

[54] **TREMULANT AND CHORUS GENERATING SYSTEM FOR ELECTRICAL MUSICAL INSTRUMENTS**

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Related U.S. Application Data

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[52] U.S. Cl. **84/1.24; 84/DIG. 4; 84/1.25**

[51] Int. Cl. **G10h 1/02**

[58] Field of Search **332/22; 84/DIG. 4, 1.24, 84/1.25, 1.01**

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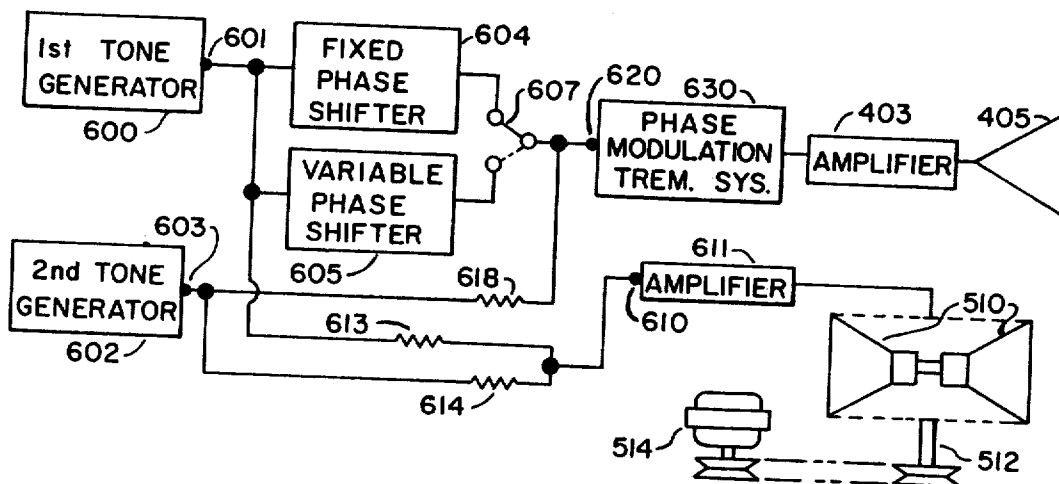
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[57]

ABSTRACT

The invention relates to tremulant and chorus generating systems for use with Electrical Musical Instruments. Signals from an instrument such as an organ are simultaneously applied to at least two amplification channels each with a separate loudspeaker. The signals in each channel are separately phase modulated in a manner that results in a strong stereophonic illusion. Apparatus for achieving phase modulation of the desired character is disclosed.

13 Claims, 14 Drawing Figures



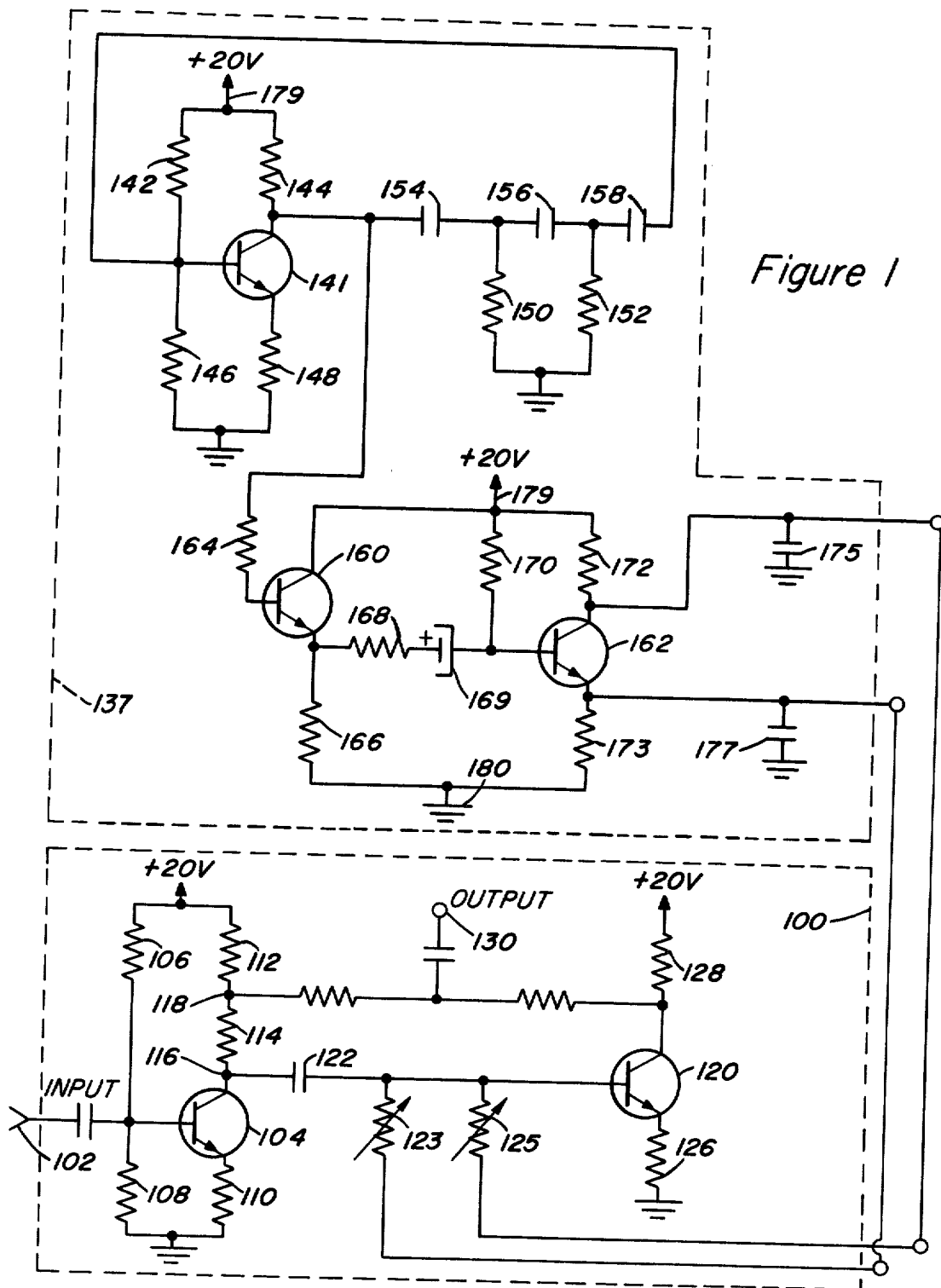
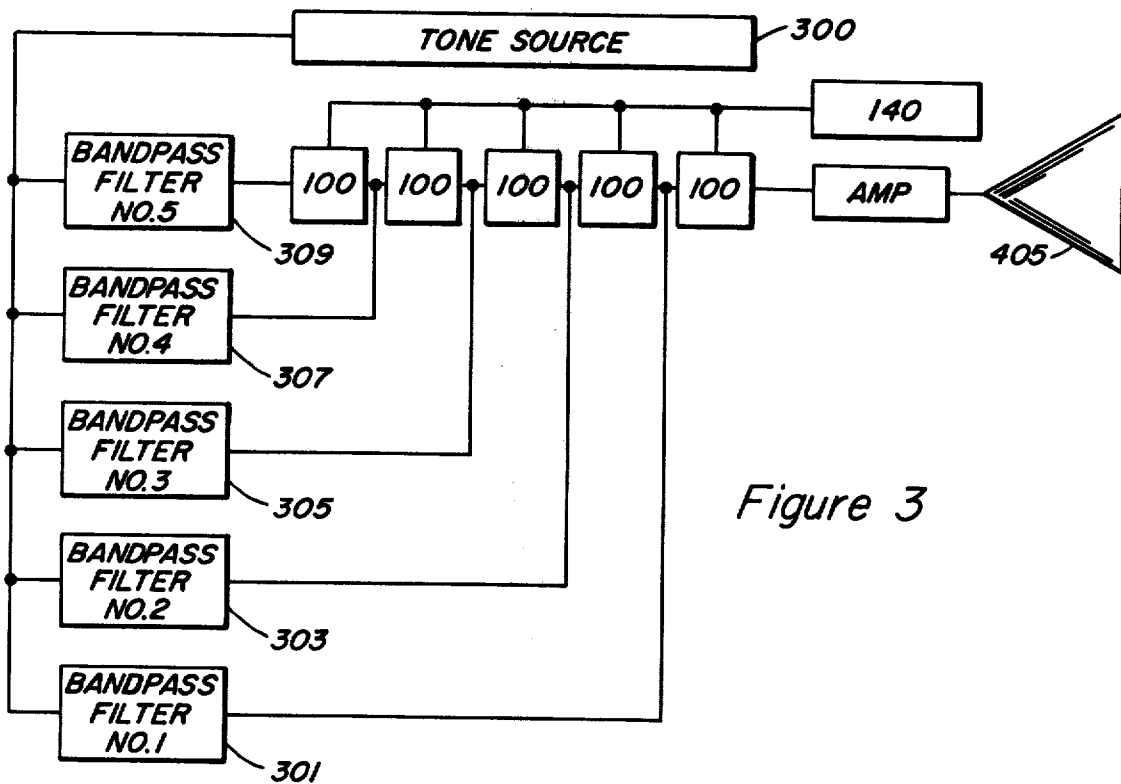
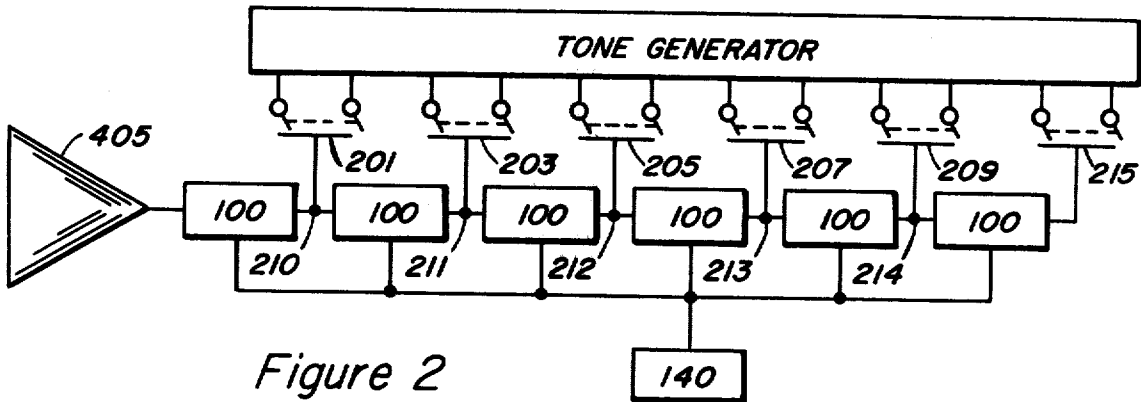


