in the case of complex signals. Once the signals are injected, they proceed independently in the two separate channels. In addition, it should be especially noted that only the tibia signal is subjected to two stages of phase shift in both the right and left channels; that is, approximately 720°. Such signal processing is desirable musically since the tibia voice is almost a pure sine wave; that is, it contains very little higher harmonic content. With a tibia voice, therefore, it is possible to phase shift the signal to a larger degree because the absence of higher harmonics prevents a discordinant sound even though large phase shift is utilized. The large phase shift is desirable since it results in a very deep tremulant effect, which is especially pleasing on a tibia voice. To effectuate the larger phase shift, two stages of phase shift are utilized. Once the tibia voicing signals have passed through the right and left channel of phase shifting circuitry, they are applied separately via lines **82** and **84** to the right channel preamplifier **72** and the left channel preamplifier **66**, respectively.

If it is desired to not apply tremulant to the tibia voicing signal, switch **170** is placed in the dotted line position and the tibia voicing signal is passed along line **68** to preamplifier **62**.

The operation of the phase shifting circuitry, and associated stages, is shown and explained with reference to FIGS. **3**, **4** and **5**. To provide a phase shift tremulant effect, the electrical phases of the left and right channels must by cyclically advanced and retarded at a rate of approximately 6.7 cycles per second. In the present invention, the electrical phases of signals passing through the right and left channels can be rotated throughout almost 360° in each of the pair of cascaded stages in both the left and right phase shifters.

In performing this function the phase shifting circuitry of the present invention provides a more pleasing tremulant effect than prior art phase shifting, in that it dynamically shifts the phase of lower frequency harmonics less than upper frequency harmonics. This results in what might be termed a constant percentage frequency deviation, which is highly desirable for the following reason. If low frequency harmonics of a musical signal (for example those below 200 Hz) are dynamically phase shifted through a significant number of degrees (say approximately 720°) at the rate of 6.7 Hz, the perceived variation in frequency due to the Doppler effect is quite extreme. This result occurs because the number of cycles which the frequency deviates above and below the nominal frequency is dependent on the tremulant rate and the number of degrees of dynamic phase shift. If the number of Hz which the frequency deviates is significant in comparison to the nominal frequency, the percentage frequency deviation will be quite large. This percentage frequency deviation is the critical factor in producing a desirable tremulant. For example, if high frequency harmonics are phase shifted the same number of degrees at the same tremulant rate as low frequency harmonics, the percentage frequency deviation of low frequency harmonics would be much greater than that of high frequency harmonics, due to the difference in nominal frequencies. This is a serious drawback of known phase shift tremulant systems, since it is musically pleasing to have the percentage frequency deviation approxmately equal regardless of the nominal frequency. The phase shifters of the subject invention effectuate this in a manner to be explained below.

The principle of operation of the phase shifting circuits used in the present invention may be understood by referring to FIG. **4**. A single light bulb **200** illuminates a light dependent resistor **202**. If an AC signal is applied via a line **204** to the base electrode of a transistor **206**, the signal at a collector electrode **208** of the transistor **206** will be 180° out-of-phase with respect to the applied signal on line **204**. Furthermore, the signal at an emitter electrode **210** of the transistor **206** is in-phase with the appied signal. Thus, two outputs are provided which are 180° out-of-phase. The collector electrode **208** is coupled through an inductor **212** to an output line connected to a junction **214** of inductor **212** and the light dependent resistor **202**.

