

[72] Inventors **Bernhard Weingartner;**
Werner Fidi, both of Vienna, Austria
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 [73] Assignee **Akustische u-Kino Gerate Gesellschaft**
m.b.H
Vienna, Austria
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Primary Examiner—Herman Karl Saalbach
Assistant Examiner—Paul L. Gensler
Attorney—McGlew & Toren

[54] **ARRANGEMENT FOR PRODUCING ARTIFICIAL REVERBERATION COMPRISING FREQUENCY DIVIDING MEANS**
16 Claims, 2 Drawing Figs.

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ABSTRACT: An artificial reverberation arrangement includes first and second transmission lines. Each transmission line includes a helical spring, adapted to transmit torsional vibrations at frequencies up to a predetermined limiting frequency, an actuating transducer connected to one end of the spring and a pickup transducer connected to the opposite end of the spring. The spring of the first transmission line is longer, and has a longer transit time and a lower limiting frequency, than the spring of the second transmission line. The actuating transducers are operable to impart torsional vibrations to the associated springs, and the pickup transducers are operable to convert torsional vibrations of the respective springs and to electric oscillations. The arrangement includes frequency dividing means operable to suppress transmissions above a predetermined division frequency through the first transmission line, and to suppress transmission at frequencies below the predetermined division frequency through the second transmission line.

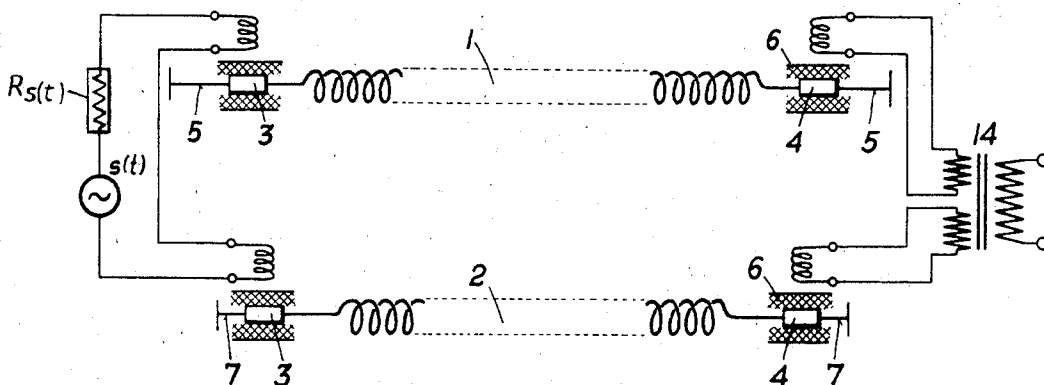


FIG. 1

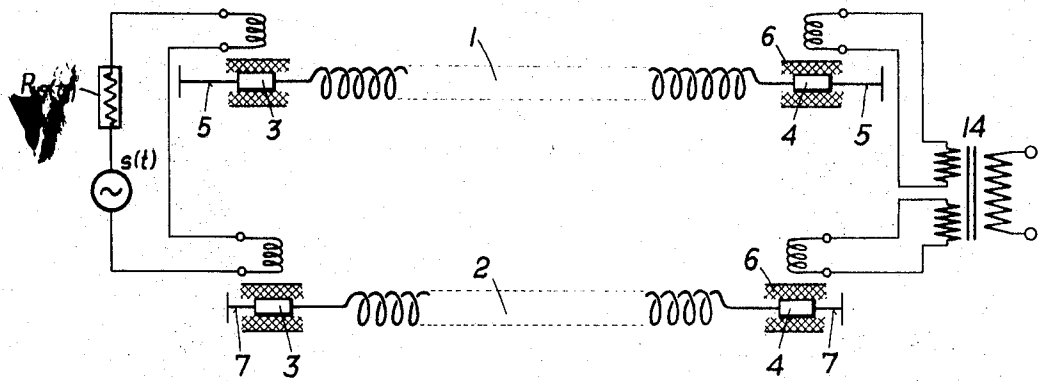
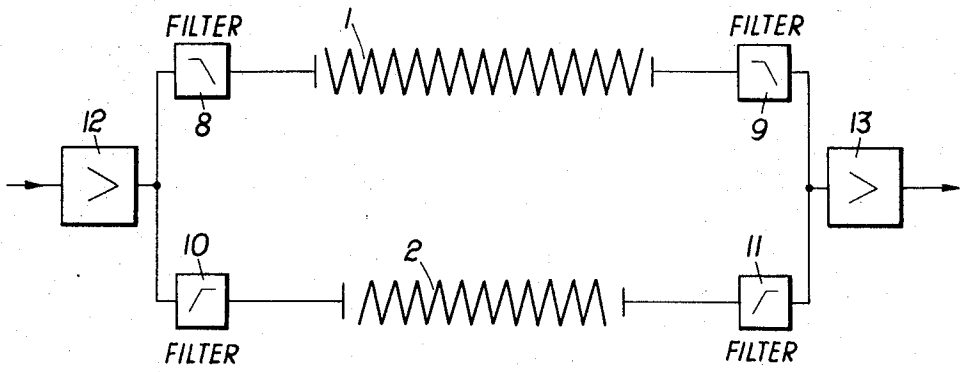