Figure 1

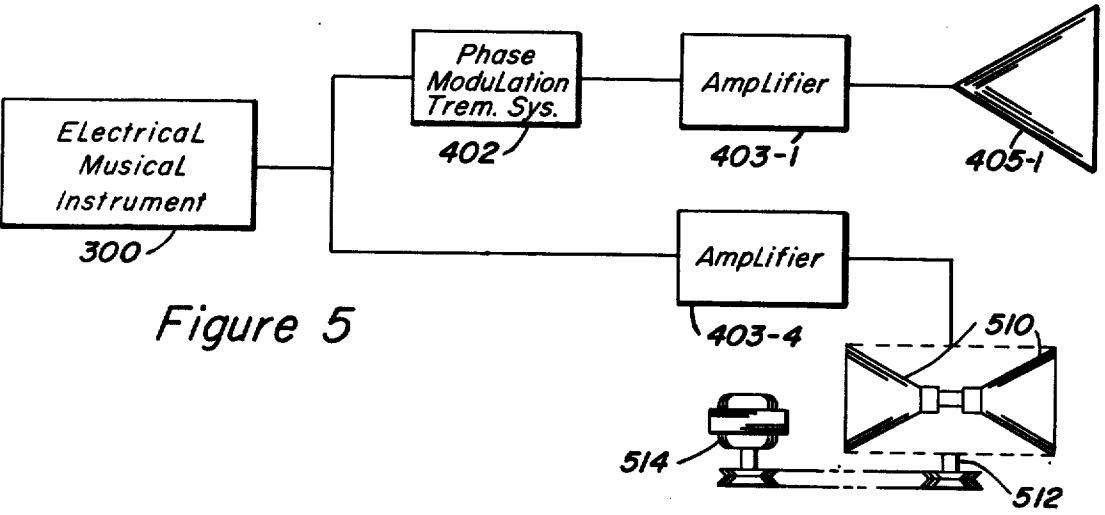
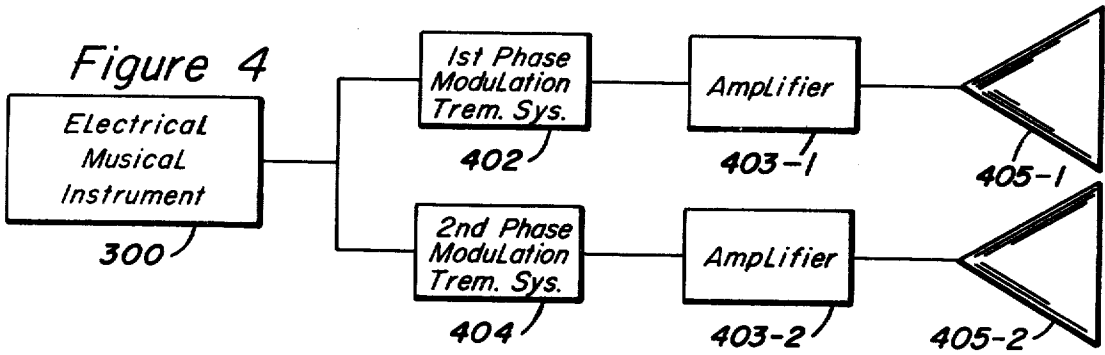
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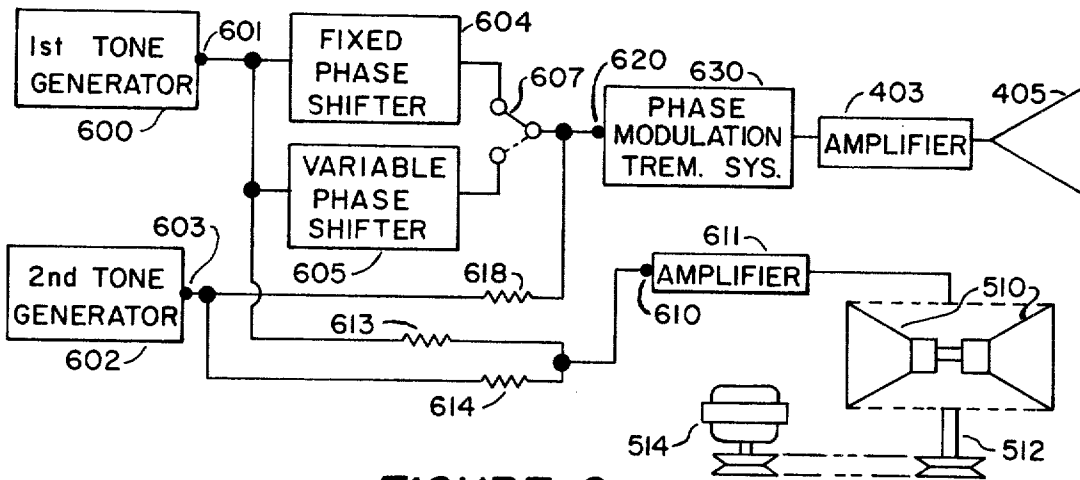


