Oct. 23, 1956 A. F. KNOBLAUGH 2,768,235

REVERBERATION DEVICES

Filed July 14, 1950 2 Sheets-Sheet 1

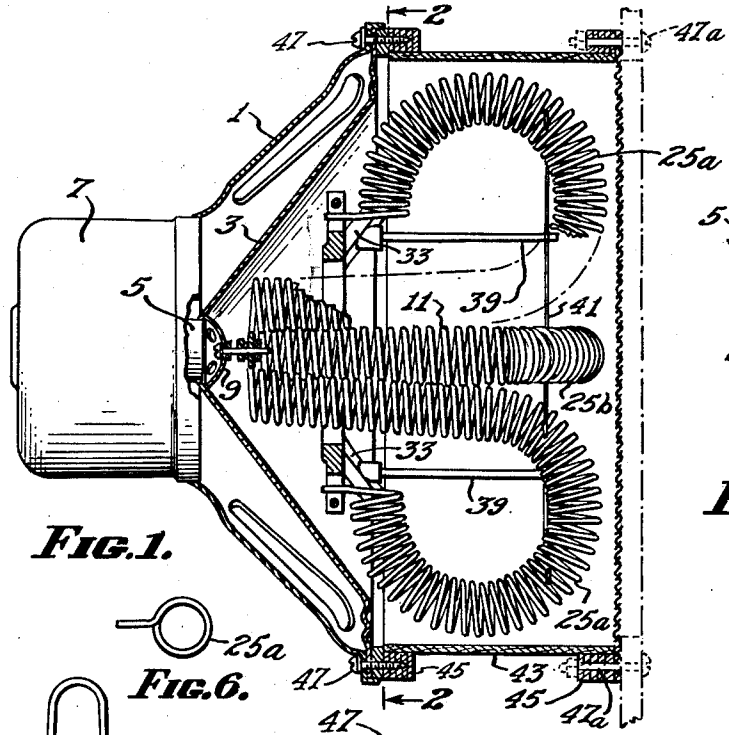

FIG. 1.

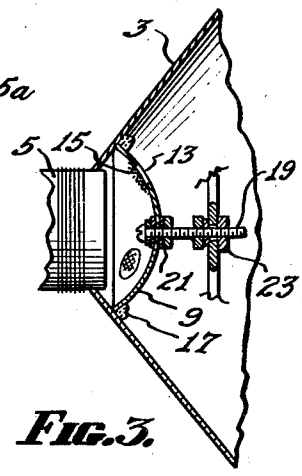

FIG. 3.

FIG. 6.

FIG. 4.

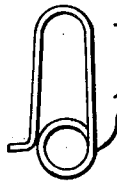

FIG. 7.

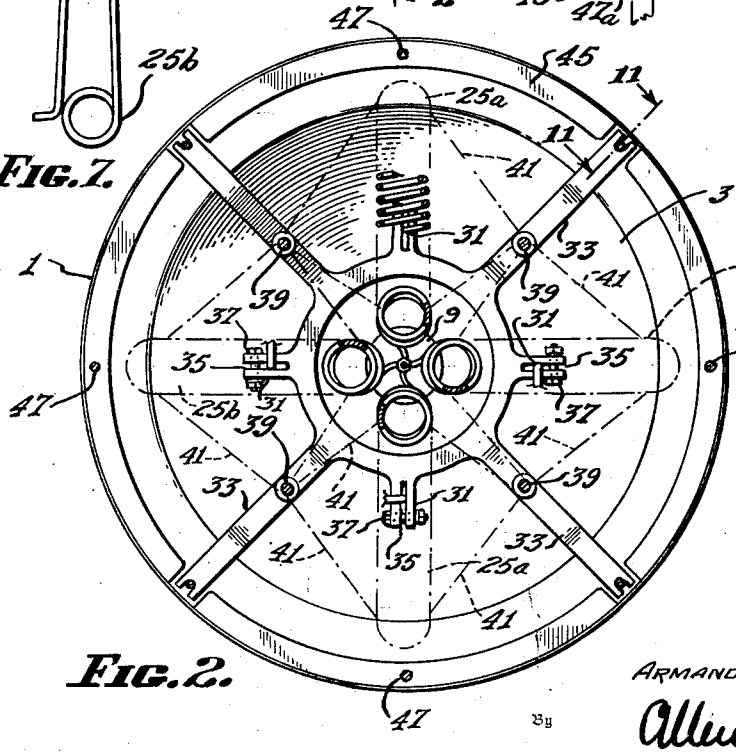

FIG. 2.