FIG. 2



INVENTORS
BERNHARD WEINGARTNER
WERNER FID
BY *M. J. Lewis and Toren*
ATTORNEYS

ARRANGEMENT FOR PRODUCING ARTIFICIAL REVERBERATION COMPRISING FREQUENCY DIVIDING MEANS

BACKGROUND OF THE INVENTION

Various arrangements for producing artificial reverberation have been disclosed, and arrangements including helical springs, to which torsional vibration is imparted, have found the widest use. Torsional vibration is imparted to the helical springs, preferably at one end thereof, by electromechanical means, and is reconverted into electrical oscillation by a pickup transducer which is connected at the other end of the springs.

Reverberation is produced due to the fact that the signal to be reverberated, which is a propagated along the helical spring or springs, is delayed relative to the original signal which is directly amplified, and because the signal to be reverberated is partly subjected to multiple reflection within the helical spring or springs, which are terminated at opposite ends by respective transducers. This reflection causes a fading of the signal, due to internal friction.

To produce a reverberation of maximum fidelity, the helical spring should have the same properties, with respect to transit time, reflection and damping, as a reverberating space. As this requirement can be met to only a certain extent, due to different physical conditions, artificially produced reverberation can be distinguished clearly from natural reverberation. Even if a plurality of springs having respective different transit times are employed, the resulting improvement will be accompanied by disturbing effects, which are absent in naturally reverberated sound.

There have been proposed spring assemblies comprising either one spring or several springs connected in parallel. Where two springs are employed, the associated transit times are, in most cases, 50—80 milliseconds and 20—40 milliseconds, respectively. This is a compromise between a high frequency response with minimum frequency intervals between the natural resonance frequencies and a dense pulse spectrum (large frequency intervals between the natural resonance frequencies). Both of these results cannot be accomplished adequately, in such arrangements, in conjunction with a good reverberation effect. In most cases, the spring having a short transit time produces a predominating metallic sound, which suggests a small confined space. If the spring having the short transit time were omitted, the reverberation effect would be good, but disturbing echoes would result and would be heard clearly in addition to the reproduction of the original sound. These echoes are highly disturbing.

SUMMARY OF THE INVENTION

This invention relates to means for producing artificial reverberation and, more particularly, to a novel means for this purpose which is free of disadvantages of prior art means or arrangements, as set forth above.

More specifically, an arrangement for producing artificial reverberation in accordance with the invention comprises at least two delay elements consisting of helical springs which differ in length and transit time properties and which are adapted to have torsional vibration imparted thereto. Each helical spring has associated with it separate actuating and pick up transducers, which are preferably of the electrodynamic type. The signal to be transmitted and reverberated is applied to the helical springs by mechanical or electrical devices or arrangements, or both, which have a frequency range dividing effect with respect to a division frequency which is approximately the same as the limiting frequency of the helical spring having the longer transit time. Only the frequencies below its limiting frequency are transmitted by or supplied to the helical spring having the longer transit time, and only the higher frequencies, preferably up to the limiting frequency of the helical spring having the shorter transit time,

are transmitted by or supplied to the latter spring. The division frequency is preferably in the middle of the frequency range of the sound to be reverberated.