FIGURE 6

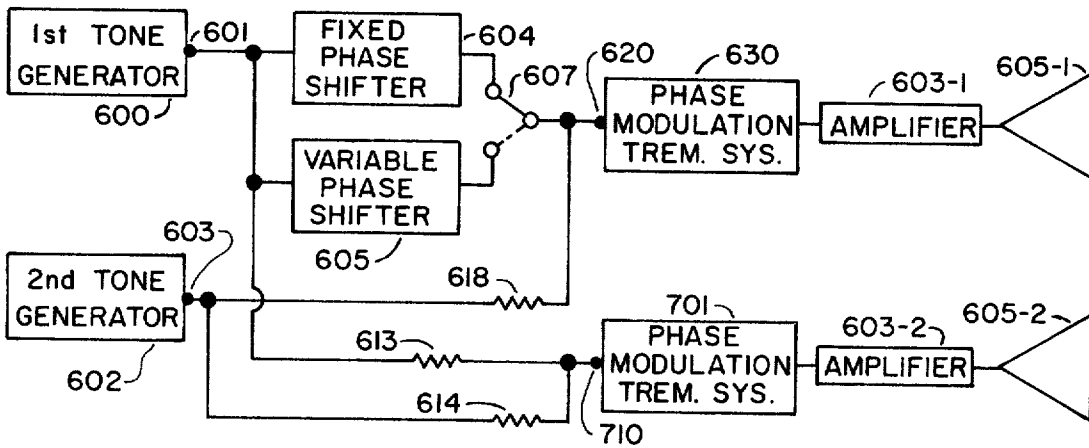


FIGURE 7

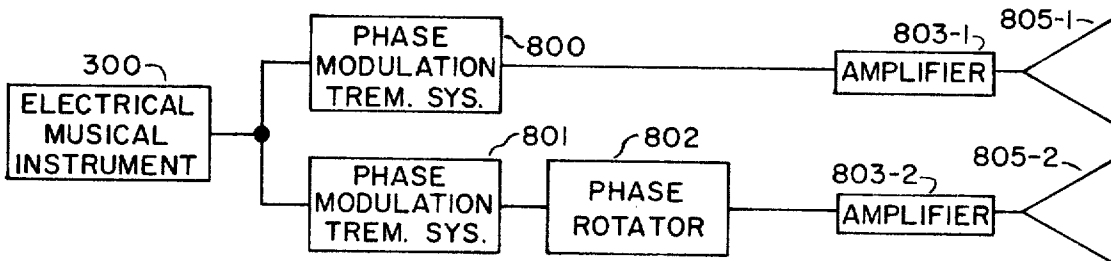


FIGURE 8

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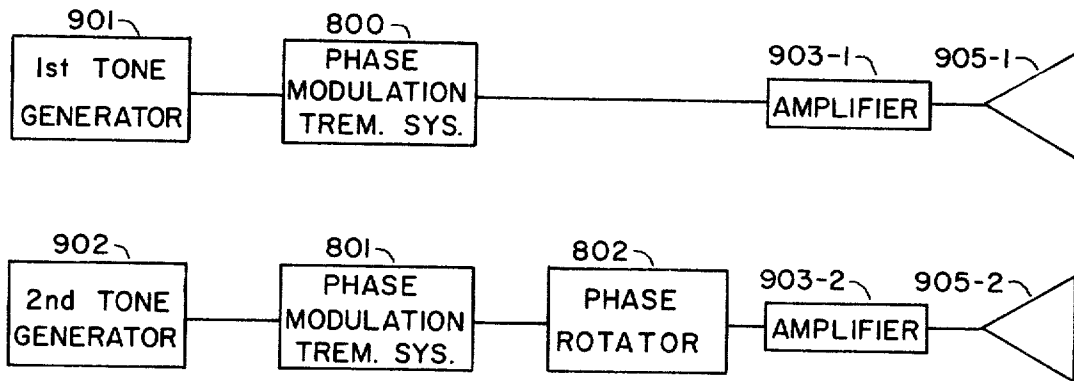


FIGURE 9

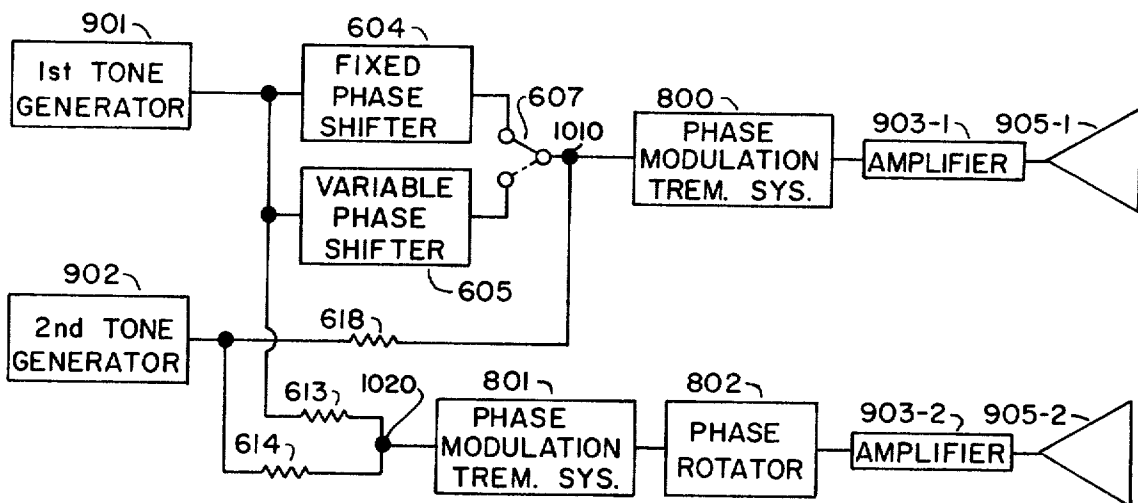


FIGURE 10

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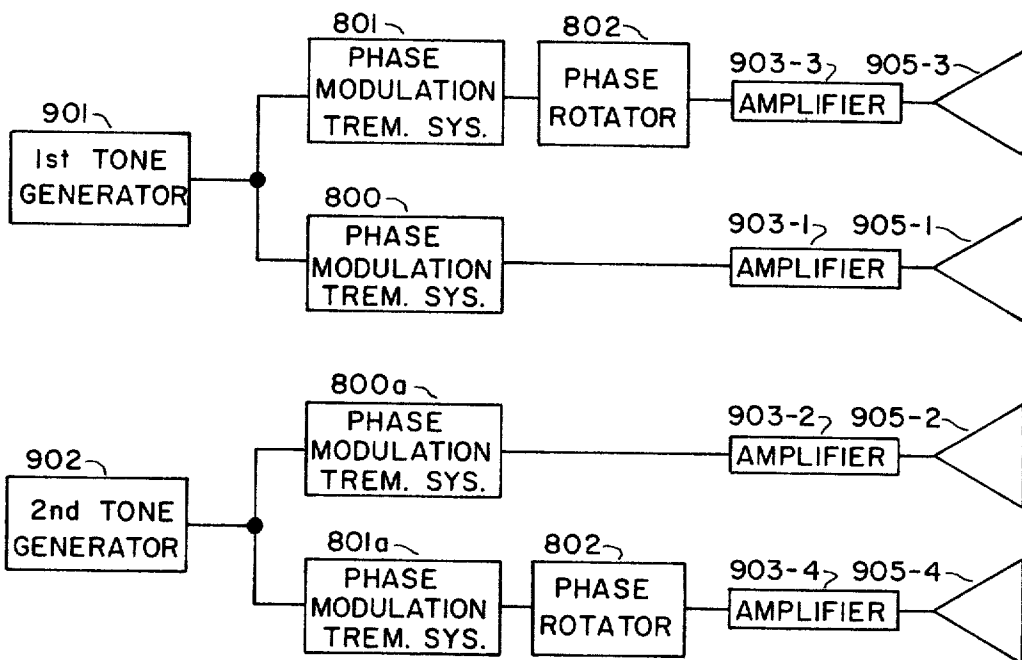


