June 9, 1964 A. J. BISSONETTE ET AL 3,136,853

MUSIC ENHANCING SYSTEMS

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FIG. 1

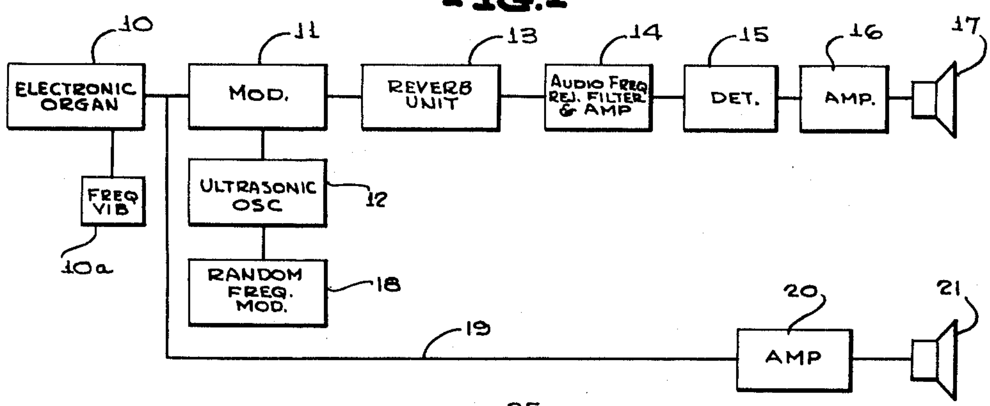


FIG. 2

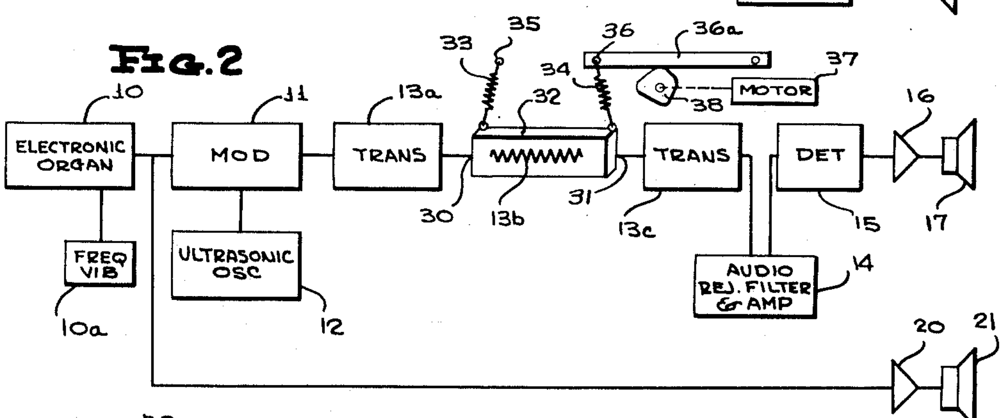


FIG. 3

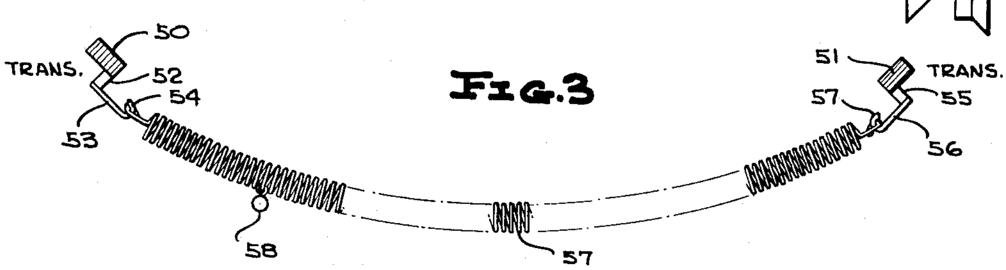
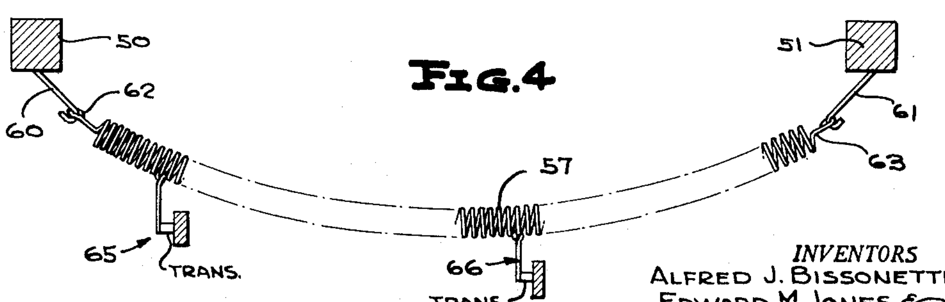