Assuming that light bulb **200** is de-energized, the light dependent resistor (LDR) **202** receives no light, and its resistance is high. It will be assumed that LDR **202** has an infinite impedance at a no light condition. In this case, inductor **212** is unloaded and thus has no AC current flowing therethrough. The output is a shifted signal on line **214** which is in-phase with the signal on collector **208**, which in turn is 180° out-of-phase with the input signal on line **204**. When the light bulb **200** is energized and it begins to illuminate, a point is reached at which the resistance of LDR **202** is equal to the inductive reactance of inductor **212**. At this point, the combined effect of inductor **212** and LDR **202** is to provide a 90° lag between the output voltage and the input voltage. Finally, when the LDR **202** is fully illuminated, it has a minimum resistance and the in-phase component at the emitter **210** predominates on output line **214**. Thus, if we assume a short circuit condition in LDR **202**, the output on line **214** will be in-phase with the input on line **204**. As the light bulb **200** is again dimmed to a zero light output condition, the voltage on line **214** again goes 180° out of phase with the input on line **204**. Thus, as lamp **200** is illuminated and darkened, the phase of the signal on line **214** is progressively advanced and retarded with respect to the input on line **204**. While the simplified phase shifting circuit in FIG. **4** makes use of an inductor **212**, it is obvious that a capacitive element could be substituted therefor. Should such be done, the direction of the phase shift, as lamp **200** is alternately illuminated and darkened, would be the opposite of that resulting when an inductive element is utilized.

Turning now to FIG. 3 and referring to the first stage **78a** of the right phase shifter, note that a capacitor **400** is included in the phase shifting circuitry. Capacitor **400** forms a series resonant circuit with inductor **212**. When a signal having a frequency below the resonant frequency of the series resonant circuit is applied to line **204**, the effect of capacitor **400** will predominate, and the phase shift circuitry will operate in a capacitive mode. When a signal having a frequency above the series resonant frequency appears on line **204** the phase shift circuitry operates in an inductive mode. In a preferred embodiment of subject invention, capacitor **400** has a value of 10 microfarads and inductor **212** has a value of 0.350 henries. This results in a series resonant frequency of 84 Hz. Hence, for signals applied to line **204** with frequencies below 84 Hz, the dynamic phase shifting effectuated will be in a direction opposite to that for applied signals with frequencies above 84 Hz. Thus the phase of signals appearing on line **214** having a frequency below 84 Hz is caused to continually vary in accordance with the output of lamp **200**. Signals on line **204** having frequencies above 84 Hz are also continually varied in phase according to the illumination of lamp **200**, but in the opposite direction from signals having a frequency below 84 Hz.

The phase shifter just described is followed by a phase inverter utilizing a Darlington amplifier **220**, which provides a high input impedance for minimum loading, and a low impedance split load to drive the second phase shifter. The second phase shifter is similar to the first described phase shifter, and includes a capacitor **402** in series with inductor **222.** Here again, a series resonant circuit is formed by capacitor **402** and inductor **222,** which connects to the collector electrode of the Darlington amplifier **220.** LDR **224** couples to the emitter of the Darlington amplifier **220,** and is actuated by lamp **200.** In a preferred embodiment of the subject phase shifter, capacitor **402** has a value of 40 microfarads and inductor **222** has a value of 0.350 henries, giving a series resonant frequency of 42 Hz. Hence in this phase shifter, applied signals having a frequency below **42** Hz will be dynamically phase shifted in the same direction as signals having a frequency below 84 Hz in the first portion of this phase shifter. Applied signals with frequencies between **42** Hz and **84** Hz will be dynamically phase shifted in a direction opposite to that effected in the first phase shift circuit. Signals with frequencies above **84** Hz will of course be dynamically phase shifted in the same direction in both phase shifters. The output of the second phase shifter is applied to output transistor **226** prior to introduction into the second stage of the right phase shifter.

The third and fourth phase shifters which comprise the second stage of right phase shifter **78*b*** operate in a manner similar to the first and second phase shifters in the first stage of the right phase shifter. However, in a preferred embodiment, capacitor **404** has a value of 2 microfarads and inductor **406** has a value of 0.350 henries, resulting in a series resonant frequency of 190 Hz. Capacitor **408** has a value of 10 microfarads and inductor **410** has a value of 0.350 henries, giving a series resonant frequency of 84 Hz. Thus, in the second stage of the right phase shifter, all signals and frequencies above 190 Hz will be dynamically phase shifted in the same direction by both phase shifters. All signals with frequencies below 84 Hz will also be dynamically phase shifted in the same direction, but this direction will be opposite to that for signals having frequencies above 190 Hz. For signals having a range of frequencies between 84 and 190 Hz, the dynamic phase shift direction in the first phase shifter will be opposite from that of the second phase shifter.

