ELECTRONIC SOUND ABSORBER

Filed April 30, 1953

2 Sheets-Sheet 1

Fig.1.

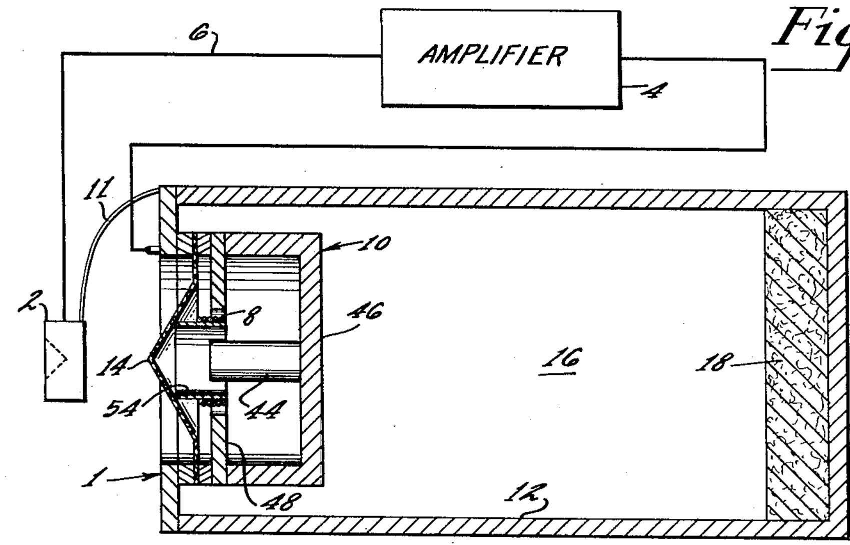


Fig.2.

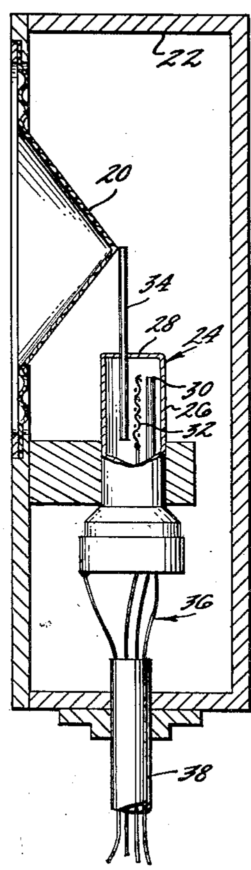
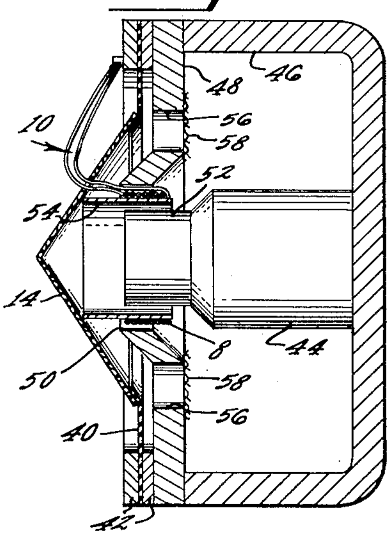


Fig.3.



INVENTOR.
Harry F. Olson
BY Morris A. Rabtin
ATTORNEY

May 9, 1961 H. F. OLSON 2,983,790
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Fig. 4.

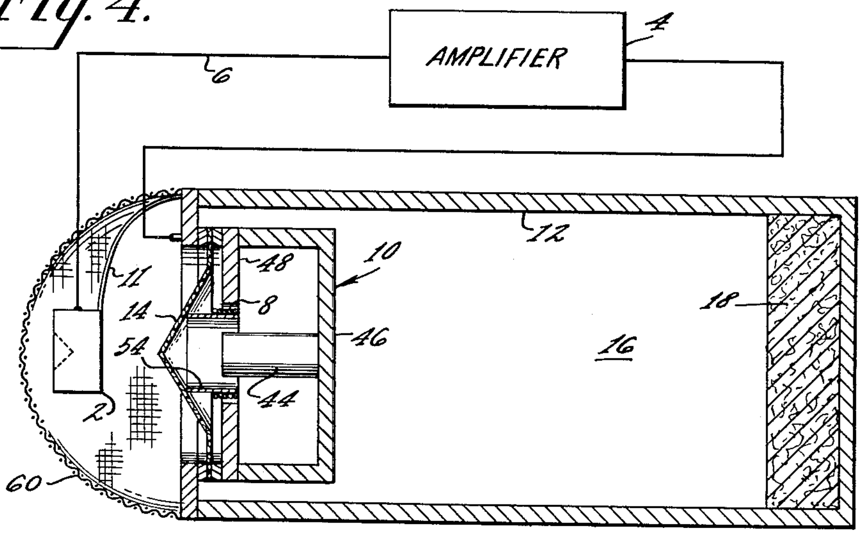


Fig. 7.