FIG. 4



INVENTORS
ALFRED J. BISSONETTE,
EDWARD M. JONES &
JOHN B. BROMBAUGH
BY Hurvitz and Rose
ATTORNEYS

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FIG. 5

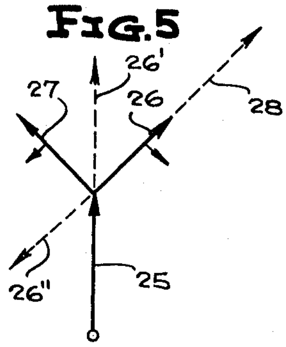


FIG. 9

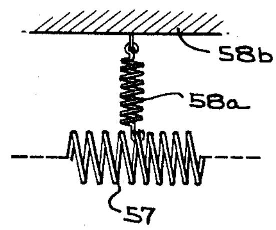


FIG. 6

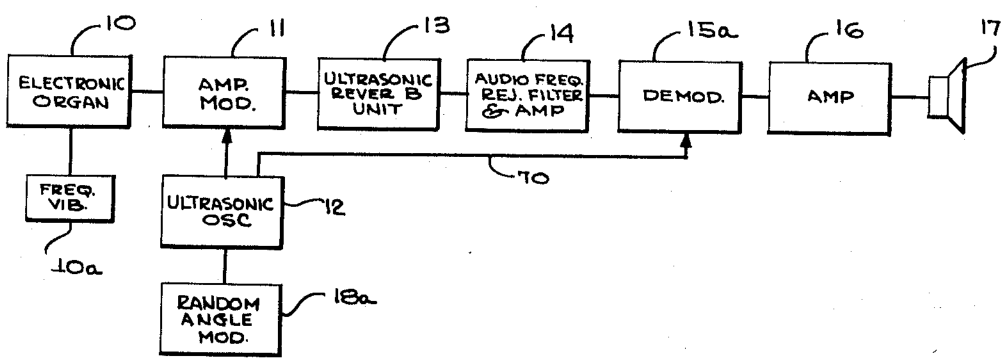


FIG. 7

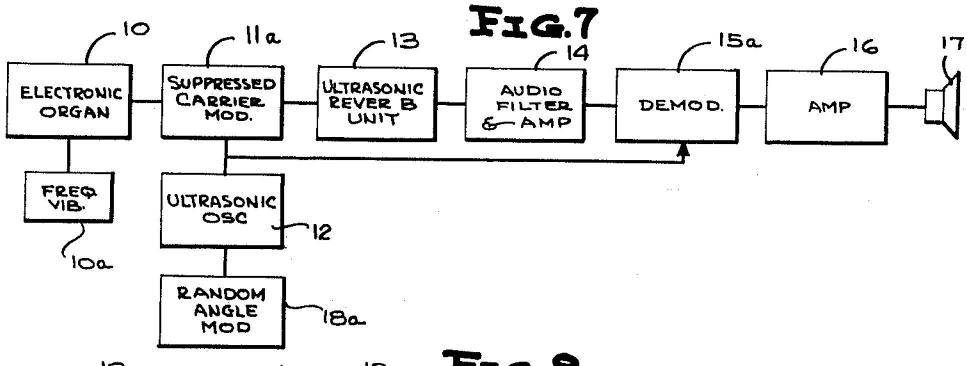
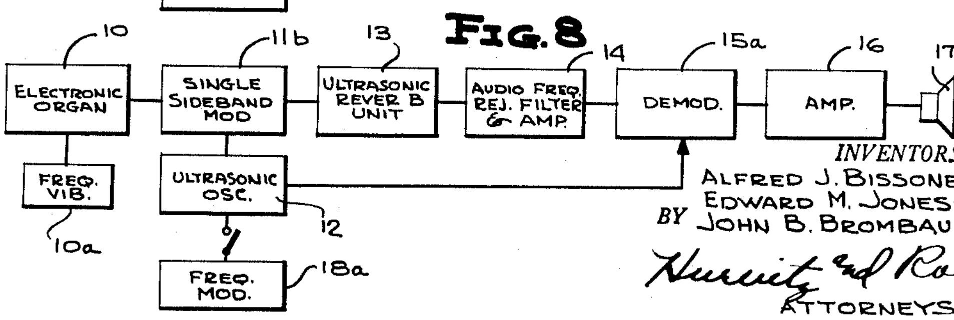


FIG. 8



INVENTORS
ALFRED J. BISSONETTE,
EDWARD M. JONES &
BY JOHN B. BROMBAUGH
Hurvitz and Rose
ATTORNEYS

United States Patent Office

3,136,853
Patented June 9, 1964

3,136,853
MUSIC ENHANCING SYSTEMS

Alfred John Bissonette, Milford, and Edward M. Jones and John B. Brombaugh, Cincinnati, Ohio, assignors to D. H. Baldwin Company, a corporation of Ohio

Filed Apr. 12, 1961, Ser. No. 102,443
21 Claims. (Cl. 179—1)

The present invention relates generally to systems for producing reverberation artificially at ultrasonic frequencies, and more particularly to systems utilizing a reverberatory unit capable of improving the quality of sound by superimposing thereon both reverberatory and chorus effects, the reverberatory unit including a long ultrasonic delay line.

It has long been known in the art of sound generation and reproduction, and more particularly in the art of electronic organs and electronic music production, that improvement in the quality of sound generated by such instruments may be attained by introducing reverberation artificially. It has also been long known that the tonal qualities of electronic musical instruments, such as electronic organs, may be improved by processing the tones generated directly by the instruments, by adding chorus effect thereto. The desirability of adding chorus effect to electronic organ tones in particular, may derive in part from the lack of randomness in the output of some types of organs and the chorus effect may involve the generation of new frequencies or the continuous or random modification of the relative phases and/or amplitudes of the normal frequency components of the tones as produced directly by the instruments.

Elongated helical spring devices have been utilized for introducing reverberatory effects, but these have always hitherto been operative in the audio frequency range. Such springs have been vibrated or driven in various modes, and more particularly in the longitudinal, the transverse and the torsional modes, design formulas for devices operating in such modes being provided in the U.S. patent to Wegel 1,852,795. Such helical spring delay devices have been found to have considerable flutter, and accordingly, in practice reverberatory devices utilizing helical springs have required a plurality of such springs of different length, all operated in parallel. It is characteristic of such springs that they have high attenuations at the high audio frequencies, and furthermore it is extremely difficult to drive such springs uniformly over the required number of octaves, so that audio frequency reverberative devices consisting essentially of one or more helical spring delay lines have frequency characteristics that are hard to compensate for.