The net effect of selecting the resonant frequencies of each of the four phase shifters as specified above is to lessen the dynamic phase shift for signals having frequencies below 190 Hz. For example a 50 Hz signal will be dynamically phase shifted in opposite direction by the first and second phase shifters. This will result in a partial cancellation of the phase shift effect, since the resultant phase shift will be the difference of the individual dynamic phase shifts. However, in the third and fourth phase shifters the phase shift direction for the 50 Hz signal will be the same, and thus the total phase shift will be the sum of the two individual dynamic phase shifts. Of course for all signals with frequencies greater than 190 Hz, dynamic phase shifts in all four phase shifters will be additive, which will result in a dynamic phase shift of approximately 720°, since each of the four phase shifters can effectuate almost a 180° shift. Since the dynamic phase shift of signals having frequencies below 190 Hz is less than that of signals with frequencies above 190 Hz, due to selective cancellation of phase shift effect by interaction of the four phase shifters, the resulting percentage, frequency deviation of signals having nominal frequency below and above 190 Hz is closer to being equal than with known phase shift tremulant systems.

The left phase shifter, first and second stages, is identical to the right phase shifter, first and second stages. Hence no detail description of the left channel phase shift circuitry is necessary. A signal applied at line **75*a*** or **75*b*** thus passes through both the first and second stages of their respective phase shifters to provide about 710° of electrical rotating phase shift. If the signal is inserted only into the second stage *b* of its respective channel phase shifter, as occurs with signals applied to lines **104** and **102,** only about **355** degrees of electrical rotating phase shift is provided. As previously noted, only the tibia voicing signal is subjected to the full 710° of phase shift, resulting in a desirable deeper tremulant.

To effectuate a smooth advancement and retardation of phase by the right channel phase shifter, lamp **200** must be cyclically driven from a darkened to a lightened condition. The energization of the lamps for the right and left channels is controlled initially by a tremulant oscillator **90** which provides a 6.7 Hertz signal to a tremulant modulation system. Two out-of-phase outputs are provided from the oscillator **90,** shown in detail in FIG. **3.**

The tremulant oscillator **90** includes transistors **250, 252** and **254.** When transistor **250** is conducting, positive charging voltage is supplied through resistors **256** and **257** to a capacitor **260.** As the voltage on capacitor **260** rises, the collector current of transistor **254** increases accordingly. The voltage on the collector of transistor **254** then drops toward ground potential. As the voltage on the collector goes towards ground, a signal on a line **262** connected to the collector of transistor **254** also goes toward ground, causing the base drive for transistor **252** to drop. This causes transistor **252** to go out of conduction, resulting in a rise in its collector potential. As the potential at the collector of transistor **252** rises, transistor **250** is forced out of conduction. Capacitor **260** then discharges through the resistors **257, 256** and a resistor **264.** As the voltage on capacitor **260** decreases, the collector current of transistor **254** decreases thereby causing a rise in its collector voltage. As the voltage on the collector of transistor **254** rises the signal on line **262** increases thereby providing an increased base drive to transistor **252.** Thereafter, transistor **250** returns to a conducting state and the oscillation cycle just described begins over again.

The oscillation frequency is governed by the RC time constant of the capacitor **260** and the resistors **256,257** and **264.** The value of resistor **256** is variable, and is selected to produce an oscillation rate of approximately 6.7 Hertz. As the oscillator cyclically oscillates, a rectangular wave is developed on an output line **270,** and another rectangular wave out-of-phase therewith is developed on a line **272.** These output lines are coupled to the right channel lamp driver and the left channel lamp driver, respectively.

The square wave signal on output line **270** is fed to the double shaper circuit **94.** The circuit **94** is used to develop a double frequency pulse which is coupled to only the right phase shifter lamp driver **96.** In essence, the double shaper acts like a dual switch, one side being responsive to the positive going portion of the input signal, and the other side being responsive to the negative going portion. The outputs of the two sides are then combined to provide a doubled frequency output driving signal.