In this connection, the term "limiting frequency" refers to the upper limit of the frequency range in which torsional vibration can be transmitted by a helical spring, whereas preferably only compressional vibration and possibly transverse vibration is transmitted at frequencies above the limiting frequency.

The limiting frequency f_s , in cycles per second, is mathematically defined by the equation

$$f_s = K_1 \frac{WR^2}{a} \sqrt{\frac{\rho}{E}}$$

The transit time T in seconds is calculated by the equation

$$T = K_2 \frac{a}{R^2} \sqrt{\frac{\rho}{E}}$$

In the two equations, a is the radius of the spring wire in meters, R is the mean spring radius in meters, E is the modulus of elasticity in kilograms per square meter, and ρ is the density of the spring material in kilograms per cubic meter. K_1 and K_2 are specific constants which must be determined individually for each spring with respect to a given spring material, a given initial spring tension, and a given spring uniformity, and w is the number of turns of the spring.

For a given dividing frequency and desired transit time, each of the two helical springs can be designed so as to meet the requirements of the invention.

The invention arrangement has the advantage that the frequency range which is to be transmitted and to be reverberated is divided between two helical springs which are actuated only at frequencies at which pure torsional vibration is transmitted. The inherent short transit time of the smaller spring does not result in a loss of quality. On the contrary, the small delay of the trebles relative to basses has the result that the first echo cannot be perceived if the division frequency or the natural frequency of the spring having the longer transit time lies between 3 and 4 kilocycles per second. The invention results in an improved reverberation effect as compared to known arrangements, and also in a reduction of the size of the arrangement because, for a given diameter of the spring wire, a reduction of the limiting frequency of the spring by a factor of 0.5 results, for a given transit time, in a reduction of the length of the spring by a factor of 0.25.

The division of the frequency range to be transmitted or reverberated may be effected by mechanical means, by electrical means, or by both. A feature of the mechanical means, in accordance with the invention, is that the means suspending the helical spring having the longer transit time at either the actuating end, the pickup end, or both ends, has a small damping effect on torsional vibration but is stiff and has a large damping effect for compression waves. At least one of the suspending means for the spring having a shorter delay time assures that this spring transmits torsional vibrations above the division frequency.

Where rotary magnets are used to actuate the helical springs and to pick up vibrations therefrom, it is sufficient if the suspending means for the helical spring having the longer transit time comprises essentially a piece of wire which is soft in respect to torsional vibration, but presents a resistance to compressional vibration. The rotary magnet, preferably that of the actuating transducer, is embedded in foam material, which suppresses compressional vibration. The spring having the shorter transit time is suspended at one or both ends by a short, stiff piece of wire, and the rotary magnets are also embedded in foam material, if desired.

The frequency division may be effected by electrical means. Thus, in accordance with the invention, a filter circuitry may be included in the input circuit, the output circuit, or both circuits associated with each spring, and the filter circuitry associated with the spring having the longer transit time has a pass band up to the limiting frequency of the spring. The filter

circuitry associated with the shorter spring has a pass band from the division frequency up to the limiting frequency of the shorter spring. A particularly effective frequency division can be accomplished by the combination of electrical and mechanical filter circuits.

An object of the present invention is to provide an improved arrangement for producing artificial reverberation. Another object of the invention is to provide such an arrangement including two helical springs, acting as delay elements, and which differ in length and transit time properties, each of the helical springs being arranged to have torsional vibration imparted thereto.

A further object of the invention is to provide such an arrangement in which each helical spring has associated therewith separate actuating and pickup transducers.

Another object of the invention is to provide such an arrangement in which the transducers are preferably of an electrodynamic type.

A further object of the invention is to provide such an arrangement in which the signal to be transmitted and reverberated is applied to the springs by mechanical, electrical, or combined mechanical and electrical devices having a frequency range dividing effect with respect to a division frequency which is approximately the same as the limiting frequency of the helical spring having the longer transit time. Another object of the invention is to provide such an arrangement in which only those frequencies below its limiting frequencies are transmitted by, or supplied to, the helical spring having the longer transit time.