As a further difficulty, audio frequency delay lines employed in reverberatory devices possess the basic defect that any mechanical disturbance of the springs results in generation of signals which fall within the same audio frequency band as the desired tonal signals, and which consequently cannot be reduced by filtering. On a theoretical basis it might appear that the noise can be eliminated by vibrating the helical springs torsionally in response to the desired signal, since the disturbances are not normally torsional. Nevertheless, limitations in practical designs of transducers and the random character of perturbations radically reduce the improvements which may be attained by this expedient.

While the recited properties of audio frequency delay lines in the form of helical springs have not destroyed their usefulness as reverberatory devices, and while quite adequate delay lines have been achievable by means of relatively small springs, such reverberatory devices have not been wholly successful in improving the tonal quality of electronic organs or other musical instruments, because of the limitations inherent in helical springs as audio frequency mechanical transmission lines.

In summary, then, audio frequency spring reverberators are limited in usefulness by their poor frequency characteristics, by difficulties in achieving a drive over the required number of octaves, and by their susceptibility to mechanical noise or perturbations.

According to the present invention an audio frequency band representative of music, such as may, for example, be derived from a conventional electronic organ, is converted to an ultrasonic band and the latter subjected to reverberatory delays in a helical wire delay device. The direct output of the reverberatory device may then be filtered to remove audio frequencies, thereby eliminating substantially all direct signals due to mechanical audio frequency disturbances of the helical spring. The ultrasonic band of frequencies may be converted to an audio frequency band and the converted band of signals may be electro-acoustically transduced.

The general concept of generating reverberations at ultrasonic frequencies is known to the art, being disclosed, for example, in U.S. Patent No. 2,318,417 to William B. Phelps, and in U.S. Patent No. 2,421,424 to Barton Kreuzer. However, devices of the latter types have not heretofore utilized long helical wire springs as delay devices. One reason for this failure has been that the design formulas as provided by the Wegel patent, hereinabove referred to, and similar design formulas available from other sources, have appeared to indicate that helical wire delay lines are almost totally ineffective at ultrasonic frequencies, both because of the large attenuations involved in traveling along the delay line at these frequencies, and also because of the shorter total pulse travel time achievable for a given spring because of the increased velocity of travel of the vibrations at the higher frequencies. Reverberation times of the order of 1 to 3 seconds are required in order to achieve satisfactory musical effects, and while these have been readily achieved at audio frequencies, they have been found very difficult to achieve at ultrasonic frequencies when designs were attempted based on the Wegel formulas, and also on the basis of results attained empirically.

It is, accordingly, a feature of the present invention to provide a satisfactory ultrasonic helical spring reverberatory delay device by utilizing a suitable combination of spring material and dimensional factors.

The value of a helical wire spring as a reverberatory delay device appears, to the best of our knowledge, to derive from utilization of a type of vibration which is foreign to any of those discussed in the Wegel patent. It appears that the vibrations which are induced in our helical springs exist primarily in planes substantially perpendicular to the axis of the spring and may be represented by transverse vibrations traveling along the wire of which the spring is fabricated. Calculations indicate that such vibrations travel along the spring as if the spring were a straight wire not under tension, at least to a first approximation. This effect has been observed experimentally in springs fabricated of beryllium copper, and having diameters of the order of ½" to ¾". The effect presumably occurs for other materials, but appears to be useless in such materials as have been tested, in the sense that it has to date proved impossible to construct a delay device having a sufficient reverberation time, of these materials. Furthermore, it has been found that even with beryllium copper as a spring material, a spring having an outer diameter of the order of ¼" is not particularly effective, while a spring having a diameter of the order of 1" provides an extremely brassy and noisy output. The dimensions and character of the spring utilized have been arrived at largely on an empirical basis but there is no theoretical reason to believe that other materials or dimensions will not eventually be found which will be operative and practical.

It will be appreciated that the tonal spectrum on a percentage basis which is involved in an ultrasonic reverberation unit, is relatively small in comparison with spectrum width on a percentage basis in an audio reverberator. This fact enables an ultrasonic reverberator to have, on the average, a flat frequency characteristic over the entire audio spectrum of interest, i.e. low attenuation exists at least adjacent to any given frequency.

An ultrasonic reverberation unit in the form of a long line, having a length of the order of 900 wavelengths, has the property that a very small change in the frequency of a vibration traveling along the line, or a very small change in the wave propagational characteristics of the line, will result in a considerable change in phase in the course of one passage along the delay device. For example a change of frequency of one part in 3600 produces a phase shift of the order of $\lambda/4$ in one passage along a delay device having the length of 900λ, where λ is wavelength. Since the delay device is reflective, so that each signal passes many times therethrough, the net change in phase shift for a very slight change in frequency can be very considerable, before the signal decays to unusable level. The consequence of this characteristic of the ultrasonic delay line is that for a spectrum of input frequencies many resonances occur, of the order of 100 or more, the resonant frequencies being separated by small increments of frequency, of the order of several cycles per second. Certain frequencies of the ultrasonic spectrum are accordingly accentuated and certain others are diminished and in the limit may be decreased to zero.

Where the ultrasonic spectrum consists of an ultrasonic carrier plus upper and lower side bands, the resonant characteristics of the ultrasonic transmission line can have the effect for any particular side band frequency of accentuating the upper side frequency and decreasing the lower side frequency, or vice versa, or of shifting the relative phases of the upper and lower side band frequencies from the phase relation which is normal for an amplitude modulated signal. In the alternative the carrier frequency may find a resonant or an anti-resonant point, while given side band frequencies may be relatively unaffected, or may be simultaneously affected differently. The net result of these variations in spectrum characteristic caused by the ultrasonic delay line, which are extremely complex, and which can be considered to occur at random, is to introduce a form of frequency randomization into the music in superposition of the reverberative effect.

It is, accordingly, an object of the present invention to provide an ultrasonic reverberative delay line having extremely long length in terms of wavelengths thereby to introduce a very large number of random modifications of signal amplitude and phase distributed over the spectrum of interest.