The operation of the double shaper circuit **94** will be described assuming that a positive going rectangular wave is received on line **270.** A pair of capacitors **280, 282** differentiate the rectangular pulse to produce positive and negative going pulses as shown at **284.** The positive going pulse causes a transistor **286** to deliver an output pulse on a line **287.** The negative going pulse causes a transistor **290** to go into conduction, and provide a second pulse on line **287.** Thus, the combined offset signals to the right lamp driver **96** appear across a resistor **292.** In FIG. 5A, the double frequency pulses developed across resistor **292** are depicted by curve **300.**

As a pulse arrives, a transistor **302** in the right lamp driver **96** is biased into conduction. As a result, a cascaded transistor **304** is also biased on. When transistor **304** conducts, it supplies current through a line **306** to lamp **200.** As a result, the illumination level of the lamp **200** is controlled by the waveform **300,** FIG. 5A, applied across the resistor **292.**

The circuit of the left lamp driver **92** is identical to the circuit just described for the right lamp driver **96.** However, since no double shaper is interposed between the tremulant oscillator **90** and the lamp driver, the lamp **320** in the left channel phase shifter **80** is not illuminated in the same manner as lamp **200** in the right channel phase shifter **78.** Rather, lamp **320** is energized by a signal **322** as shown in FIG. 5B. Thus, the two driving waveforms **300** and **322,** shown in composite form in FIG. 5C, are time offset and produce an alternating, or interleaving effect. It has been discovered empirically that a most desirable form of tremulant is produced by the signals shown in FIG. 5.

Since the wave shapes are critical in producing the highly desirable tremulant effect of the present invention, they will be considered in greater detail. First, the double-shaped waveform **300,** which is applied to the right channel lamp **200,** will be considered. The waveform **300** is comprised of a first pulse **330** followed by a second pulse **332.** These dual pulses do not cause the lamp **200** to flash twice because of thermal lag inherent in the lamp. Rather, it appears that the first pulse **330** causes preheating of the lamp, so that when pulse **332** is applied, the lamp's light output rises faster than would be the case without preheating. When pulse **332** returns to zero, the decrease in light output of the bulb does not follow the waveform of the trailing edge of pulse **332** because the light output is decreased in accordance with the thermal lag of the lamp.

While the exact light response curve of the bulb **200** when driven by the waveform **300** is not illustrated, such a driving waveform is used to compensate for certain nonlinearities in the response curve of the lamp and the associated LDR. The resulting resistance of each of the LDR's in the right channel phase shifter versus time is shown by curve **340** in FIG. 5A. Referring to FIG. 5A, it is noted that as pulse **332** drops to zero as indicated by the portion of the waveform indicated **332***a*, the resistance of the right channel LDR does not begin to rise until a substantial period of time later. As indicated above, this occurs because the light output of bulb **200** does not cease immediately when its driving voltage is removed, but rather dies out slowly. Such results in a delay before the LDR ceases to be illuminated and; hence, its rise in resistance is delayed as shown by waveform **340.** When the voltage pulse **330** is applied to bulb **200,** it does not immediately result in light output therefrom. This causes a slight delay in the time when the LDR resistance begins to drop. As indicated above, the pulse **330** also pre-heats the bulb **200** such that when pulse **332** is applied to bulb **200,** it illuminates very rapidly thereby causing a rapid decrease in the resistance of the LDR, as illustrated by the portion of curve **340** indicated **340***a*. This variation in LDR resistance causes the phase shift circuitry to shift the phase of a signal passing therethrough in such a manner that the frequency deviation of the signal varies, as indicated by curve **344,** FIG. 5D.

Similarly, the resistance of each LDR in the left channel phase shifter versus time is shown by curve **346** in FIG. 5B. The application of a pulse such as that indicated at **322** results in the resistance curve **346** which then causes a frequency deviation in the left channel as shown by curve **350,** FIG. 5E.