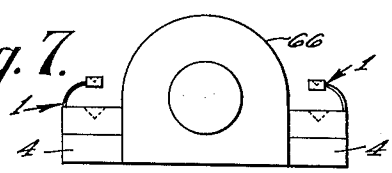
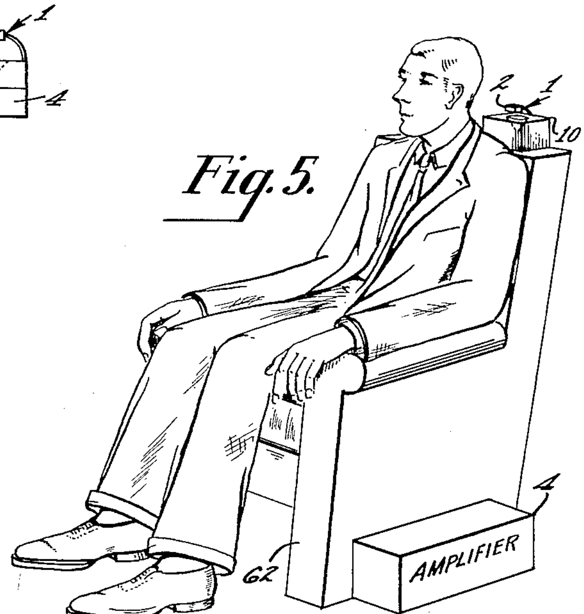


Fig. 5.



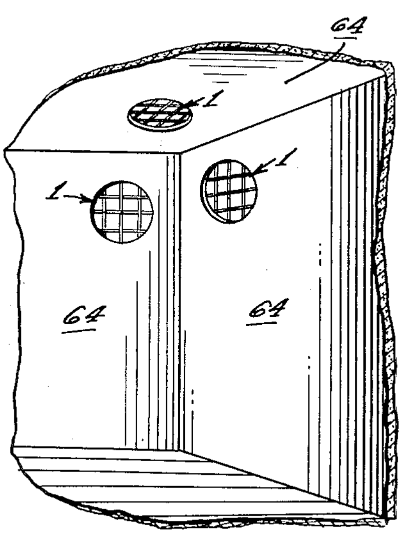


Fig. 6.

INVENTOR.
Harry F. Olson
BY Morris A. Rabkin
ATTORNEY

2,983,790
Patented May 9, 1961

2,983,790

ELECTRONIC SOUND ABSORBER

Harry F. Olson, Princeton, N.J., assignor to Radio Corporation of America, a corporation of Delaware

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The present invention relates to acoustics, and more particularly to electronic sound absorbers.

When sound energy impinges upon a surface it may be tacitly assumed that the energy is divided into three portions, namely; the incident, reflected and absorbed energy. Furthermore, it may also be assumed that the fraction of absorbed incident energy is a property of the physical characteristics of the surface exposed to the sound. It is upon these assumptions that the classical theories of sound absorption are based. The result was the evolution of a quantity termed the sound absorption coefficient of a material which is the ratio of the absorbed sound energy to the incident sound energy. In general, the object is to obtain a large absorption coefficient over a wide frequency range with a practical material.

Substantially all of the conventional sound absorbing materials are made of some sort of porous material. The absorption of sound is due to dissipation of energy incurred by viscosity as the sound passes through the narrow tortuous passages in the porous material. When this material is used as a surface sound absorber, the volume current is inversely proportional to the acoustical impedance of the material. The sound absorption is the product of the square of the volume current and the acoustical resistance. Since the acoustical impedance of all practical sound absorbing materials in conventional mounting arrangements is very high in the low frequency range, the resultant volume current is small and as a consequence, the sound absorbing efficiency is poor.

There are many applications for a sound absorber which exhibits high absorption efficiency in the low frequency range. Some applications involve the reduction of low frequency noise in spot locations, as for example, in the vicinity of some machines, in airplanes, in automobiles and in trains. Other applications involve the noise quieting of the low frequency sound output of machinery.

Conventional sound absorbing systems with high efficiency in the low frequency range are extremely bulky. Therefore, conventional sound absorbing systems are unsuitable because the above mentioned applications require a compact high efficiency sound absorbing system.