As a result of the frequency response characteristics of the ultrasonic delay line, particularly as a result of the large number of closely spaced resonances which occur, chorus effects may be generated by varying the frequency of the ultrasonic carrier, or by mechanically changing the transmission characteristics of the delay line, as by perturbing the latter mechanically. The mechanical perturbations, or the variations in carrier frequency may preferably be random, but cyclical variations if of sufficiently long term character are not unpleasant.

It is accordingly another object of the present invention to provide a system for generating reverberation effects ultrasonically, and for superimposing on these effects chorus effects, by transferring along an ultrasonic delay line an ultrasonic frequency replica of the audio spectrum of interest, and either modifying the frequencies transmitted or the mechanical transmission characteristics of the delay line, or both.

One of the consequences of the multiple resonances inherent in an ultrasonic long line reverberation device is the possibility that the carrier frequency itself may be eliminated. In such case an amplitude modulated signal passed along the delay line cannot be demodulated by means of a simple detector. In accordance with a feature of the present invention the detection occurs by means of a demodulator which is continuously connected with an ultrasonic oscillator at carrier frequency. This technique may be referred to as enhanced carrier technique, and has certain important advantages.

Where the driving transducer in an ultrasonic reverberator system must supply the ultrasonic delay line with both the carrier and side bands, the total energy which can be devoted to the side bands alone, in distinction to the carrier, is radically reduced. The total driving voltage is made up in major part of carrier frequencies, and in minor part of side band frequencies which truly carry the desired information. In order to assure the presence of carrier at the detector substantially at all times, the carrier must have a large amplitude relative to the side bands, i.e. the depth of modulation cannot be very great. This represents a design safety factor, but serves further to reduce the efficiency of the system in terms of effective output for a given driving voltage. By utilizing the enhanced carrier technique, the carrier may be reduced in amplitude, i.e. 100% modulation may be employed, or in the limit the carrier may be dispensed with entirely in transmission, i.e. suppressed carrier transmission may be utilized, resulting in radically increased efficiency of operation of the overall system.

Not only may suppressed carrier transmissions be utilized in accordance with the present invention but it is also feasible to utilize single side band modulators, where the carrier is re-introduced at the demodulator, although the types of audio effects which are produced when the various kinds of modulation are utilized are slightly different.

In the case of transmission of a carrier plus side bands the relative phases and amplitudes of the carrier and the separate side bands may be modified at random, introducing a form of phase modulation superposed on the amplitude modulation, i.e. the signals as they appear at the output of the delay line are not only amplitude modulated but are in part phase modulated and in part amplitude modulated. The same may be true in respect to carrier suppressed transmissions, wherein the re-inserted carrier may have any random phase relation to the two side bands so that either phase modulation or pure amplitude modulation or combinations of these may occur, the combinations being predominant. In the case of single side band transmission, the phase relations of the carrier and side bands are no longer of any importance, and the effects which occur are largely due to random enhancement of various frequencies in the spectrum.

It is, accordingly, an object of the present invention to provide an ultrasonic reverberator in which a band of audio frequencies may be converted to the ultrasonic range for transmission along a very long ultrasonic delay device, the ultrasonic band being in the form of any of (1) a carrier plus side bands, (2) a carrier suppressed spectrum, (3) a single side band spectrum.

The mathematical properties of the long ultrasonic delay line in the form of a helical spring indicate that such a delay device is frequency dispersive, i.e. that the velocity of propagation of waves along the delay device is a function of frequency. More specifically, it has been found that wave length is inversely proportioned to the square root of frequency. The dispersive character of the ultrasonic delay line in itself introduces relative phase shifts of the corresponding upper and lower frequencies of an amplitude modulated signal. The dispersive effects are probably largely masked by the amplitude or resonance effects of an ultrasonic delay line, but nevertheless they serve to enhance random variations of phase and amplitude of the various frequencies making up the spectrum being processed by the delay line. Moreover, where either the frequency of the carrier or the mechanical characteristics of the line, is continually varied, there results a continual mutual interchange of phase positions of the frequency components of the audio frequency band, superposed on those changes which occur due to the multiple resonances of the line, and these are equivalent to the generation of new frequencies, or in any event serve to reduce the monotonous effect inherent in some types of music due to the phase locked character of the tones generated by the instruments involved. It is, accordingly, still another object of the present invention to provide a reverberative system, utilizing a dispersive transmission line as a delay device.

The character of the reverberations generated by an ultrasonic long delay line may be very considerably enhanced by introducing multiple reflections into the line, so that the line acts effectively as would a plurality of lines of different lengths. It has been found that the reflections may be introduced in an ultrasonic delay line which takes the form of a coiled helical spring, by introducing a mass load at a point along the line, in the form of a dead weight such as a mass of solder, or in the alternative by suspending the spring at one or more points intermediate its ends, from a resilient device. Either of these expedients may be utilized to introduce reflection of the order of 50%, in which case approximately half the wave energy is reflected from the point of reflection and the remainder travels along the transmission line to be reflected from its ends. The distance to points of reflection may be selected to be incommensurate with the total length of line involved.

It is, accordingly, a further object of the present invention to provide a system of ultrasonic reverberation by means of long lines having reflection points intermediate the ends of the line.

In the case of electronic organs in particular, and in the case of certain other musical instruments, frequency vibrato is resorted to. Such vibrato has the effect of superposing a small periodic variation of frequency of the ultrasonic frequency band applied to reverberator of the present invention. It follows that a musical spectrum subjected to frequency vibrato, and to reverberation according to the present invention, also incorporates a chorus effect which is at least subjectively random because of its complexity.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a functional block diagram of a system according to the present invention;

FIGURE 2 is a functional block diagram of a modification of the system of FIGURE 2, employing random mechanical disturbances of an ultrasonic reverberator to produce chorus effect superposed on reverberative effect;

FIGURE 3 is a view in plan of a reverberative ultrasonic helical line, including transducers, according to the invention;

FIGURE 4 is a view in plan of a modification of the system of FIGURE 3;

FIGURE 5 is a phasor diagram useful in explaining the systems of FIGURES 1 and 2;

FIGURES 6–8, inclusive, are functional block diagrams of further modifications of the system of FIGURES 1 and 2; and

FIGURE 9 is a view in front elevation of a device for mounting a spring delay line.