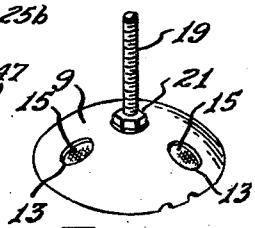

FIG. 5.

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REVERBERATION DEVICES

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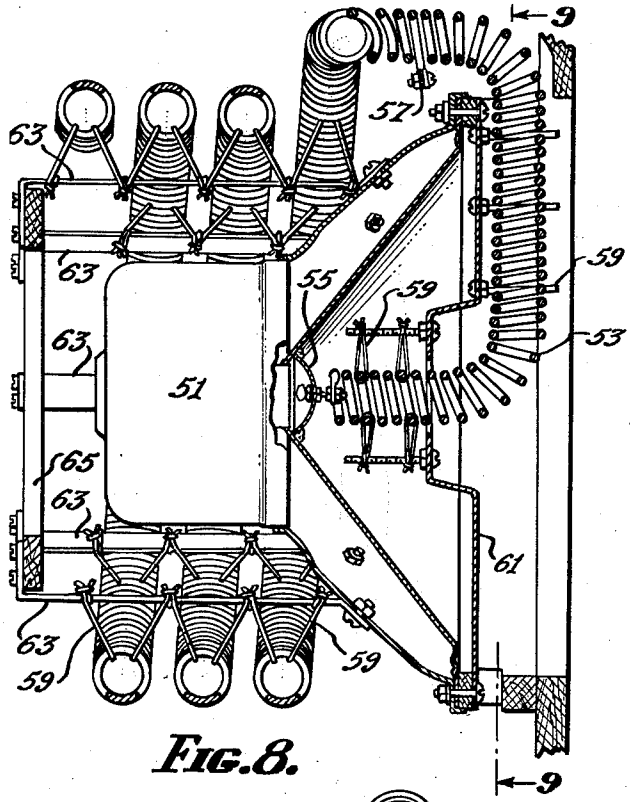

FIG. 8.

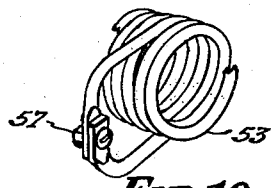

FIG. 10.

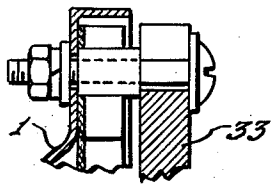

FIG. 11.

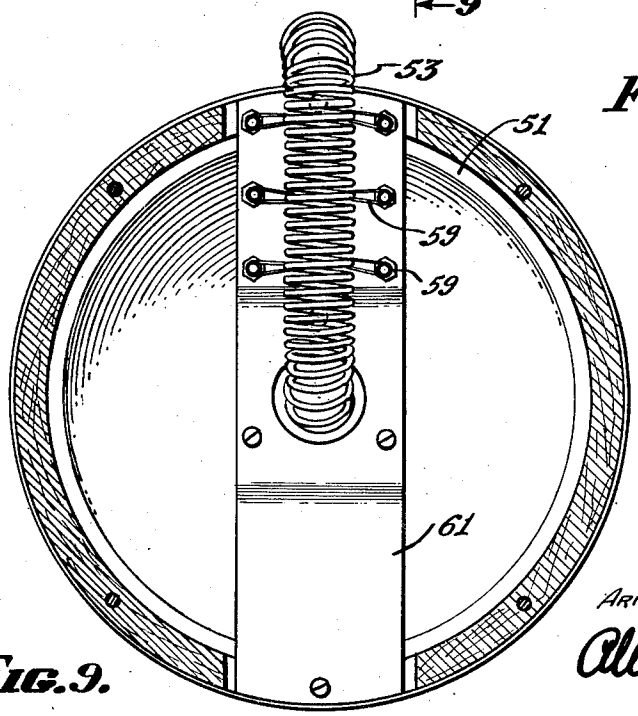

FIG. 9.