Figure 11

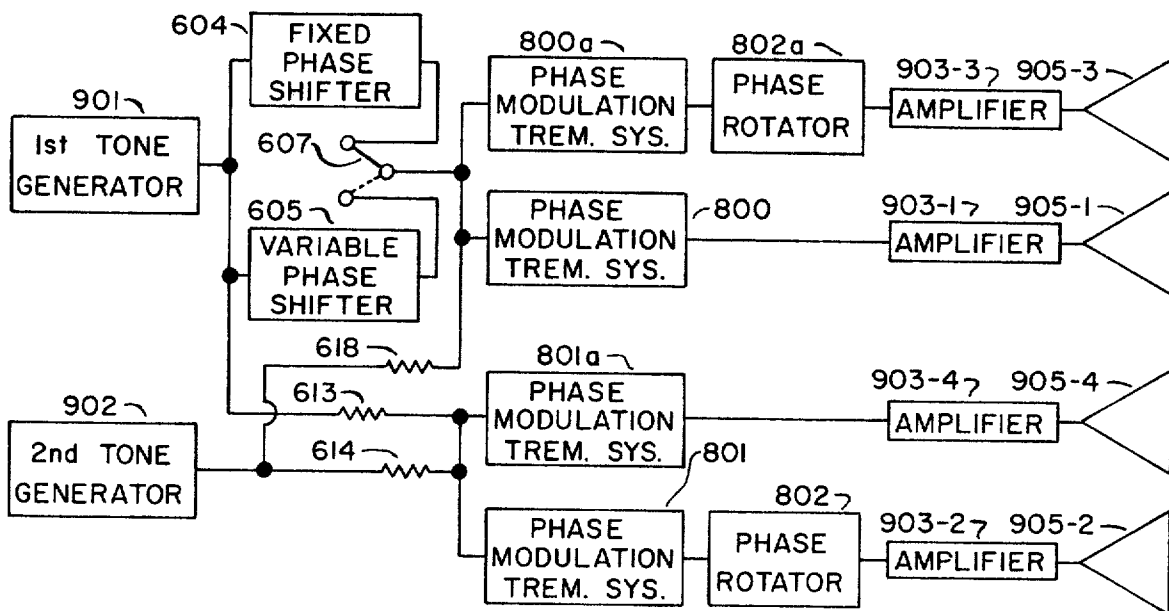


Figure 12

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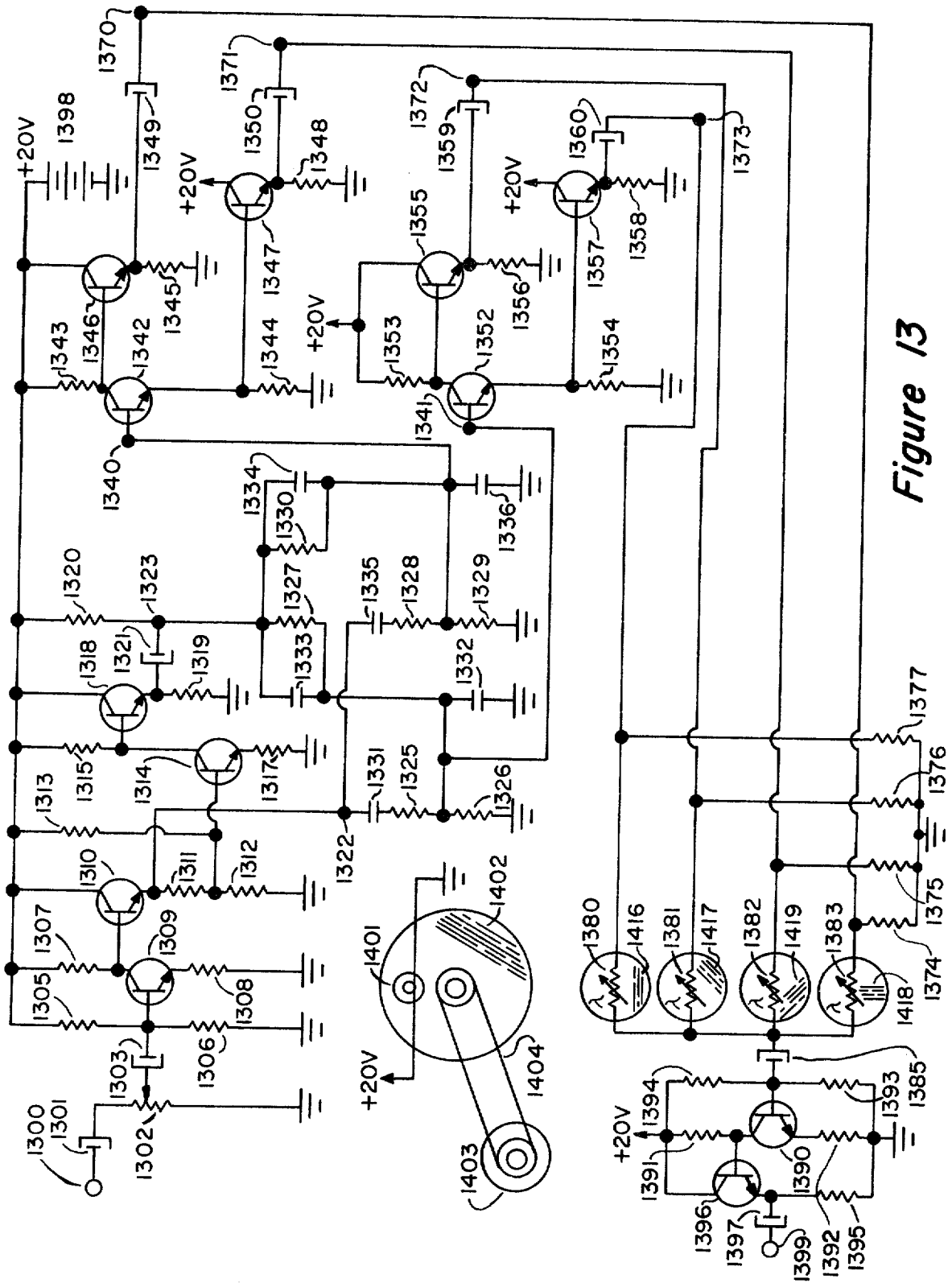


Figure 13

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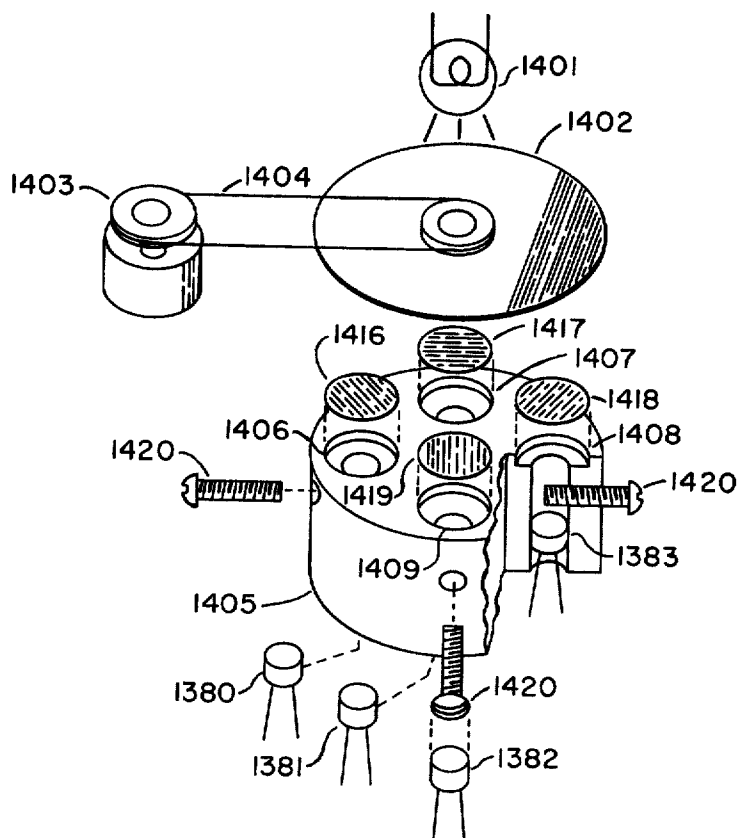


Figure 14

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TREMULANT AND CHORUS GENERATING SYSTEM FOR ELECTRICAL MUSICAL INSTRUMENTS

This is a continuation of application Ser. No. 44,276, filed June 6, 1970, now abandoned. This application is a continuation in part of my co-pending application Ser. No. 656,925 titled, "Tremulant Systems for Electrical Musical Instruments", filed July 28th, 1967 now abandoned.