Referring now more particularly to FIGURE 1 of the accompanying drawings, the reference numeral **10** denotes an electronic organ capable of providing a gamut of notes in the musical scale, in electrical form. Nevertheless, the electronic organ **10** represents merely one possible source of audio frequencies, and in substitution for its output may be utilized the output of a radio receiver, a phonograph transducer of the disc or magnetic tape type, a transducer of sound recorded on photographic film, or the like.

The output of electronic organ **10**, having provision **10***a* for frequency vibrato, is applied to an amplitude modulator **11**, which may be of conventional character per se, and which is supplied with an ultrasonic carrier, by means of an ultrasonic oscillator **12**. The output of the modulator **11** then consists of an ultrasonic carrier having superposed thereon as side bands the gamut of tones provided by the electronic organ **10**. The output of the modulator **11** is applied to a reverberative unit **13**, capable of providing a reverberative effect in response to an ultrasonic band of frequencies, and which may be constructed in accordance with the helical spring units illustrated in FIGURES 3 and 4 of the accompanying drawings, and hereinafter described in detail. The reverberative unit **13** is assumed to include an input electro-mechanical transducer and an output mechanico-electrical transducer, so that its output is in electrical form and may be applied via a suitable audio frequency rejection filter and amplifying unit **14** to a detector **15**. The detector **15** extracts the audio frequency band from the carrier and side bands supplied thereto and applies the detected audio frequency band to a suitable power amplifier **16**, the latter in turn driving an electro-acoustic transducer **17**.

A random frequency modulator may be connected to the ultrasonic oscillator **12**, the character of the modulator **18** being such that the frequency of the ultrasonic oscillator **12** is modified by a factor of perhaps .1% or .2% in a relatively random fashion but quite slowly. For example, the total cycle through which the frequency of the oscillator **12** may be constrained to move may require approximately 8 seconds, the maximum frequency deviation of the normal value may be the order of .1 or .2%, and during the 8 second interval variations in both directions and of varying amounts may take place, but preferably never at a rapid rate.

In parallel with the channel terminating in the electroacoustic transducer **17** is a further audio channel leading from the electronic organ **10**, via the line **19**, to a power amplifier **20** which supplies electrical energy to an electroacoustic transducer **21**. The acoustic transducers **17** and **21** may be located 6 to 10 ft. apart, for example, and in any event may be located in the same acoustic space, in order to provide a stereo effect or effect of depth in acoustic radiation.

The reverberative unit **13** may take a variety of specific forms, all, however, based on the use of an ultrasonic long line, which takes the form of a helical coil in order to conserve space. The character of the vibrations on the long line may be transverse. The vibrations are such that the helical spring does not vibrate as a unit, but rather the wire of which the spring is composed vibrates as if it were a long unstressed wire, and generally has a large component of motion in the plane of the turns. The acoustic length of the rod may then be very many wave lengths, perhaps of the order of 900, at, say, 20 kc. This implies that the wire, considered as a resonant structure, has a great many resonance frequencies, perhaps 900. It further implies that the audio frequencies which correspond with resonant frequencies of the mechanical system are readily modifiable by changing either the frequencies of the signals applied, i.e. the carrier frequency as representative of these, or by changing the physical length or other physical constants of the line. These resonances are separated by gaps of the order of several c.p.s.

By transmitting the ultrasonic frequency band along the line as a carrier plus two side bands, various effects can occur. For example, the line may be resonant to a frequency in one side band, but not resonant to a corresponding frequency in another side band and this can occur whether or not the line is dispersive. Assuming that the line is dispersive, further effects can occur, i.e. the phase at the receiving transducer of the reverberative unit **13**, of a given frequency in the upper and lower side bands, may be completely changed from the normal values which occur in response to amplitude modulation.

So in FIGURE 5 of the accompanying drawings, the reference numeral **25** is a phasor which denotes a carrier, the reference numerals **26** and **27** being phasors denoting upper and lower side bands, respectively, for a given modulation frequency. These side bands, in the phasor diagram of FIGURE 5, are conventionally assumed to rotate in opposite directions. If, now, the reverberative unit is resonant to the frequency represented by the phasor **26**, but not **27**, the amplitude of that phasor **26** may extend, as shown in dotted lines, to the value represented by phasor **28**, whereas the phasor **27**, if the latter does not find a resonant point on the line, remains unaffected. Thereby, the normal phase relation of the sum of the side-band frequencies **26**, **27** to the carrier **25** is disturbed.

Likewise, the phase of the side band frequency **26** may be changed to the position **26′** or **26″**, while the side band **27** is unaffected. This again modifies the phase relation between the side bands and the carrier, and introduces some of the effects of phase or frequency modulation of the carrier.

It then appears that the reverberative unit **13**, by virtue of its operation at ultrasonic frequencies, and its extremely long length electro-mechanically, and of variation of driving frequencies or resonance points (or both), introduces sonic effects which are impossible with devices which utilize ultrasonic carriers to produce reverberation, but which utilize acoustic chambers or short lines as the delay devices.