The efficiency of sound absorption can be increased by using a resonator in conjunction with the absorbing material which in effect improves the coupling between the medium and the absorbing material. The frequency range of high sound absorption obtained by the use of a resonator is confined to a fraction of an octave. Furthermore, the resonator must be of considerable size to obtain high absorption. These two factors make the range of usefulness of the resonator somewhat limited because in order to obtain absorption over one or two octaves requires the use of several resonators. Such a system is too bulky for most applications.

It is an object of this invention to provide a novel absorber for low frequency sound waves which is economical of space.

A further object of this invention is to provide an absorber as set forth which is electronically operated.

Another object of this invention is to provide an improved low frequency sound wave energy absorber which is responsive over a relatively wide range of low frequencies including the lower audible frequencies.

In accomplishing these and other objects, there has been provided, in accordance with the present invention, an electronic sound absorber for immersion in a sound field comprising a microphone, an amplifier and a loudspeaker. The microphone detects incoming signals including signals of the lower audible frequencies which are amplified and fed to the loudspeaker. The signals emanating from the loudspeaker are substantially in phase opposition to the indicent waves, substantially nullifying them. The incident waves are, of course, of long wave length relative to the spacing between the microphone and the speaker.

A better understanding of this invention may be had from the following detailed description when read in connection with the accompanying drawings, in which,

Figure 1 is a sectional view, partly schematic, illustrating a sound absorber made in accordance with the present invention,

Figure 2 is an enlarged view, in section, of a microphone suitable for use in the apparatus embodying the present invention,

Figure 3 is a view, in section of a loudspeaker suitable for use in apparatus embodying the present invention,

Figure 4 is a view similar to that of Figure 1 but showing a different form of apparatus embodying the present invention, and

Figures 5, 6 and 7 are views showing applications of the present invention.

Referring now, to the drawings in more detail, there is shown in Figure 1, a sound energy absorbing apparatus **1** comprising a microphone **2** connected to a suitable amplifier **4** by a lead **6**. The amplifier output is connected to the voice coil **8** of a speaker **10**. The microphone **2** is supported a few inches in front of the loudspeaker **10** by a support member or bracket **11**.

The speaker **10** is mounted in a cabinet **12** which entirely encloses the back side of the diaphragm **14** of the loudspeaker **10**.

The cabinet **12** forms a low frequency resonant chamber **16** on the closed or concave side of the loudspeaker. The volume of the chamber is a well known function of the size of the speaker diaphragm. For example, if the speaker diaphragm is three inches in diameter, a chamber volume of about one-half of a cubic foot is required. Sound wave energy absorbing material **18** is placed within the chamber **16** to prevent the establishment of standing waves in the chamber.

One type of suitable microphone which may be used in this arrangement is shown in more detail in Figure 2. This microphone is an electronic microphone in which the impinging sound vibrations directly control the electron stream in a vacuum tube. A microphone of this type is described in more detail and claimed in U.S. Patent No. 2,491,390.

The microphone comprises a sound wave responsive diaphragm **20** mounted in a housing **22**. Also supported in the housing is a vacuum tube **24** which has rigid sides **26** and a flexible diaphragm end member **28**. Within the vacuum tube **24** are a cathode **30** and a grid **32**. An anode member **34** extends from an operative position within the tube, through the flexible diaphragm **28** to a position external of the vacuum tube **24**. The sound wave responsive diaphragm **20** is operatively connected to the external end of the anode member **34**. Thus, whenever the diaphragm **20** is caused to vibrate, the anode member **34** is accordingly caused to vibrate. This in turn, causes a corresponding variation in the spacing between the several electrodes in the vacuum tube 24 modulating the stream of electrons flowing therebetween in accordance therewith. Suitable electrical connections 36 are provided for the electrodes of the vacuum tube 24 and are brought out of the housing 22 in a cable 38. The advantages of the electronic microphone for this application are as follows: the response in the low frequency range is independent of the frequency, the output impedance is a constant electrical resistance, the phase relation between the sound pressure and the voltage output is a constant in the low frequency range and the sensitivity is relatively high. The response is very smooth below 1000 cycles. Furthermore, uniform response extends down to zero cycles or D.C. sound pressure. Under these conditions the variation in phase angle between the activating sound pressure and the voltage output is less than two degrees from 20 to 400 cycles. Since the electrical impedance of the microphone is an electrical resistance of about 10,000 ohms, the problems of maintaining uniform phase and response in coupling an amplifier to the microphone are simplified.