The subject matter is also related to that disclosed in my co-pending application Ser. No. 864,026 titled, "Vibrato System for Electrical Musical Instrument," filed Oct. 6th, 1969.

STATE OF THE ART

Many systems have been proposed for producing tremulant effects in electrical musical instruments such as organs, guitars and the like. Amplitude modulation of an audio channel is easy to accomplish, but musically the result is not generally satisfactory. In electronic organs it is common to frequency modulate the tone generator, and the resulting "vibrato" is more pleasing than amplitude modulation, but still leaves much to be desired, musically. In addition, varying the pitch of the generator causes all of the signals derived therefrom to have vibrato, and it precludes, in the case of an electric organ, the possibility of having vibrato on one keyboard and not on another, or on one voice and not on another.

One of the reasons for the limited musical appeal of the above tremulant systems is the simplicity of the effect. Most real musical instruments and organ pipes produce complex tremulant effects that involve several types of modulation. In addition, most instruments radiate sound energy from several parts of the instrument at the same time and when such instruments are modulated (as for example by modulating the air pressure applied to a wind instrument), the resultant acoustic modulation is very complex, and produces a subjective effect on the listener that differs from that produced by simple electrical modulation, in much the same way as a stereophonic recording differs from a monoral recording. In the latter case one dimension is missing.

Acoustic, or mechanically imparted tremulants are well known and widely used. One example is shown in the Patent to Donald J. Leslie, Re-issue 23,323, issued Jan. 9, 1951. Such "rotor" tremulants are very effective in producing certain complex tremulant effects having many of the dimensional qualities previously referred to. So far, however, they have been employed most successfully on electrical signals substantially devoid of natural harmonics. On such flute-like sounds the tremulant effect is very natural and pleasing, but on more complex waveforms, all rotors appear to produce much more severe modulation of the higher order harmonics as compared to the fundamental and low order harmonics, and, as a result, the tremulant is unnatural. Many attempts have been made to synthesize the chorus effects inherent in the sound of large pipe organs, but the results have been generally disappointing.

SUMMARY OF THE INVENTION

This invention relates to tremulant and chorus generating systems for electrical musical instruments, and to systems for applying a tremulant effect to signals that have been generated without tremulant.

Throughout this disclosure, the term "tremulant" refers to any sub-audio modulation of the musical signal and may include frequency modulation, phase modulation, amplitude modulation, timbre modulation, etc. Similarly, the term "vibrato" refers to frequency modulation only. It is believed that these definitions correspond to the generally accepted uses of these terms in this art.

A primary object of this invention is to provide improved and more natural tremulant and chorus effects for electrical musical instruments.

In one form of the invention, tone signals are applied simultaneously to two audio channels, each having a separate loudspeaker. When signals in each channel are separately phase modulated according to the invention, the listener perceives a complex "stereophonic" illusion as a result of the acoustic mixing of the signals from the two loudspeakers.

In other forms of the invention, signals representative of different notes of a chord are processed differently in the two channels to create chorus effects having a strong three dimensional character.

In another embodiment signals are applied to a plurality of channels, at least some of which channels contain means for phase modulating the signals at a tremulant rate and also for continuously and simultaneously phase rotating the signals at a sub tremulant rate.

All forms of the invention are independent of the type of tone generator employed, and can be used in musical systems where it is desired to have the tremulant effect selectively applicable to different divisions, or to different stops of an instrument.

These and other objects and advantages inherent in the invention will become apparent from the following description of certain embodiments of the invention as shown in the accompanying drawings.

IN THE DRAWINGS

FIG. 1 is a schematic diagram of certain distinctive components of a phase modulating tremulant system; FIG. 2 is a block diagram of an entire electrical phase modulation tremulant system;

FIG. 3 is a block diagram of a different phase modulation tremulant system;

FIG. 4 is a block diagram of a stereophonic tremulant system according to the invention;

FIG. 5 is a block diagram of an alternative stereophonic tremulant system;

FIG. 6 is a block diagram of a tremulant system for instruments utilizing more than one tone generator and including a mechanically rotated tremulant device;

FIG. 7 is a block diagram of an alternate system to that shown in FIG. 6 but which is all electronic in operation;

FIG. 8 is a block diagram of a stereophonic tremulant system similar to that of FIG. 4 and with additional means for producing an enhanced chorus effect;

FIG. 9 is a block diagram of a tremulant and chorus generating system especially useful with organs of the "locked octave" type;

FIG. 10 is a block diagram of an alternate arrangement to that shown in FIG. 9;

FIG. 11 is a block diagram of a tremulant and chorus generating system for an electrical musical instrument having two tone generator coupled to four audio channels and four loudspeakers;

FIG. 12 is a variation on the system of FIG. 11;

FIG. 13 is a schematic circuit diagram of a phase rotation system suitable for use with the invention; and FIG. 14 is a photo electric scanning device for use with the circuitry of FIG. 13.

It is known that a tremulant effect can be produced by phase modulating an electrical signal. Two such systems are described in U.S. Pat. No. 3,146,292 to Donald Bonham, dated Aug. 25, 1964 and U.S. Pat. No. 2,382,413 to John W. Hanert, dated Aug. 14, 1945.

Referring first to FIG. 1, I have indicated a phase modulation tremulant system having desirable characteristics for use in the invention. The circuitry included within the dotted line 100 constitutes a phase modulator, capable of shifting the phase of signals applied to its input terminal 102 by any amount up to a maximum of 180 electrical degrees. Transistor 104 and resistors 106, 108, 110, 112, and 114 constitute a common emitter amplifier having dual output terminals at 116 and 118. The output signal at terminal 116 is applied to the base of transistor 120 through a phase shift network including capacitor 122 and resistors 123 and 125. If signal from terminal 118 is mixed in a suitable proportion with the signal that appears at the collector of transistor 120, it will be found that the combined signal at the output terminal 130 will have a substantially constant amplitude but will vary in phase in response to the phase shift that takes place in the phase shift network including capacitor 122 and resistors 123 and 125, but with an amount of phase shift equal to twice the phase shift occurring in the network.

If the resistance of resistors 123 and 125 are made to vary at a suitable tremulant rate, unmodulated signals applied to input terminal 102 will appear modulated at output terminal 130. In the embodiment shown, resistors 123 and 125 are silicon carbon varistors which have a resistance that varies as a function of applied current. Still referring to FIG. 1, the circuitry enclosed within the dotted line 137 constitutes a tremulant frequency oscillator, and varistor driver for the purpose of causing a current varying at tremulant frequency to flow through the varistors. In this way the signal frequency resistances of the varistors 123 and 125 are caused to vary at the tremulant frequency.

The transistor 141, within the rectangle 137, resistors 142, 144, 146, 148, 150 and 152, and capacitors 154, 156 and 158 constitute a conventional phase shift oscillator. By suitable selecting the values of the components, this oscillator can be tuned to supply a suitable sub-audio frequency signal (generally between about $\frac{1}{2}$ hz and 8hz). This signal is applied to the emitter follower consisting of transistor 160 and resistors 164 and 166, which is in turn connected to the varistor driver consisting of transistor 162 and components 168, 169, 170, 172, 173, 175 and 177. Ordinarily, current can flow in the circuit including the plus 20 volt supply 179, resistor 172, varistors 123 and 125, resistor 173 and ground at 180. The collector-emitter resistance of transistor 162, however, acts as a variable resistance shunt, which in turn causes the varistor current to vary in response to the drive signal applied to the base of transistor 162. If, for example, transistor 162 is driven into saturation, practically no current can flow in the varistors because the collector and emitter potentials are almost equal. At the other extreme, if the transistor is driven to cut-off, the maximum current in the varistors will be determined primarily by the value of the resistors 172 and 173.