A further object of the invention is to provide such an arrangement where only the higher frequencies, preferably up to the limiting frequency of the helical spring having the shorter transit time, are transmitted by or supplied to the helical spring having the shorter transit time.

Another object of the invention is to provide such an arrangement which has a division frequency preferably in the middle of the frequency range of the sound to be reverberated.

For an understanding of the principles of the invention, reference is made to the following description of typical embodiments thereof as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a diagrammatic view of an arrangement embodying the invention and in which frequency division is effected by strictly mechanical means; and

FIG. 2 is a diagrammatic view of an arrangement embodying the invention and including electric filter circuitry.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As has been mentioned above, the essence of the present invention resides in that the frequency range to be transmitted or to be reverberated is divided between at least two helical springs, each of which has optimum transmitting qualities for part of the frequency range, and that the difference between the delay times of the two frequency bands has the result that the first echo, as well as flutter echoes, cannot be perceived although a good reverberation effect is produced.

FIG. 1 illustrates an arrangement comprising two helical springs and in which only strictly mechanical means are employed. A longer spring 1 introduces, into the transmission path of the reverberating system, a longer transit time in which the delay may amount to 120 milliseconds, for example. The shorter spring 2 is so designed that it delays the impressed signal by about 60 milliseconds. The transducers which are used are of the dynamic type and are supplied from the source $s(t)$ having the internal resistance $R_i(t)$. The drawing shows only those parts of the transducers which are directly connected to the helical springs.

The illustrated parts include rotary magnets 3 at the actuating end and rotary magnets 4 at the pickup end. In accordance with the invention, these magnets are connected by respective wire elements to a fixed part of the reverberating device. Wire elements 5 are relatively long and present a very high resistance to a movement in an axial direction, whereas they have virtually no effect on torsional motions. In addition, rotary magnets 3 and 4 are embedded in damping material 6, such as a foam material, so that residual compressional vibration will be damped whereas this damping will not have any substantial effect on torsional vibration.

The suspending means for the shorter spring 2, which has a shorter transit time, must have an adequate stiffness for torsional vibration, and consists, for example, of a relatively thick and short wire member 7 which is guided centrally.

The electric output signals from the two pickup systems are delivered to respective transducers connected to an audio frequency transformer 14 having two primary windings and a single secondary winding. Transformer 14 is connected to the input of a further amplifier (not shown), and can be coupled through the latter, into the main amplification path.

In the reverberating device embodying the invention, as illustrated in FIG. 2, electric means are used to divide the frequency range to be transmitted or reverberated. In the same manner as for the embodiment shown in FIG. 1, the two helical springs are designed in accordance with the principles set forth above. The electric filter circuitry may consist substantially of high pass and low-pass filters, and may precede the actuating transducers and precede or succeed the pickup transducers.

Referring to FIG. 2, the arrangement illustrated therein includes an input or dividing amplifier 12 to whose output is connected an electric separating network consisting of a low-pass filter 8 and a high pass filter 10. The signal to be reverberated is transmitted from the output of low-pass filter 8 to the actuating transducer for the longer spring 1. In this actuating transducer, the signal is converted into torsional vibrations which, in a known manner, travel along spring 1 and are reconverted into electric oscillations by a pickup transducer at the other end of spring 1.

The output of high pass filter 10 is supplied to the actuating transducer for the shorter spring 2, and after traveling through spring 2, the torsional vibration is reconverted into electric oscillations by a pickup transducer. Filter circuits 9 and 11 are connected to the pickup transducers which are connected to the ends of springs 1 and 2, respectively. The outputs of filter circuits 9 and 11 are combined and supplied to the input of the common amplifier 13 whose output may be reintroduced into the main amplification path, or which may be used to actuate a separate loudspeaker for reverberated sound.

A satisfactory effect generally will be produced if the electric separating network is provided only at the actuating end. A further improvement may be obtained if the high pass filter is replaced by a band-pass filter, which limits the transmission range of the shorter spring to that range which lies between the two limiting frequencies.