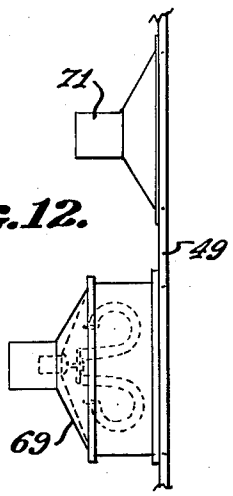

FIG. 12.

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United States Patent Office

2,768,235

Patented Oct. 23, 1956

2,768,235

REVERBERATION DEVICES

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Application July 14, 1950, Serial No. 173,749

9 Claims. (Cl. 179—1)

My invention relates generally to synthesizing sound reverberant effects such as are present in large rooms or auditoriums, the boundaries of which reflect at least a portion of the sound energy which strikes them either directly or indirectly from the original source of the sound. The invention has to do with a device which may be employed with electrical musical instruments, sound amplifying systems, radios, television sets and the like wherein it may be desired to introduce reverberation effects. The particular structures which I shall describe as embodiments of my invention were designed primarily for use with electric organs used in homes or small church auditoriums wherein little natural reverberation occurs. It will be obvious, however, that the utility of my invention will be limited neither to the embodiments herein described nor to the particular usage which I make of them.

The numerous systems and devices which have hitherto been proposed for accomplishing results which I attain by my invention have been both complex and expensive and in many cases impractical for the uses to which I put my invention. Therefore, it is a primary object of the present development to provide a reverberation device which is simple in construction so that it may be produced easily by mass production methods, and at relatively low cost.

It is an important object of my invention to provide a reverberation system which employs as an integral part available standard electro-acoustic equipment.

It is also a present object to provide a device which is interchangeable with standard electro-acoustic devices already in use in electric organs, radios, phonographs and the like.

It is a further object of my invention to provide a small compact reverberation device which occupies little more space than the standard electro-acoustic device which it may be used to supplement or replace.

It is a still further object of the present invention to provide a simple, direct method of simulating the sound conditions in large rooms having walls which reflect at least a portion of the sound energy present in the room.

It is a specific object of my invention to provide a method and a single electro-mechanico-acoustic structure in which electric oscillations are converted into mechanical vibratory energy and thence into acoustic energy, in which the mechanical energy is converted partly and directly into acoustic energy, and partly stored and thence converted into acoustic energy in a gradual manner.

These and other objects, which will be set forth hereinafter or which will be apparent to one skilled in the art upon reading these specifications, I obtain by those constructions and arrangements and parts of which I shall now describe certain exemplary embodiments, reference being had to the accompanying drawings, wherein:

Figure 1 is a side elevation, partly in section, of a preferred embodiment of my invention.

Figure 2 is a sectional view, taken on the plane 2—2 of the device in Figure 1.

Figure 3 is an enlarged sectional view of a portion of the device of Figure 1.

Figures 4–7 inclusive illustrate certain details of construction of the embodiment in Figure 1.

Figure 8 is a side elevation, partly in section, of a modified form of my invention.

Figure 9 is a sectional view, taken on the plane 9—9 of Figure 8.

Figure 10 illustrates a detail of construction of the device in Figure 8.

Figure 11 is a partial sectional view taken on the plane 11—11 of the device in Figure 2; and

Figure 12 is a side elevation of an exemplary installation employing my invention.

General description

Briefly, in the practice of my invention, I preferably employ a usual electro-acoustic device such as a direct radiating cone-type electrodynamic loud speaker as used in radio receivers, sound amplifiers and the like, modifying it slightly at the central portion of its cone or diaphragm so that I may attach thereto one or more long helical coils of fairly heavy wire, preferably metal wire. The other end of the coil or coils is fastened, as will be explained later, to a support attached to the loud speaker frame. The diaphragm, upon being energized by audio frequency electric currents flowing through the voice coil of the loud speaker will, of course, transform part of the corresponding mechanical vibratory energy thus imposed in it, immediately and directly into acoustic energy in the form of corresponding audio frequency sound waves, in a well-known manner.