If apparatus according to FIG. 1 is interposed in an audio channel of an electrical musical instrument, the resulting tremulant effect is similar to that of a true vibrato but with a significant difference. To fully correspond to a true vibrato, it would be necessary that the amount of phase shift produced increase in direct proportion to the frequency of the signal being modulated. Since this does not happen, the amount of vibrato is less on high frequency signals than it is on low frequency signals.

For certain types of musical sounds, this type of tremulant is very satisfactory, but it is noticeably different than a vibrato.

Rotors, such as those previously referred to, produce tremulants having a greater effect at high frequencies than at low frequencies, and so have different characteristic sound. For flute-like sounds, the rotor tremulant is highly satisfactory, and in FIG. 2, I have shown an electronic system that can be arranged to produce a tremulant very much like a vibrato, or that can be arranged to produce a phase shift tremulant that actually has relatively greater phase shift at high frequencies than a true vibrato, and, hence, more nearly simulates a rotor tremulant.

Referring now to FIG. 2, I have indicated at 201, 203, 205, 207, 209 and 215 a tone generator divided into groups of notes of low frequencies, medium low frequencies, medium frequencies, medium high frequencies and high frequencies. I have indicated signal input terminals 210, 211, 212, 213, and 214 to a cascaded plurality of variable phase modulators 100 (circuit of FIG. 1). The generators are arranged so that the low frequency notes are affected by only a single phase modulator while the low medium frequency notes are subjected to two phase modulators, and so on up through the highest combined action of many stages of phase shift. It is to be understood, of course, that all the individual phase modulators 100 are connected to a single drive 140, so that all the phase modulators act in synchronism. By adjustment of the resistance values of the varistors 123 and 125, or the drive current through them, it is possible to make any individual phase modulator produce a maximum phase shift having any value up to 180 electrical degrees. Thus, by proper selection of the values of the components of the individual modulators, and by using a suitable number of sections, it is readily possible to produce any desired "phase shift versus frequency" characteristic.

Referring now to FIG. 3, I have indicated an alternate system for producing tremulant effects wherein almost any desired phase shift versus frequency characteristic can be produced. At 300 I have indicated an electrical tone source which may, for example, represent the electrical signals from an electric organ, or from an electric guitar or other instrument. At 301, 303, 305, 307, and 309, I have indicated band pass filters, each of which passes electrical signals within a relatively limited frequency range. Band pass filter 301, for example, might be arranged to pass frequencies between about 50 to 250 hz. Similarly, band pass filter 303 might be adjusted to pass frequencies between 200 and 400 hz.; band pass filter 305 passes 400 to 800 hz.; band pass filter 307 passes 800 to 1600 hz.; and filter 309 passes all frequencies higher than 1600 hz.

Each of the band pass filters is associated with one or more phase modulator sections. Since the higher frequencies require greater phase shifts, I have shown a

total of five stages 100 associated with the highest group. Again, by suitable arrangement of the individual phase modulator sections, and by selection of the number of stages associated with each band pass filter, it is readily possible to process the signal to produce a tremulant having almost any desired frequency versus phase shift characteristic.

Referring now to FIG. 4, I have indicated a tremulant system that produces a pronounced stereo effect. At 300 I have indicated an electrical tone source, which again may represent an electronic organ, amplified guitar or any other source of electrical signals. At 402 I have indicated an electrical phase shift tremulant system of the type that produces a tremulant having a relatively constant phase shift regardless of frequency, an amplifier 403-1 and speaker 405-1. This, for example, may be a system as shown in FIG. 1. Also associated with the source 300, is a second channel including a tremulant system 404, amplifier 403-2, and loudspeaker 405-2, in which channel is produced a tremulant effect as a function of frequency, and preferably to a greater degree than in a vibrato. Such a system may, for example, be made according to either FIG. 2 or FIG. 3.

In my prior U.S. Pat. No. 3,229,019 dated Jan. 11, 1966 I disclose how two different tremulant systems, each having certain undesirable characteristics, can be made to affect a single signal in such a way as to overcome the limitations of each system. Apparatus according to FIG. 4 does the same thing and, in addition, adds an important additional dimension to the effect by virtue of the amplitude modulation that occurs acoustically due to the dynamically changing phase difference between the signals in each of the two channels. Since this amplitude modulation is the result of the mixing of signals from the two sources at the ear, it will be found that due to difference in the path lengths from the two sources to each of a listener's ears, the amplitude modulation that occurs in one ear will at most frequencies be out of phase with the amplitude modulation occurring in the other ear. This, apparently, is the basis for the strong stereophonic illusion.

In FIG. 5 I have indicated a stereo tremulant system based on the *modus operandi* of the system of FIG. 4, except that the electrical phase shift tremulant 404, and amplifier 403-2 (of FIG. 4) have been replaced in FIG. 5 with an amplifier 403-4 and a mechanical tremulant in the form of loudspeakers 510, arranged to rotate about the axis 512. A motor 514 is provided, to rotate the rotor at a speed equal to one half of the desired tremulant frequency.

As previously mentioned, almost all "rotor" tremulant devices produce substantially greater amounts of modulation at high frequencies as compared to low frequencies and so are equivalent, insofar as the operation of the stereophonic tremulant is concerned, to the electronic systems of FIGS. 2 and 3.

The particular rotor shown in FIG. 5 uses two loudspeakers 510, and the resultant acoustic comparison between the signals emanating from these two speakers 510, and the electrically modulated signals emanating from loudspeaker 405-1 is especially effective. It should be understood, however, that any rotating loudspeaker system, or any system for mechanically imparting a tremulant effect, as for example by the rotary sound channel described in the aforementioned Leslie

Reissue Patent, can be substituted, with many of the benefits of the embodiment illustrated.

Some electronic organs employ two or more tone generating systems in order to get better chorus effects than are available from a single generating system. To realize any important chorus effect, it is necessary to reproduce signals from each generating system through separate amplifiers and loudspeakers. To obtain the advantages of the stereophonic tremulant according to this invention, it would of course be possible to duplicate apparatus according to FIG. 4 or FIG. 5 for each tone generator, but this would involve considerable expense.

I have found that it is possible to retain all of the advantages of a two generator organ and still produce the stereophonic tremulant using but two amplification channels.

Referring to FIG. 6, blocks 600 and 602 indicate separate groups of oscillators, or other generators of electrical signals, having output terminals 601 and 603 respectively. Signals from both generators are applied to the input terminal 610 of amplifier 611 by means of the mixing resistors 613 and 614. The output of amplifier 611 is applied to the speakers 510 which may be as described in connection with FIG. 5.

Block 630 indicates an electronic phase modulation tremulant system having an input terminal 620. Tremulant modulation as produced by any of the previously described methods is effective. Signals from tone generator 602 are applied to input 620 through mixing resistor 618. Signals from the generator 600 are applied to the input 620, but only after going through one of the blocks 604 or 605 as determined by the setting of the switch 607. 604 may be any type of phase inverter such as a common amplifier, or a transformer, or it may be any kind of phase shift network capable of producing a phase shift preferably in the order of 180 electrical degrees. With switch 607 in its full line position, the operation of the stereophonic tremulant system is as previously described, but any amplitude modulation caused by alternate addition and subtraction beating signals from separate sources 600 and 602 will be phase displaced by 180 degrees as reproduced by loudspeaker 405 in comparison to the amplitude reproduced by loudspeakers 510.

With switch 607 set in its dotted line position, a slowly occurring variable phase shift is introduced instead of the constant 180 degree phase shift, and the beating occurring in the two channel goes through a slowly varying phase cycle which produces an enhanced chorus effect. The variable phase shifter 605 may be any device for introducing a slowly occurring phase shift. The use of a phase rotator as shown in FIG. 13, and as described in connection with FIGS. 13 and 14 is one way of introducing a suitable slowly occurring phase shift. It would also be possible to use any type of phase shifting network to slowly vary one of the phase shifting elements, either electrically or mechanically. In either position of switch 607, a highly desirable chorus effect with stereophonic tremulant is produced.