A loudspeaker which has been found suitable for use in the present apparatus is illustrated in Figure 3. The loudspeaker comprises a conical diaphragm 14 which is mounted with its vertex pointed in the general direction of radiation. The diaphragm 14 is supported, at its periphery by a thin sheet rubber suspension member 40 which is, in turn, held in mounting rings 42. A permanent magnet 44 provides a magnetic field for the speaker. The magnet 44 is mounted on a yoke member 46 to which is secured a top-plate member 48. The top-plate member 48 has a central aperture 50. A pole cap 52 is secured to the end of the permanent magnet 44 remote from the end secured to the yoke member 46. The end of the pole cap 52 projects into the aperture 50 defining an annular air gap.

The voice coil 8 is carried by a coil support member 54 which is secured to the back side of the diaphragm 14 coaxially with the cone of the diaphragm. This voice coil extends into and operates in the air gap defined by the top-plate member 48. The mounting rings 42 carrying the rubber suspension member 40 are secured to the surface of the top-plate member 48 adjacent to the periphery thereof. The top-plate member 48 is circular in shape and is conically deformed in the area surrounding the central aperture 50 to somewhat conform to the conical shape of the diaphragm 14. The top-plate member thus substantially completely encloses the back of the diaphragm. However, in order to allow the diaphragm to operate freely, apertures or holes 56 through the plate are provided about the central aperture to allow the air to pass in response to the movement of the diaphragm. To provide a measure of damping to the passage of the air through these holes, acoustical resistance material 58 such as silk cloth is fastened over the holes 56. Since, for low frequency operation, transformer coupling between amplifier and voice coils introduces considerable adverse phase shift conditions, the voice coil 8 of the speaker 10 suitable for use in the instant application is so wound as to have a sufficiently high electrical impedance that it may be directly coupled to the output of the amplifier 4.

The amplifier 4 may be of any well known type the characteristics of which include susbtantially undistorted output in the very low frequency range which may include the lower audible frequencies and preferably may further include known means for limiting the frequency response to a desired low level, say, for example, 200 cycles per second upper limit.

In operation, the apparatus, as shown in Figure 1 is positioned near to the area to be influenced by the electronic sound absorber. The higher frequency sound waves may be absorbed in the usual manner. The low frequency waves which fall upon the microphone are converted into corresponding electrical signals by the microphone. These electrical signals are amplified by the amplifier 4 then applied to the voice coil 8 of the speaker 10. In response to the signals applied to the voice coil, the diaphragm 14 of the speaker vibrates, generating a pressure wave train which corresponds to the sound waves that impinge upon the microphone 2. At low frequencies, the wave length is very long with respect to the spacing between the microphone and the loudspeaker, at the upper limit of 200 cycles per second the wave length is about 5.5 feet while the spacing between the microphone and the speakers is only a matter of a very few inches. Thus there will be very little phase shift due to the spatial placement of the microphone and the speaker. The phase and amplitude of the radiated signal from the speaker are adjusted to substantially neutralize the low frequency component of the incident sound waves. Operating in this manner, the unit acts as a sound pressure reducer. A slightly modified apparatus is required to make a sound absorber.

The problem in low frequency sound absorption is to provide an acoustical impedance of a relatively small value so that the volume current which introduces the sound absorption will not be limited by a high acoustical impedance. A unit including such an acoustical impedance is shown in Figure 4. The apparatus shown in Figure 4 is susbtantially identical with that shown in Figure 1 with the exception that a screen 60, comprising an acoustical resistance, encloses the open side of the loudspeaker 10 and the microphone 2. The electronic sound absorber provides a low acoustical impedance for terminating the dissipative acoustical impedance provided by the screen 60.

Applications for utilization of such electronic low frequency sound absorbers might be, for example, in an airplane. Assume that the man, Figure 5, is sitting in a seat 62 of an airplane. The high frequency component of the usual airplane noise is removed by the usual means such as the fibrous wall covering material. However, in an airplane there is a substantial low frequency component to the noise. An electronic sound absorber is employed. The microphone 2 and loudspeaker 10 units are placed near the passenger's head, for example, on the back of the seat. The amplifier 4 may be placed at a more remote position, for example, in the floor beside or under the seat. The low frequency component of the noise sound waves falls upon the microphone. The microphone picks up the signal and sends it through the amplifier 4 to the loudspeaker 10. The loudspeaker vibrates in accordance with the signal applied thereto. The vibrating speaker diaphragm absorbs the energy of the low frequency component of the noise in the immediate vicinity of the passenger's head. Used in this manner, the electronic sound absorber has a localized or spot neutralization effect.