Due, however, to the structure added to the loud speaker by my invention, the vibrations of the central portion of the loud speaker diaphragm will also be communicated to the aforementioned helical coil or coils attached thereto, creating in them corresponding mechanical vibratory energy. These helical coils, or helical springs, as I construct them, are in effect mechanical transmission lines in which the time of transit of vibratory energy from one end of a coil to the other is not infinitestimal nor inappreciable as compared with the period—time of a vibration—of acoustic energy generated by the device.

The vibratory energy, then, in the aforementioned helical coils—which I chose to call reverberation coils—will be in the form of mechanical waves which travel along the coils. Therefore, upon initiating audio frequency electric currents in the voice coil of the loud speaker, a part of the vibratory energy of the loud speaker diaphragm will be communicated to the reverberation coils as mechanical waves which travel to the far end of a coil, to be reflected and returned to the diaphragm to be partly retransformed thereby into acoustic energy at a time later than the initial sound produced by the diaphragm. The remainder of the mechanical vibratory energy, reflected from the near end of the reverberation coil, will again traverse the coil, to be reflected from its far end, returned and produce sound at a still later time, and so on, the process being repeated for all subsequent electric excitation of the loud speaker voice coil. In this way, the creation of sound in the present structure is characterized by an initial production of acoustic energy followed by a transient rise in energy to a steady-state condition upon steady excitation of the loud speaker voice coil by audio frequency electric currents.

The cessation of sound from my device occurs in a similar but reversed process. When electrical excitation of the voice coil ceases with respect to a given sound, the corresponding energy stored in the reverberation coils—which energy is appreciable as I shall point out in

detail in the design considerations later herein—is converted into acoustic energy in a decaying gradual manner. This feature of gradual cessation of sound corresponds to the most important aspect of a reverberant auditorium. Such a characteristic has been found to be very desirable in the production of organ and orchestral music. For organ music a decay to inaudibility in from two to five seconds has been found to be pleasing.

The rate of decay of sound in an auditorium is determined by the acoustic storage capacity, namely the cubic content of the enclosure containing the air carrying the sound waves and the reflecting qualities of the interior surfaces of the enclosure. Absorption of sound takes place at the walls and ceiling dependent upon their surface and structure, and by objects such as carpets and the listening audience. In the proper acoutic design of an auditorium for musical purposes, the foregoing are controlling.

In my device the energy storage capacity of the reverberation coils corresponds to the acoustic storage capacity of an auditorium. The sound absorbing quantities of an auditorium have their counterparts in my structure in the rate of transformation of mechanical energy of the reverberation coils into acoustic energy, in the mechanical hysteresis losses in the coils, and to a minor extent in the sound radiated by the coils in vibrating. In view of this, it is an important feature of my invention not only that the transit time of the reverberation coils be suitable for the purpose desired, but that the mass or weight, and "impedance" of the coils, be properly related to the loud speaker—to produce sufficient energy storage effects desired and so that the transformation of mechanical vibratory into acoustic energy at a desired gradual rate, be obtained. It is also important that the material composing the coils be properly selected. These features which I have outlined thus far I shall take up in detail later herein.

The preferred device

The preferred embodiment of my invention is illustrated in Figures 1–7, 11 and 12 of the drawings. In Figure 1 the left-hand portion is a loud speaker comprising a usual frame **1** supporting a cone or diaphragm **3**, a voice coil **5** attached to the diaphragm at its central portion, and a magnet structure for the voice coil enclosed in the housing **7**. Attached to the central portion of the diaphragm **3** opposite the voice coil is illustrated a dome or cap **9**. In usual loud speaker practices this dome, known as a "dust cap," is employed to prevent foreign particles from entering the narrow gap between the voice coil and its enclosing magnet structure. In my device I have specified that this dome **9** be composed of metal such as aluminum of suitable thickness and rigidity so that a reverberation coil structure, indicated generally at **11**, may be attached thereto to be vibrated by and to vibrate the dome and the diaphragm **3**. The dome **9** is attached to the diaphragm at **17** by a suitable adhesive. As shown particularly in Figures 3 and 5, the dome **9** is provided with apertures such as **13** to help equalize the air pressure on both sides of the dome in vibrating. To prevent incursion of foreign particles, I have provided filter screens such as thin cloth **15** over the apertures **13**.