Reference is now made to FIGURE 2 of the accompanying drawings wherein is illustrated a modification of the system of FIGURE 1. The distinction between the systems of FIGURES 1 and 2 is that in the system of FIGURE 1 the ultrasonic carrier frequency is modified at random, whereas in the system of FIGURE 2, the physical character or dimensions of the ultrasonic delay line is itself mechanically varied in a random fashion. The systems of FIGURES 1 and 2 are, therefore, broadly or generically similar. In the system of FIGURE 2 the reverberative unit **13** of FIGURE 1 is shown as composed of an input electro-mechanical transducer **13*a***, which drives an ultrasonic long delay line **13*b***, the latter in turn supplying acoustic signal to a mechanico-electrical transducer **13*c***, and the latter in turn supplying signal to the audio frequency rejection filter and amplifier **14**.

The long line **13*b*** consists of a helical spring, and is mounted at two points **30** and **31** on a rigid support of considerable mass. Support **32** is itself spring mounted by means of two springs **33** and **34**, from fixed points **35**, **36**. A clock motor **37** is provided, which rotates at the rate of once per minute, for example, and which drives an irregular cam **38**, or an analogous device, which has the function of perturbing the mounting **36** by means of a lever **36*a*** once every several seconds, by raising and lowering it in an essentially random manner. Thus, the mounting spring **34** is utilized as a mechanical filter for ultrasonic vibrations which may be generated in the cam-lever relationship. The mounting **32** executes a series of complex oscillations in each time interval between successive perturbations. These movements or oscillations, being relatively random, have a random mechanical effect upon the vibrational constants of the ultrasonic spring **13*b***, since the latter is composed of a resilient spring mounted at only two points. Spring **13*b*** is thus perturbed or shaken in a random fashion, which modifies its wave transmission properties sufficiently that a very marked acoustic effect is evident at the output of the acoustic transducer **17**, as a function of the movement of the support **32**.

Analysis appears to indicate that mechanical motion of the ultrasonic delay device **13*b*** is similar to the effects of frequency modulation of the ultrasonic oscillator **12**, i.e. that the wave propagative properties of ultrasonic line **13*b*** are changed sufficiently to randomly modify the relative amplitudes and phases of the frequencies making up the ultrasonic spectrum.

The net effect of random sub-audio perturbations of the constants of the line is to introduce ultrasonic perturbations of phase and amplitude, which are randomly distributed over the ultrasonic spectrum and constitute a chorus effect. In the case of audio frequency reverberators these same random perturbations would have negligible effect except to produce undesired signals in the low audio range.

Referring now more particularly to FIGURE 3 of the accompanying drawings there are shown rigid mounting blocks **50** and **51**, separated in space by a distance of about 2 ft., and mounted on a common support (not shown). To the mounting block **50** is cemented one end of an electro-acoustic transducer **52**, which may be in the form of a ceramic crystal. Extending at right angles to the crystal **52**, at or adjacent to its free end, is located a length of wire **53**, which is relatively rigid and which terminates in a hook **54**. Similarly, another mechanico-electric transducer **55** is cemented at one end to the mounting block **51**, so that it acts as a cantilever vibrator. The transducer **55** may duplicate the transducer **52**. To the free end of the transducer **55** is cemented a short length of rigid wire **56** having a hook **57** at its free end. Between the hooks **54** and **57** may be suspended a long helical coil or spring **57**. The helical coil **57** is made of beryllium copper wire, and in one operative example the percentage of beryllium was approximately 2%. Excellent results were obtained with a .028″ diameter spring 21″ long and having a ½″ outer dia., the spring having been heat treated on a mandrel for 3 hrs. at 600° F. The precise physical effect which the heat treatment has on the spring is not known, but the heat treatment was found to decrease the attenuation, thus increasing the reverberation time.

It was found by experimentation that when the outer dia. of the spring **57** was reduced to ¼″ or increased to 1″ inferior results obtained. We have no explanation of the reason for the degradation of performance for the dimensions recited.

We have deduced it to be highly probable that the equation governing the operation of the spring **57** is as follows:

$$\lambda=\frac{2}{D}\sqrt{\frac{d}{\omega}}\sqrt[4]{\frac{Q}{\rho}}$$

(equation gives close approximation for less than one turn)

where

λ is group wavelength in turns (group velocity divided by carrier frequency)
D is pitch diameter of spring
d is dia. of wire
ω is angular velocity
Q is modulus of elasticity of wire
ρ is density of wire
(CGS units)

The stated equation appears correctly to predict the performance of the operative springs (where the wavelength is less than one turn) which have been constructed over the range of frequencies adjacent to those specified as operative, i.e. for carrier frequency of about 20 kc./sec. The equation does not predict the operation of the spring at audio frequencies, where the formula would predict wavelengths of many turns, but for audio frequencies the

Wegel formulas, as provided in U.S. Patent 1,852,795, appear to be reasonably accurate. It further appears that a transition range of frequencies exists, for which neither of the formulas is adequate.

Equation 1 indicates that the wavelength on the spring is not an inverse function of frequency, but is proportional to the inverse square root of frequency. This explains the dispersive character of the spring.

A considerable improvement in the operation of the system of FIGURE 3 has been found to accrue from the addition of a mass load **58** at a point along spring **57**, which is such that the distance from the support **54** to the mass load **58** is incommensurate with the total length of the spring and with the distance from the mass load **58** to the support **57**. The mass load **58**, when so selected as to provide approximately 50% reflection by reason of the discontinuity which it introduces in the line, has been found to reduce flutter very appreciably, and to increase the total number of resonances which occur.

The term "flutter echo" is used to denote the acoustic effect generated by a signal traveling back and forth along the line **57** at a sufficiently slow and periodic rate that successive reflections have become readily identifiable and are so regular as to become obtrusive. The effect of the mass load **58** is to introduce plural and highly irregular flutter times, which in effect mask the flutter by rendering it non-cyclical or non-periodic. Also, the loading may enhance the chorus effect by the introduction of additional sets or arrays of resonance frequencies due to the location of mass load **58**, which are superposed on the array of resonances due to the total length of the coil **57**, considered as a mechanical wave transmission line.