It should be understood that in FIG. 6, the block 600, labeled "First Tone Generator," and the block 602, labeled "Second Tone Generator," can be either complete full-range tone generators, or can each supply only some of the notes within the range of the instrument, in such a way that every note is supplied by at least one of said generators.

It has been found, for example, that very desirable chorus effects are created when each of the generators 600 and 602 produce alternate semi-tones of the scale, or when they produce alternate octaves. Any grouping wherein signals from each generator contain strong partials having coincident frequencies can be effective in producing the desired, enhanced chorus effect.

The system of FIG. 7 is similar to that of FIG. 6 except that the rotary tremulant channel has been replaced by an additional electronic phase modulation tremulant system 701, amplifier 630-2, and loudspeaker 605-2. Phase modulation tremulant systems 603 and 701 may both be as previously described in connection with block 402 in FIG. 4 or both according to block 404, or one may be according to 402 and the other according to 404. Alternately they may be according to my previously mentioned co-pending application titled, "Vibrato System for Electrical Musical Instrument." Output signals from each phase modulation tremulant system are amplified by amplifier 603-1 and 603-2 and are reproduced by loudspeakers 605-1 and 605-2. The loudspeakers are preferably placed far apart; the best effect being obtained when they are positioned on opposite sides of a room.

In FIG. 3 the output of the electrical musical instrument 300 is applied to two amplification channels, the first including the phase modulation tremulant system 800, amplifier 803-1, and loudspeaker 805-1. The second channel includes a phase modulation tremulant system 801, continuous phase rotator 802, amplifier 803-2 and loudspeaker 805-2. Phase rotation is a process by which the phase of a signal is continuously changed in the same direction, in this case at a rate in the order of 360 electrical degrees per second. FIGS. 13 and 14 which will be explained more fully hereinafter show one satisfactory way of accomplishing this low phase rotation. Attempts have been made previously to use various types of phase shift devices for producing chorus effects in electrical musical instruments, but even very complicated systems have produced disappointing tonal results. The rich and satisfying chorus effect produced according to the system of FIG. 8 is a result of the acoustic mixing of the differently phase processed signals reproduced by the separate loudspeakers 805-1 and 805-2. While it is preferable that the tremulant frequency produced by each of the individual phase modulation tremulant systems 800 and 801 be different, it is not essential that the character of the modulation be different. Any combination of the phase modulation tremulant systems described in this application or in my co-pending applications are effective.

FIG. 9 illustrates a two channel system for use with a dual tone generating system as described in connection with FIG. 6. An amplification channel for the first tone generator 901 includes the phase modulation tremulant system 800, amplifier 903-1 and loudspeaker 905-1. A separate amplification channel for the tone generator 902 includes the phase modulation tremulant system 801, the continuous phase rotator 802, and the amplifier 903-2, and loudspeaker 905-2. This system is especially useful with organs in which the various octavely related pitches are generated from locked or synchronized frequency dividers. Very effective octave chorus is synthesized if generator 901 is arranged to supply all of the tones of the first, third, and fifth octaves of the musical instrument and the second

tone generator 902 is arranged to produce the second, fourth, and sixth octaves.

The system of FIG. 10 is similar to that of FIG. 9 but produces a superior chorus effect by virtue of the matrixing of the signals from both of the tone generators into each of two audio channels. Resistors 613 and 614 couple signals from both tone generators to the input terminal 1010 of an amplification channel including phase modulation tremulant system 801, continuous phase rotator 802, amplifier 903-2, and loudspeaker 905-2. Signals from both tone generators are also coupled to the input terminal 1020 of the amplification channel including phase modulation tremulant system 800, amplifier 903-1, and loudspeaker 905-1. Signals from generator 902 are directly connected through resistor 618, but signals from the generator 901 are first phase shifted by the fixed phase shifter 604, or by the variable phase shifter 605 as described in connection with FIG. 6. In this form of the invention all of the notes are subjected to the processing of both phase modulation tremulant systems and by the continuous phase rotator, and reproduced by both loudspeakers.

FIG. 11 is a four channel version of FIG. 9. As in FIG. 9 all of the tones of the instrument are produced by the two tone generators 901 and 902. Tone signals from generator 901 are applied to two amplification channels; the first including phase modulation tremulant system 800, amplifier 903-1, and loudspeaker 905-1; the second including phase modulation tremulant system 801, phase rotator 802, amplifier 903-3 and loudspeaker 905-3. Tone signals from the second tone generator 902 are identically processed in a duplicate pair of channels; the first including phase modulation tremulant system 800a, amplifier 903-2, and loudspeaker 905-2; the second including phase modulation tremulant system 801a, phase rotator 802a, amplifier 903-4, and loudspeaker 905-4.

FIG. 12 is another tremulant and chorus generating system using two tone generators and four amplification channels. The system is identical to that of FIG. 10 with two additional amplification channels, the first including the phase modulation tremulant system 800a, phase rotator 802a, amplifier 903-3 and loudspeaker 905-3; the second including phase modulation tremulant system 801a, amplifier 903-4, and loudspeaker 905-4. In this system all tone signals are reproduced by all four loudspeakers after being differently phase processed in each of the four channels.

The chorus effect produced by the systems of either FIG. 11 or FIG. 12 are very dramatic, and in listening tests have been judged to be subjectively superior to the ensemble produced by a moderate sized pipe organ. It is of significance that since all of the loudspeakers are reproducing the same signal information, the total power required to be handled by the individual amplifiers and loudspeakers is relatively small and inexpensive loudspeakers and amplifiers may be used.

FIG. 13 is a schematic circuit diagram of a phase rotation system suitable for use with the embodiments of the invention disclosed in FIGS. 8, 9, 10, 11, and 12. The circuitry of FIG. 13 is used with the photo electric scanning device shown in FIG. 14.

Referring first to FIG. 13, 1300 is an input terminal coupled through capacitor 1301 to the level adjust control 1302 which is coupled through capacitor 1303 to the input of the common emitter amplifier including transistor 1309 and resistors 1305 through 1308. 1310

is a direct coupled emitter follower having an output at terminal 1322. A portion of the output signal determined by the ratio of resistors 1311 and 1312 is applied to the base of the common emitter amplifier including transistors 1314 and resistors 1315 and 1317. Transistor 1318 is an emitter follower direct coupled to the collector of transistor 1314 and having a load resistor 1319. Coupling capacitor 1321 connects the output to terminal 1323. Resistors 1311 and 1312 are selected so that the amplitude of the signal at output terminal 1323 will be equal in amplitude to the signal on output terminal 1322, but it will be inverted in phase due to the inverting action of transistor 1314. Each of these terminals is connected to a separate input of the phase shift network consisting of resistors 1325 through 1330 and capacitors 1331 through 1336. This phase shift network has two output terminals 1340 and 1341 connected respectively to two phase inverters; the first including transistor 1342 and resistors 1343 and 1344, and the second including transistor 1352 and resistors 1353 and 1354. Four output signals taken respectively from the collector and emitter of transistor 1342 and from the collector and emitter of transistor 1352 are each "hardened" by an emitter follower transistor 1346, 1347, 1355, and 1357, and are connected to the output terminals 1370, 1371, 1372, and 1373 through the coupling capacitors 1349, 1350, 1359 and 1360. Resistors 1345, 1348, 1356 and 1358 are load resistors for the respective emitter followers. When suitable values are selected for the resistors and capacitors in the phase shift network, identical signals appear at terminals 1340 and 1341 except that they have a constant phase separation of 90 electrical degrees. The phase inverters 1342 and 1352 produce inverted and non-inverted outputs from each of these inputs with the result that terminals 1370, 1371, 1372, and 1373 experience identical signals except that the four signals have relative phases of 0, 90, 180, and 270 degrees. Each of these signals is applied to one terminal of a photo resistor 1380, 1381, 1382, or 1383, the output terminals of which are all connected through capacitor 1385 to the output amplifier including transistors 1390 and 1396 and resistors 1391 through 1395.