Through a hole in the dome **9**, I secure thereto an outwardly extending screw or stud **19**, of non-magnetic strong material, such as stainless steel, by means of a nut and washers, indicated at **21**, which preferably are of stainless steel and Phosphor bronze respectively. The elements **19** and **21** and the dome **9** are composed of non-magnetic materials to avoid an undesired static magnetic pull upon the diaphragm **3** by the magnetic structure of the loud speaker.

To the screw **19** of the dome **9**, at a point displaced outwardly from the body of the dome, I attach the reverberation coil structure **11** by means of suitable hardware indicated at **23**, comprising two nuts and a lock washer. The structure **11** comprises four helically wound coils or springs **25***a* and **25***b* of galvanized iron wire, outwardly extending on the concave side of the cone **3**. As illustrated, each of the coils is composed of an inner straight portion and an outer curved portion—approximately three-fourths of a circle. As further shown, the coils are arranged in two planes at right angles, two coils in the one plane being designated **25***a* with the remaining members in the quadrature plane indicated as **25***b*. I shall discuss later a specific difference between the pairs of coils.

The inner ends of the four coils may be joined by brazing as at **27** (see Figure 4), a hole **29** being drilled in the brazed joint for attaching the coil structure to the screw **19**, as previously described. For securing the respective outer ends of the coils, I have provided a heavy spider-shaped metal frame **33**, preferably of brass, the legs of which are screwed to the main frame **1** of the loud speaker, as illustrated in detail in Figure 11. As further shown, the inner portions of the coils **25***a* and **25***b* extend outwardly through the ring portion of the frame **33**, the coils terminating at their outer ends at integral lug extensions **31** on the ring (see Figure 2) located between the legs of the frame. These lugs **31** contain lengthwise slots **35**, through which holes of suitable size have been bored to receive the coil ends. Respective cross holes have been bored in the lugs near their outer ends, into which hexagonal headed screws **37** have been inserted with nuts and washers at their stud ends. By drawing up these screws **37**, simple effective clamps for the outer ends of coils **25***a* and **25***b* are thus provided.

I have found it desirable to inhibit spurious, lateral movements of the reverberation coils both in shipping the present structure and in its operation. For this purpose, and to prevent lateral sagging of the coils in any mounting of the structure, I have provided outwardly extending metal rods **39** which are screwed into the legs of the frame **33**. Strong light-weight textile cords **41** extend laterally from the reverberation coils to the rods **39** to confine the coils to longitudinal motions.

There remains a means for providing a complete acoustic structure embodying my invention. A loud speaker should be "baffled," i. e. tightly attached to a panel or the like having a closely mating aperture for the loud speaker so that destructive interference between sound waves emitted by the front and rear sides of its diaphragm is minimized. In my device the reverberation coils extend somewhat beyond the confines of the loud speaker. As a baffle extension, then, for the structure, I have provided a cylindrical housing **43** which may be constructed of wood or plywood in part, having respective collars **45** at its ends. This housing **43** envelopes the reverberation coils, acoustically houses the structure and adapts it to panel mounting. The structure and housing are attached by means of screws **47**. Screws **47***a* mount the complete device on a panel. An exemplary installation employing my invention in conjunction with a usual loud speaker is shown in Figure 12.

An alternate structure

A modified form of my invention is illustrated in Figures 8–11. A loud speaker similar to that described in the previous embodiment is indicated generally at **51**. In a manner similar to that described above, a single, considerably longer reverberation coil **53** of galvanized iron wire is attached to a dome **55**, similar to the dome **9** shown in detail in Figure 5. The coil of spring **53**, helically wound, is later formed as shown in Figures 8 and 9. As illustrated, it extends outwardly from the central portion of the loud speaker diaphragm, thence across the front of the loud speaker, and then to the rear in a helical pattern around the housing of the loud speaker magnetic structure. The coil may be divided at one or more points as at **57** (Figures 8 and 10) to simplify its fabrication and assembly. The coil may be supported throughout its length by strong light-weight textile cords

59, fastened to a bracket 61 extending across the front of the loud speaker and to rearwardly extending rods 63 arranged in a cylindrical array joined by a plywood ring 65.