Referring now more particularly to FIGURE 4 of the accompanying drawings, there is illustrated a pair of rigid supports **50** and **51** to which are secured hooks **60** and **61**, the helical coil **57** being secured to the hooks **60** and **61** by means of hooks **62** and **63** formed in the ends of the helical coil **57**. The helical coil **57** is driven at a point separated from the support point **62**, by means of an electro-mechanical transducer **65** and the mechanico-electrical transducer **66** is secured to the coil **57** at a point intermediate its ends but not at either of its ends, to pick up reverberated vibrations passing along the coil. The distances of the transducers **65** and **66** with respect to the end-points of the coil are selected to be incommensurate with respect to the length of the coil **57**. The points at which the transducers **65**, **66** are secured to the coil **57** represent the equivalent of mass loads, or discontinuities in the coil **57**, and introduce reflections. By properly designing the modes of securement of the transducers **65** and **66** to the coil **57**, sufficient reflection may be caused to occur to produce a significant increase in chorus effect and a significant decrease in flutter.

The structure of FIGURE 4 possesses the advantage that the coil **57** is not directly supported or hung from the transducers as **53**, **56** in FIGURE 3 and there may be some further advantage in that the driving transducer **65** initially transmits vibrations in both directions along the coil **57**, whereas the transducer **52** (FIGURE 3) can only transmit in a single direction.

While the outer diameter of the coil **57** and the material of which it is made, and probably the diameter of the wire itself, are of primary interest in effecting a practical and efficient design, it appears that the total length of the coil considered as a mechanical transmission line is of minor importance in determining the reverberation time, i.e. a shorter line operates at about the same reverberation time as a relatively longer line. The reason for this is that the device operates by repeated reverberations and not in terms of a single translation of a given phase point along the line. A loss or attenuation occurs at each reflection of the wave. A loss also occurs internally of the line and independent of the reflections. For a short line many more reflections

are permitted, while the loss internally of the line per unit time is the same. For a long line the internal loss is the same but fewer traverses take place so that the total number of reflections is reduced and the total losses due to reflection are reduced. But the losses due to reflections are not very large in any case for lines which give desirable effects.

In the systems of FIGURES 1 and 2 of the accompanying drawings the ultrasonic spectrum transmitted along the reverberation units **13** or **13*b*** consists of carrier plus two side bands. In such a system the possibility exists that the carrier frequency itself will fall on an anti-resonant point of the reverberation unit, and in such case the detector **15** is incapable of performing its function, which requires the presence of a carrier. During absence of the carrier the detector will produce a distorted output. In order to avoid this possibility recourse is had to the system of FIGURE 6 of the accompanying drawings, wherein a portion of the ultrasonic output of the ultrasonic oscillator **12** is supplied via lead **70** to a demodulator capable of operating on a heterodyne basis and identified by the reference numeral **15*a***. In the system of FIGURE 6, accordingly, carrier is always present at demodulator **15*a***, and accordingly no gaps in the detection process can occur with respect to all the frequencies simultaneously. As a further modification, in the system of FIGURE 6 the random frequency modulator **18** of FIGURE 1 is supplanted by a random angle modulator **18*a***, to indicate that either frequency modulation or phase modulation may be resorted to. In the case of phase-angle modulation, the modulation may be applied to either the modulator **11** or the demodulator **15*a***, or both. In case it is applied only to one of these, the demodulated signal is frequency modulated with respect to the original signal.

The embodiment of our invention illustrated in FIGURE 7 of the accompanying drawings duplicates that of FIGURE 6 except in that the modulator **11** is supplanted by a suppressed carrier modulator **11*a***. Since the carrier is to be resupplied at the demodulator **15*a***, it is not necessary that it be transmitted along the reverberative unit **13**, and thereby it becomes possible to transmit a maximum quantity of audio spectrum information along the reverberative unit for a minimum value of driving voltage at the input transducers.

In the system of FIGURES 1 or 2, wherein carrier and side bands are transmitted, the phase of the carrier and its amplitude are subject to continual random variation as the phase of the ultrasonic oscillator output is varied, since the carrier may find itself at the peak or along the side of a resonance characteristic inherent in the ultrasonic reverberation unit **13**. In the system of FIGURE 7 this cannot occur, since the carrier is not transmitted, but the relative phases and relative amplitudes of the side band frequencies with respect to the fixed amplitude, fixed phase carrier is subject to variation as in the systems hereinabove explained.

In the system of FIGURE 8 of the accompanying drawings the modulator **11** of FIGURE 6 is supplanted by a single side band modulator **11*b***, i.e. one which transmits a converted band of frequencies consisting of either an upper side band or a lower side band, alone, and having no associated carrier. In such a system the demodulator output is entirely independent of phase of the carrier with respect to the side band frequencies, but the relative phases of the side band frequencies themselves and their relative amplitudes are nevertheless modified by the reverberation unit **13**, as in the other systems hereinabove explained.

The structure of FIGURE 9 is a substitute for the mass load **58**, having the same general function and may be similarly located along the transmission line **57**. The line **57** is suspended by means of a resilient member, in the form of a short helical spring **58*a***. The latter is in turn suspended from a rigid support **58*b***. This type of suspension provides a point of reflection, which is essentially loss-less, but which can be designed to provide approximately 50% reflection, as can the mass load 58.

While we have described and illustrated one specific embodiment of our invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

What we claim is:

1. A system for producing chorus effect and reverberation of a gamut of plural octave musical tones, means for converting said gamut of musical tones to an ultrasonic band of frequencies, a first transducer responsive to said means, a helical spring delay line coupled adjacent one end to said first transducer, and a second transducer coupled to said helical spring delay line adjacent its other end, reflective means for said ultrasonic band located adjacent said other end, said helical spring delay line being arranged and adapted to provide approximately uniform attenuation for all frequencies of said ultrasonic band and a delay time of more than .005 second, said transducers being respectively productive of and responsive to transverse waves in said delay line.