The frequency deviation as shown by curve **344** in FIG. 5D has been found to result in a very desirable tremulant effect. Unlike prior tremulant effects, the applicant's driving waveforms and circuitry are designed so that there is not a continuous variation in phase as has been typical heretofore. Rather, the frequency deviation of the signal as shown by waveform **344** occurs in spaced time zones, in that between times t_1 and t_2, the frequency deviates in a smooth, almost sinusoidal manner below and above the nominal frequency. However, during the period between t_2 and t_1, the frequency does not deviate, but rather remains substantially at a nominal value. This pause or absence of a continuous frequency deviation is believed to be partially responsible for the improved tremulant effect produced by the present invention.

The acoustical interaction between the right and left channels of the organ, to provide an amplitude variation or tremolo effect may be understood with reference to FIG. 5F, which shows the envelope of the beat between the left channel and right channel output signals. The modulation envelope reflects the loudness variations which a listener equidistant from each channel speaker would hear if a 1,000 Hertz sine wave were introduced into both the left and right channels, where each would be continuously dynamically phase shifted. The improvement in the tremulant effect results from various contributions of the circuitry and waveforms previously described.

As seen in FIGS. 5D and 5E, the frequency deviation in the right channel, curve **344,** does not occur during the same time period as the frequency deviation in the left channel, curve **350.** Rather, the right and left channel deviations in frequency alternate or interleave with each other since the major frequency deviation period in the right channel (the time period between t_1 to t_2) is delayed with regard to that of the left channel major frequency deviation period. The resulting acoustical effect is a more or less continual reinforcement and cancellation of waveforms, thereby giving a desired amplitude variation. It is believed that the alternation of the frequency deviation periods further contributes to the improved tremulant effect. Furthermore, the resulting pleasing tremulant effect is available on most of the custom tremulant effects which can be realized by the system through the previously described selective combination of phase shifting circuits.

Having described the invention, the embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A system for producing different cyclical variations in electrical signals representing different musical instruments, comprising:

a plurality of sources of electrical signals each having a different harmonic content to correspond to said different musical instruments;

a plurality of phase shift stages each including variable means controllable to vary the phase shift of the corresponding phase shift stage;

an oscillator coupled to said variable means for cyclically varying the phase shift produced by each of the plurality of phase shift stages;

a circuit interconnecting at least two of said plurality of phase shift stages in series to produce in an electrical signal coupled to an input junction a total phase shift approximately equal to the sum of the phase shifts of the two phase shift stages, the series interconnection including an intermediate junction between said two phase shift stages to produce in an electrical signal coupled thereto a total phase shift approximately equal to the phase shift of the last of the two phase shift stages; and

switch means for coupling one of said sources to said input junction and another of said sources to said intermediate junction whereby some of said plurality of phase shift stages are used in common by different sources corresponding to different musical instruments.

2. The system of claim **1** including a first channel for processing and a first reproducer for reproducing said electrical signals and a second channel for processing and a second reproducer for reproducing said electrical signals, the acoustical interaction of the electrical signals reprodued by the first and second reproducers producing a tremulant cyclical variation,

said two phase shift stages being located in said first channel,

said plurality of phase shift stages includes a third phase shift stage responsive to third variable means for producing a third phase shift deviation and a fourth phase shift stage responsive to fourth variable means for producing a fourth phase shift deviation, said third and fourth phase shift stages being located in said second channel,

said circuit interconnecting said third and fourth phase shift stages in series to produce in an electrical signal coupled to an input junction a total phase shift approximately equal to the sum of the third and fourth phase shift deviations, the series interconnection including an intermediate junction between said third and fourth phase shift stages, and

said switch means further couples said one source and said another source to different of said junctions located in said second channel.

3. The system of claim **2** wherein said swtich means couples said one source simultaneously to said input junctions in said first and second channels.

4. The system of claim **2** wherein said switch means couples said another source simultaneously to said intermediate junctions in said first and second channels.

5. The system of claim **4** wherein said circuit includes inversion means for producing a phase shift of approximately 180°, and said switch means interconnect said inversion means between said another source and one of said intermediate junctions to thereby input to the last phase shift stages in the first and second channels a pair of electrical signals which are 180° out of phase.