The instantaneous resistance of each photo resistor is a function of the amount of light impinging upon it, and if all four photo resistors were to be equally illuminated the output level at terminal 1399 would be zero. If the photo resistors are sequentially illuminated the phase of the output signal will constantly change. Since zero degrees and 360° are equivalent, a signal can be continuously "rotated" by sequentially scanning 0° - 90° - 180° - 270° - 0° - 90° - 180° - 270°, etc. Further, if the photo resistors are scanned by light whose amplitude varies sinusoidally, the output signal amplitude remains constant.

In FIGS. 13 and 14, 1401 is a source of light which may be a small incandescent lamp. The disc 1402 is a light polarizing filter in the form of a transparent disc about .030 of an inch thick and arranged to be rotated by a motor 1403 and belt 1404. A suitable material is made by the Polaroid Corporation of Cambridge, Mass. under the designation H. N. 32. The supporting block 1405 contains four holes or cavities, 1406, 1407, 1408 and 1409, into which are mounted the four photoresistors 1380, 1381, 1382, and 1383. Each of the cavities is further arranged to accept an additional polarizing filter 1416, 1417, 1418, or 1419. These are small discs

of the same material as disc 1402 and are assembled so that their polarizing axis are respectively rotated 45°.

Light from the lamp 1401 must pass through two polarizing filters before reaching any photo resistor. Each individual filter is substantially transparent, but only to light of a given polarity. Accordingly when light passes through two filters, the transmission is a function of the relative angles of the axis of polarization of the two filters. In the position where the axis are parallel, light transmission through both filters is approximately 85 percent. When one filter is rotated 90° the light transmission drops to about 2 percent. Furthermore, when one filter is rotated the light transmission varies sinusoidally with the angle of rotation. Since the resistance of any photo resistor is substantially a linear function of its illumination, it follows that the output voltage at terminal 1399 will be independent of the position of the disc. It should be noted that the maximum variation in light transmission occurs with every 90 degrees of rotation of disc 1402, and therefore the filters 1416, 1417, 1418, and 1419 are rotated only 45 degrees relative to one another, and the phase of the signal is rotated 360 electrical degrees for every half rotation of disc 1402.

The adjusting screws 1420 are arranged to partially shadow the light falling on the photo resistors; affording a convenient way of adjusting for variations in the characteristics of individual cells.

For use with the invention herein disclosed, it is not particularly important in which direction the disc is rotated. In one direction the phase is continually advanced, in the other it is continually retarded. There is some advantage in causing the speed of rotation to vary slightly, and in the appended claims reference to continuous phase rotation is intended to mean phase rotation in a substantially single direction for time periods of at least several seconds. If the direction of phase rotation were to change over a longer period of time it would not be noticed when playing ordinary music and the effect would be equivalent to continuous rotation.

Others may readily adapt the invention for use under various conditions of service by adapting one or more of the novel features disclosed.

As at present advised with respect to the apparent scope of my invention I desire to claim the following subject matter.

1. A stereophonic tremulant system for an electrical musical instrument comprising:

a source of electrical signals representative of music; a first transmission channel having an input and output and including a first loudspeaker connected to said output;

a second transmission channel having an input and an output and including a second loudspeaker connected to said output;

first modulation means connected between said input and output of said first transmission channel for continuously phase modulating signals in said first channel so that the resulting frequency modulation of said first channel signals is greater at low signal frequencies than at high signal frequencies;

second modulation means connected between said input and output of said second channel for continuously modulating signals in said second channel so that the resulting frequency modulation of said second channel signals is greater at high frequencies than at low frequencies; and

means for applying the same signals from said source of electrical signals to both said first and said second transmission channel inputs.

2. Equipment according to claim 1 wherein said second modulation means includes a rotor.

3. A tremulant system for an electrical musical instrument, comprising:

a plurality of tone generators, each capable of producing at least some of the notes of a musical scale; means for collecting a first sub-group of signals from certain of said generators;

means for collecting a second sub-group of signals from others of said generators;

a first transmission channel having an input and an output and including a first loudspeaker connected to said first output;

a second transmission channel having an input and output and including a second loudspeaker connected to said second output;

first modulating means connected between said input and said output of said first transmission channel for continuously modulating signals in said first transmission channel;

second modulating means for continuously and differently modulating signals in said second transmission channel;

first matrixing means for combining signals from both said first and said second sub-groups and for applying the combined signals to the input of said first transmission channel; and

second matrixing means including phase shifting means for combining signals from both said first and said second sub-groups in a displaced phase relationship and for applying the combined signals to the input of said second transmission channel.

4. A tremulant system according to claim 3, further including means for causing said phase relationship to vary at a sub-audio rate.

5. A system according to claim 4, in which said second modulating means includes a rotor.

6. A tremulant system for an electrical musical instrument, comprising:

a plurality of tone generators, each capable of producing at least some of the notes of a musical scale; means for collecting a first sub-group of signals from certain of said generators;

means for collecting a second sub-group of signals from others of said generators;

a first transmission channel having an input and an output and including a first loudspeaker connected to said output;

a second transmission channel having an input and an output and including a second loudspeaker connected to said output;

first modulating means connected between the input and output of said first transmission channel for continuously modulating signals in said first transmission channel;

second modulating means for continuously modulating signals in said second transmission channel;

first matrixing means for combining the signals from both said first and second sub-groups and applying the combined signals to the input of said first transmission channel; and

second matrixing means including phase shifting means for combining in a displaced phase relationship the signals from said first and said second sub-

groups and applying the combined signals to the input of said second transmission channel.

7. A tremulant system according to claim 6, and including additional means in said second transmission channel for causing the signals in said second channel to be continuously phase rotated at a sub tremulant rate.

8. A tremulant system according to claim 6, wherein one of said plurality of tone generators produces only some of the notes of a musical scale and wherein another of said plurality of tone generators produces other notes of said musical scale.

9. A tremulant system according to claim 6, wherein said plurality of tone generators produce the tones of a musical scale, one of said tone generators producing alternate tones of said scale and another one of said tone generators producing the remaining tones of said scale.

10. A tremulant system according to claim 6, wherein one of said plurality of tone generators produces a first octave of a musical scale, and wherein another of said plurality of tone generators produces a second octave of said musical scale.

11. A chorus producing tremulant system for an electrical musical instrument comprising:

a source of electrical signals representative of music; a first transmission channel having an input and an output and including a first loudspeaker connected to said output;

a second transmission channel having an input and an output and including a second loudspeaker connected to said output;

means connecting said source of signals to the input of both said first and said second transmission channels;

first modulation means connected between the input and output of said first transmission channel for continuously phase modulating signals in said first channel at a tremulant rate;

second modulation means connected between the input and output of said second channel at a tremulant rate; and

additional means in at least one of said channels for causing signals in said one of said channels to be continuously phase rotated at a sub tremulant rate.

12. A chorus producing tremulant system for an electrical musical instrument comprising:

a first tone generator for producing a first series of notes of a musical scale;

a second tone generator for producing a second series of notes of a musical scale;

a first transmission channel having an input and an output and including a first loudspeaker connected to said output; the input to said first transmission channel being connected to said first tone generator;

a second transmission channel having an input and an output and including a second loudspeaker connected to said output, the input to said second transmission channel being connected to said second tone generator;

first modulation means connected between the input and output of said first channel for phase modulating signals in said channel at a tremulant rate;

second modulation means connected between the input and output of said second channel for modu-

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lating signals in said second channels at a tremulant rate; and
additional means in at least one of said channels for continuously phase rotating signals in said one of said channels at a sub tremulant rate.
13. A chorus producing tremulant system for an electrical musical instrument comprising:
a source of electrical signals representative of music;
a first transmission channel with an input and output;
first modulation means connected between the input and output of said first channel;
a first loudspeaker connected to said output of said first channel;

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a second transmission channel with an input and output;
second modulation means connected between the input and output of said second channel;
a second loudspeaker connected to said output of said second channel;
means for applying the same signals from said source of electrical signals to the said inputs of said first and second transmission channels; and
additional phase rotating means connected between the modulation means and the output of said second channel.

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