2. The system according to claim 1, wherein said delay line is at least 300 λ long, where λ is an operating ultrasonic wavelength.

3. A system for producing concomitant chorus effect and reverberation of a gamut of musical tones, converter means for converting said gamut of musical tones to an ultrasonic band of frequencies, an ultrasonic helical spring delay line, an electro-mechanical transducer coupled electrically to said converter means and mechanically to one point of said ultrasonic helical spring delay line, an acoustic transducer, a detector for deriving said gamut of musical tones from said ultrasonic band of frequencies, said detector being connected in cascade with said acoustic transducer, and a mechanico-electrical transducer coupled mechanically to a further point of said ultrasonic helical spring delay line and electrically to said detector, wherein said ultrasonic delay line is arranged and adapted to transfer said ultrasonic band of frequencies with approximately uniform attenuation over said band with a delay of at least .005 second, and reflective means for introducing multiple resonances at said ultrasonic frequencies on said ultrasonic helical spring delay line.

4. The combination according to claim 3 wherein is provided means for mechanically continuously perturbing said ultrasonic helical spring delay line.

5. The combination according to claim 3 wherein is provided means for continuously varying the frequencies of said ultrasonic band of frequencies.

6. The combination according to claim 3 wherein said helical spring is fabricated of a beryllium copper alloy.

7. The combination according to claim 3 wherein said helical spring is fabricated of a beryllium copper alloy having non-contiguous turns, with a diameter of the order of one half inch and a length of the order of two feet.

8. A device for generating reverberation, comprising an elongated resilient helical wire, an electro-mechanical transducer coupled to said wire at one point, a mechanico-electrical transducer coupled to said wire at another point, and a wave reflector secured to said wire intermediate said points, means for applying electrical energy of ultrasonic frequency to said electro-mechanical transducer, means for deriving electrical energy from said mechanico-electrical transducer, said frequency being sufficiently high to induce transverse vibrations of said resilient wire, said wire having a length such as to introduce a delay time of at least 5 milliseconds, said transducers being arranged to introduce substantial reflection of said vibrations.

9. The combination according to claim 8 wherein said wave reflector is located at a point located approximately X% of the length of said wire from one of said transducers, where X falls between 10% and 45%.

10. A reverberation device operative with a source of a band of ultrasonic frequencies, comprising a helical coil of resilient wire, means for coupling said source of a band of frequencies to said helical coil at one point thereof, an electro-mechanical transducer coupled to said helical coil at another point thereof, and means for randomly varying at least one of the mechanical constants of said coil which pertain to phase delay of mechanical vibrations along said wire.

11. A reverberation device operative with a source of a band of ultrasonic frequencies, comprising a helical coil of resilient wire, said helical coil having non-contiguous turns, means responsive to said band of frequencies for causing mechanical vibrations of said helical coil, means connected to said helical coil for reflecting said vibrations from predetermined points of said helical coil, and means coupled to said helical coil for continuously randomly varying the wavelengths of said vibrations.

12. The combination according to claim 11 wherein said means for continuously randomly varying the wavelengths of said vibrations is a means for modulating the frequencies of said band of frequencies.

13. The combination according to claim 11 wherein said means for randomly varying the wavelengths of said vibrations comprises means for continuously randomly perturbing the physical configuration of said helical coil.

14. A reverberation system operative from an ultrasonic source of a gamut of notes of the musical scale, comprising a mechanically reverberatory helical coil device having multiple resonances, said device being connectable to said source for driving said device, means connected to said reverberatory device for transponding the reverberations of said reverberatory device, and means for continuously randomly varying the resonances of said mechanically reverberatory device as a function of time.

15. A reverberation system operative with a source of a gamut of notes of the musical scale, comprising mechanical reverberatory means responsive to said source, said mechanical reverberatory means having a predetermined effective length in wave lengths for any predetermined frequency, and means for continuously randomly varying said effective length, said mechanical reverberatory means having a length of many wavelengths and being provided with plural reflecting points.

16. A reverberative system operative with a source of a band of ultrasonic frequencies representative of a gamut of notes of the musical scale, comprising an electro-mechanical transducer responsive to said band of frequencies, a wave reflective mechanical vibratory system responsive to said electro-mechanical transducer, said system comprising helical coil delay line means, a mechanico-electrical transducer responsive to the vibrations of said vibratory system for translating said vibrations to electrical signals, and electro-acoustic transducer means responsive to said electrical signals, said mechanical vibratory system having highly different phase shifts along its total length for different frequencies of said band, of the order of one quarter wavelength for a change in frequency of less than 1%.

17. The combination according to claim 16 wherein said transducers are piezoelectric crystals.

18. An ultrasonic reverberatory device operative in response to an audio spectrum, comprising a modulator converting said audio spectrum to an ultrasonic spectrum, a long helical wire ultrasonic reverberator having a length of the order of at least two hundred wavelengths at an operating ultrasonic frequency, piezo-electric means responsive to said ultrasonic spectrum for mechanically driving said ultrasonic reverberator in lateral vibrations, piezoelectric means for deriving a reverberated ultrasonic spectrum from said reverberator and demodulator means for converting said reverberated ultrasonic spectrum to audio

frequencies, said lateral vibrations subsisting radially of the helical turns of said helical wire.

19. The combination according to claim 18 wherein said modulator is a suppressed carrier modulator.

20. Th combination according to claim 18 wherein said modulator is a single side band modulator.

21. The combination according to claim 18 wherein is provided a source of ultrasonic carrier, and means supplying said carrier jointly to said modulator and demodulator.

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