6. The system of claim **4** wherein said circuit includes isolation means for splitting the signal from said another source into two in-phase portions, and said switch means interconnects said isolation means with said intermediate junctions to thereby input to the last phase shift stages in the first and second channels a pair of in phase signals without cross-coupling said first and second channels.

7. The system of claim **2** wherein said switch means disconnects said another source from said second channel whereby said signal from said another source is processed solely in said first channel.

8. The system of claim **1** including a first channel for processing and a first reproducer for reproducing said electrical signals and a second channel for processing and a second reproducer for reproducing said electrical signals, said plurality of said phase shift stages includes a first stage located in said first channel and a corresponding second stage located in said second channel, each stage including a variable means controllable to vary the phase shift thereof, and

said oscillator includes means for generating different control signals and means for coupling said different control signals to the variable means in the first and second stages to produce different phase shift deviations in the electrical signals processed by the first and second channels.

9. A system for producing a cyclical variation in an electrical signal representing a musical voice, comprising:

a source of said electrical signal;

a first channel coupled to said source for processing said electrial signal, including a first phase shift stage having a first variable means controllable to vary the phase shift deviation produced in the first channel;

a first audio reproducer coupled to said first channel for reproducing the processed electrical signal;

a second channel coupled to said source for processing said electrial signal, including a second phase shift stage having a second variable means controllable to vary the phase shift deviation produced in the second channel;

a second audio reproducer coupled to said second channel for reproducing the processed electrical signal;

an oscillator for generating a pair of control waveforms having cyclical variations, including a wave shaper for altering the shape of one of the control waveforms and means for individually coupling said pair of control waveforms to the first and second variable means, respectively, to produce different phase shift deviations in said first and second channels; and

said first and second audio reproducers coupled to said first and second channels reproduce said cyclical variation in response to an acoustical interaction produced by the difference in phase shift deviation between the electrical signals processed in said first and second channels.

10. The system of claim **1** wherein said wave shaper acts to phase off-set said pair of control waveforms, and said first and second variable means are responsive to the phase off-set control waveforms to produce off-set phase deviations in said first and second channels and thereby create an interleaving effect in said cyclical variation.

11. The system of claim **9** wherein said first variable means is responsive to the one of said control waveforms coupled thereto for producing recurring periods of phase shift, each recurring period comprising a first time portion which controls said first phase shift stage to produce a substantially continuous frequency deviation and a second time portion which controls said first phase shift stage to produce substantially no frequency deviation.

12. The system of claim **11** wherein said wave shaper acts to relatively phase off-set one of the pair of control waveforms, said second variable means being responsive to the phase off-set control waveform to cause a third time portion which produces a substantial frequency deviation in said second channel to alternate with said first time portion.

13. The system of claim **9** wherein each of said variable means comprises a light responsive impedance having an impedance value corresponding to the light energy impinging thereon, a first lamp for controlling the amount of light energy impinging on the impedance in said first channel, a second lamp for controlling the amount of light energy impinging on the impedance in said second channel, and said individually coupling means coupling the pair of control waveforms to said first and second lamps, respectively.

14. The system of claim **13** wherein said wave shaper comprises a wave doubler for causing one control waveform to comprise a pair of pulses, the other control waveform comprising a single pulse for each pair of pulses produced by the wave doubler.

15. The system of claim **13** wherein each of said phase shift stages includes a transistor having first and second output electrodes and a control electrode, means coupling the control electrode to the electrical signal being processed, a reactance coupled between said first output electrode and a junction, and said light responsive impedance being coupled between said second output electrode and said junction to cause the electrical signal at the junction to have a phase shift corresponding to the impedance value of said impedance.

16. The system of claim **15** wherein each of the first phase shift stage and the second phase shift stage include a plurality of transistors, reactances and light responsive impedances, the junction associated with the first connected transistor in each phase shift stage being in series with the control electrode of the next transistor, and the lamp for each channel causes substantially the same light energy to simultaneously impinge all of the light responsive impedances in the associated channel.

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