Mechanical and electrical means of the kind described above may be combined, if desired, to provide a reverberating device which is substantially free of disturbing effects.

What we claim is:

1. An arrangement for producing artificial reverberation comprising, in combination, first and second helical springs each adapted to transmit torsional vibration at frequencies up to a respective predetermined limiting frequency, said first spring being longer, and having a longer transit time and a lower limiting frequency, than said second spring; first and second actuating transducers connected to said first and second springs, respectively, and operable to impart torsional vibration to the associated springs; first and second pickup transducers connected to said first and second springs, respectively, and operable to convert torsional vibration of the associated springs into electric oscillations; said first actuating transducer, first spring and first pickup transducer constitut-

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ing a first transmission line; said second actuating transducer, second spring, and second pickup transducer constituting a second transmission line; and frequency dividing means connected to said transducers suppressing transmission, at frequencies above a predetermined division frequency, by said first transmission line and suppressing transmission, at frequencies below said predetermined division frequency, by said second transmission line; said division frequency being substantially equal to the limiting frequency of said first spring.

2. An arrangement for producing artificial reverberation, as claimed in claim 1, in which said transducers comprise electrodynamic transducers.

3. An arrangement for producing artificial reverberation, as claimed in claim 1, in which said frequency dividing means comprise mechanical frequency dividing means.

4. An arrangement for producing artificial reverberation, as claimed in claim 1, in which said frequency dividing means comprise electric frequency dividing means.

5. An arrangement for producing artificial reverberation, as claimed in claim 1, in which said frequency dividing means comprise mechanical and electric frequency dividing means.

6. An arrangement for producing artificial reverberation, as claimed in claim 1, in which said frequency dividing means transmit frequencies within a predetermined range; said division frequency being approximately in the middle of said range.

7. An arrangement for producing artificial reverberation, as claimed in claim 1, in which said actuating transducers and said pickup transducers are connected to the associated springs near first and second ends, respectively, of the associated springs; respective suspending means suspending said springs at said first and second ends thereof; the suspending means at one end of said first spring having a small damping effect for torsional vibration and being stiff and having a large damping effect for compressional vibration; at least one of the suspending means for said second spring suppressing torsional vibration of said second spring at frequencies below said division frequency.

8. An arrangement for producing artificial reverberation, as claimed in claim 9, in which said transducers are electrodynamic transducers; the suspending means at the first end

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of said second spring comprising a piece of wire which is soft in torsional vibration and presents a high resistance to compressional vibration; at least one of the suspending means connected to said second spring comprising a short stiff piece of wire extending axially of said second spring.

9. An arrangement for producing artificial reverberation, as claimed in claim 8, in which said transducers comprise rotary magnets; the rotary magnet of at least one of said second transducers being embedded in foam material adapted to suppress compressional vibration.

10. An arrangement for producing artificial reverberation, as claimed in claim 9, in which the rotary magnet of at least one of said first transducers is embedded in foam material adapted to suppress compressional vibration.

11. An arrangement for producing artificial reverberation, as claimed in claim 1, in which said frequency dividing means comprises first and second electric filter means connected in said first and second transmission lines, respectively.

12. An arrangement for producing artificial reverberation, as claimed in claim 11, in which each of said electric filter means includes a filter element preceding the actuating transducer of the respective transmission line.

13. An arrangement for producing artificial reverberation, as claimed in claim 11, in which each of said electric filter means includes a filter element succeeding the pickup transducer of the respective transmission line.

14. An arrangement for producing artificial reverberation, as claimed in claim 11, in which each of said electric filter means includes a filter element which precedes the actuating transducer and a filter element which succeeds the pickup transducer of the respective transmission line.

15. An arrangement for producing artificial reverberation, as claimed in claim 11, in which said second filter means, in said second transmission line, includes a high pass filter having a limiting frequency which is approximately equal to said division frequency.

16. An arrangement for producing artificial reverberation, as claimed in claim 11, in which said second filter means, in said second transmission line, suppresses transmission of frequencies outside the range defined between the limiting frequencies of said first and second springs.

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