In Figure 6, there is illustrated an additional application of a means of utilizing the electronic sound absorber. To absorb the low frequency component of noise in a room, the electronic sound absorber may be used in substantially the same manner as conventional wall materials. For best results, one of the electronic sound absorbers 1 should be mounted on each of the surfaces 64 constituting a corner of the room.

There are, of course, many other applications of uses for the electronic sound absorbers of the type herein described. They may be used as spot noise neutralizers in such places as in a shop where the low frequency noise is normally at a high level. The sound absorber may be mounted, near to where an operator's head normally is located, in a manner similar to that illustrated by the airplane passenger of Figure 5. The device may be used, as shown in Figure 7, at or near to a piece of machinery 66 or other noisy apparatus to, at least partially, reduce at the source the low frequency sounds developed by the apparatus. It may also be used in conjunction with the exhaust lines of internal combustion engines or with the air ducts of a forced air distribution system. In all of these applications the electronic sound absorber effectively reduces the low frequency component of noises.

Thus there has been provided an improved low frequency sound absorber which is simple in operation and construction, which is economical of space, and which is electronically operated.

What is claimed is:

1. Apparatus for immersion in a sound field to neutralize low frequency sound waves in said field radiating from a vibratory member, said apparatus including a low frequency sound detecting means responsive to sound waves from said member, a loudspeaker for generating low frequency sound and for radiating said generated low frequency sound in a direction opposite to the direction of sound radiation from said member, said loudspeaker being disposed behind said detecting means in the direction of radiation of said low frequency sound waves from said vibratory member a distance equal to less than a wavelength of said low frequency sound waves, and means coupling said detecting means to said loudspeaker, said coupling means including phase reversal means and means responsive to said detecting means for driving said loudspeaker to generate low frequency sound waves substantially in phase opposition to said detected sound waves and corresponding thereto.

2. A sound absorber for immersion in a sound field for neutralizing the effect of low frequency sound waves in said field, said absorber comprising a microphone responsive to low frequency sound waves, a loudspeaker assembly disposed substantially less than a wavelength of said low frequency away from said microphone, an amplifier coupling said loudspeaker to said microphone for operation substantially in phase opposition to sound waves impinging upon said microphone, said loudspeaker assembly including a conical diaphragm having its vertex directed generally in the direction of radiation, and means completely enclosing the side of said diaphragm opposite from said direction of radiation.

3. A sound absorber for immersion in a sound field for neutralizing the effects of low frequency sound waves in said field emanating from a vibratory member comprising in combination a loudspeaker assembly including a diaphragm disposed away from said member in the direction of radiation of sound waves from said member, means defining a magnetic field, a voice coil operable in said magnetic field secured to said diaphragm, a flexible peripheral support means for said diaphragm, and means completely enclosing the side of said diaphragm opposite from said vibratory member, a microphone responsive to said low frequency sound waves disposed between said member and said diaphragm and spaced from said diaphragm a distance equal to less than a wavelength of said low frequency sound waves, and an amplifier coupling said loudspeaker to said microphone for operation substantially in phase opposition to low frequency sound waves impinging on said microphone.

4. A sound absorber for immersion in a sound field for neutralizing the effect of low frequency sound waves in said field, said absorber including a microphone responsive to low frequency sound waves, a loudspeaker, means for mounting said microphone less than a wavelength of said low frequency from said loudspeaker, a screen constituting an acoustical resistance enclosing one side of said loudspeaker and said microphone, and an amplifier electrically coupling said loudspeaker to said microphone for operation substantially in phase opposition to low frequency sound waves impinging on said microphone.

5. A sound absorber for immersion in a sound field for neutralizing the effect of low frequency sound waves in said field, said absorber comprising, in combination, a microphone responsive to low frequency sound waves; a loudspeaker assembly including a conical diaphragm having its vertex directed generally in the direction of radiation, said loudspeaker being disposed less than a wavelength of said low frequency away from said microphone, means defining a magnetic field, a voice coil operatively secured to the concave side of said diaphragm for operation in said magnetic field, means completely enclosing the concave side of said diaphragm, and a thin sheet rubber film constituting a flexible peripheral support for coupling said diaphragm to said enclosing means; means for supporting said microphone in closely spaced relation to said loudspeaker, a screen constituting an acoustical resistance enclosing the convex side of said loudspeaker diaphragm and said microphone; and an amplifier electrically coupling said loudspeaker to said microphone for operation substantially in phase opposition to low frequency sound waves impinging on said microphone.

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UNITED STATES PATENTS

2,043,416	Lueg	June 9, 1936
2,491,390	Olson	Dec. 13, 1949

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