Design considerations

I have mentioned above that the transit time of a reverberation coil in the present development is not inappreciable as compared with the period—time of a vibration—of acoustic energy under consideration. Now the useful frequency range of the acoustic energy in the production of organ music is approximately 30 to 6000 V. P. S. (vibrations per second), corresponding to a range of periods from about .033 to about .00017 second. In view of this, each of the four helical reverberation coils in the preferred embodiment of the present development, when used with a loud speaker having an over-all diameter of about 15 inches, has been designed to have a transit time of about .025 second. Each coil contains 80 turns of 0.376 centimeter diameter iron wire (#9 Washburn and Moen gauge) with a mean diameter of 2.92 centimeters for the helix. The transit time can be obtained from these values and the usual formula for the velocity of compressional waves on a helical spring, as follows:

$$V=\frac{d}{\pi D^2}\sqrt{\frac{E_s}{2P}}$$

where

E_s=modulus of rigidity of the coil material, dynes per square centimeter,

P=density of the coil material, grams per cubic centimeter,

d=diameter of the coil wire, centimeters,

D=mean diameter of the helix, centimeters,

V=propagation velocity, turns per second.

The importance of an appreciable transit time in a reverberation coil resides in obtaining modes of motion of the coil which are closely spaced in frequency and which extend into low frequencies, and for useful results the spring structure which I employ should have a transit or transmission time of at least about .01 second.

Now the coils of the pair **25***a* in one plane in the preferred embodiment of the present invention have each a "free" inner end, and a "fixed" outer end comprising a short stub end, particularly as shown in Figure 6, clamped in the heavy frame **33**. The frequencies of the natural modes of motions of these coils, for the above transit time of .025 second, are therefore

$$n/(4\times.025)=10,\ 30,\ 50,\ 70,\ \text{etc. V. P. S.}$$
$$\text{where } n=1,\ 3,\ 5,\ 7,\ \text{etc.}$$

indicative of the odd order frequencies of a quarter-wave transmission line and spaced at 20 V. P. S. separation.

However, I decrease the frequency separation of the modes of motion of the coil structure **11** by terminating the outer ends of the other two coils **25***b* in the plane at right angles to **25***a*, as shown in Figure 7. As illustrated in Figure 7, each of the reverberation coils **25***b* has an integral U-shaped extension between the coil helix and the stub clamped in the frame **33**. I construct these U shaped extensions to have sufficient compliance so that dynamically the outer ends of the helical coils **25***b* are free to vibrate, but statically are suitably supported. The coils **25***b* are then in effect half-wave transmission lines, the frequencies of the natural modes of motion of which are:

$$n/(2\times.025)=20,\ 40,\ 60,\ 80,\ \text{etc. V. P. S.}$$
$$\text{where } n=1,\ 2,\ 3,\ 4,\ \text{etc.}$$

These frequencies also are at 20 V. P. S. separation.

It will become apparent, I believe, from the foregoing that when the coil pairs **25***a* and **25***b* are combined in the structure **11**, the modes of motion of the coil structure as an entirety are at only 10 V. P. S. spacing—one-half that of either of the pairs comprising it. In the production of organ music, then, the structure will have

about 600 resonant vibration frequencies. Due to mechanical hysteresis loses in the vibrating coils and energy radiated therefrom, these resonances are sufficiently broad so that the embodiment under description presents a sufficiently uniform reverberant response over a desired frequency range. The use of iron in the coils, which has adequate but not too high hysteresis for the purpose, is appropriate in this respect.

As mentioned above, an important consideration of the present development is the energy storage capacity of the reverberation structure. An index of this capacity is the mass or weight of the reverberation coils, since for given vibration of the coils, the mass determines the kinetic energy stored. In the preferred embodiment of the development, I have succeeded in constructing reverberation coils, as described above, each having a mass of about 1.4 pounds or a total mass of about 5.6 pounds for the structure 11. I have found that this mass in conjunction with a loud speaker having an over-all diameter of about 15 inches provides sufficient capacity so that vibratory energy is converted into reverberant acoustic energy at satisfactory intensity and rate. In order to provide a spring structure which will store sufficient kinetic energy, the mass of the spring structure should be at least about 25 times the mass of the radiator to which it is coupled, and preferably considerably greater, say, in a ratio of 50:1 to 250:1, depending somewhat on the nature of the spring structure.

The "impedance" of the reverberation coils varies, of course, with frequency due to their resonances, antiresonances and other factors. Considered for the moment as infinitely long coils, each of the coils would have a characteristic or iterative impedance of Z=25,400 mechanical ohms (dynes per centimeter per second), according to the formula:

$$Z=\frac{\pi d^3}{4D}\sqrt{\frac{E_s P}{2}}$$

where the quantities in the formula are as above. The total characteristic impedance of the structure 11 would then be $4\times25{,}400=101{,}600$ mechanical ohms.

In space requirements the preferred arrangement adds about 5½ inches length to a loud speaker such as described embodying it. The diameter may remain the same.

In the alternate structure illustrated in Figures 8–11, the single reverberation coil has the following values:

Transit time, 0.10 second
430 turns
d, .488 centimeters (#6 W and M gauge)
D, 2.85 centimeters
Characteristic impedance (as an infinitely long coil), 56,800 mechanical ohms mass, 12.5 pounds.

While the alternate structure has a coil of longer transit time and greater mass, it is not quite as economical to construct as is the preferred embodiment.

It will be understood that modifications may be made in my invention without departing from its spirit. Having thus described the invention, those features which I desire to protect by Letters Patent comprise:

1. In a system for synthesizing sound reverberation effects, the combination of an electro-acoustic radiator and a spring structure connected at one end to said radiator, said spring structure having a mass at least twenty-five times the mass of said radiator and a transmission time for vibrational disturbances which is at least .01 second.

2. A device for producing both direct and related reverberant sounds from audio frequency electrical energy corresponding to said direct sounds, comprising a framework, a vibratile sound productive cone-shaped diaphragm supported by said framework and having means for being vibrated by audio frequency electric currents, a spring system comprising a plurality of helical springs

each attached at one end to the central portion of said cone and extending outwardly therefrom so as to be excitable longitudinally thereby, means supporting said springs from said framework so as to permit longitudinal, and to inhibit lateral, motions of said springs, said springs each having a transmission time for mechanical vibratory energy of at least .01 second.

3. The device claimed in claim 2 wherein at least one spring has its outer end rigidly terminated and at least another spring has its outer end compliantly terminated with respect to said diaphragm.

4. The device claimed in claim 2 wherein said cone-shaped diaphragm has a concave side, wherein said springs extend outwardly on the concave side of said cone-shaped diaphragm, and wherein the inner portions of said springs are substantially straight and the outer portions are curved.

5. The device claimed in claim 2 wherein a spider is mounted in front of said cone-shaped diaphragm, and wherein the outer ends of said helical springs are attached to said spider.

6. The device claimed in claim 5 including a forwardly extending, substantially cylindrical housing concentric with said cone-shaped diaphragm, said helical springs lying within the confines of said housing, whereby the structure may be mounted against a perforated panel acting as a baffle with said spring structure located wholly behind said panel.

7. A device for producing both direct and related reverberant sounds from audio frequency electrical energy corresponding to said direct sounds, comprising a housing, a vibratile sound productive diaphragm supported by said housing and having means for being vibrated by audio frequency electric currents to produce mechanical vibratory energy, a spring structure including at least one helical spring attached to and extending outwardly

from said diaphragm so as to be excitable longitudinally thereby, means supporting said spring structure from said housing at a point remote from said diaphragm, the mass of said spring structure being at least twenty-five times the mass of said diaphragm and having a transmission time for mechanical vibratory energy of at least .01 second.

8. The device claimed in claim 7 wherein said helical spring extends outwardly beyond said diaphragm, is curved to pass laterally beyond one end of said housing, and is folded rearwardly, with portions of said spring disposed in helical convolutions surrounding said housing.

9. The structure claimed in claim 8 wherein said housing includes a forwardly extending, substantially annular flange by means of which said structure may be mounted against a perforated panel acting as a baffle.

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