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[54] **SOUND RADIATING STRUCTURE**

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[58] **Field of Search** .... 181/31 B, 31 R, 31 A, 32 R, 181/155, 163, 160, 175

[56] **References Cited**

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[57] **ABSTRACT**

A sound radiating structure in which at least two totally enclosed sound transmission channels, or chambers having flexible walls are arranged in an adjacent spiral configuration and are individually excited by sound waves.

2 Claims, 2 Drawing Figures

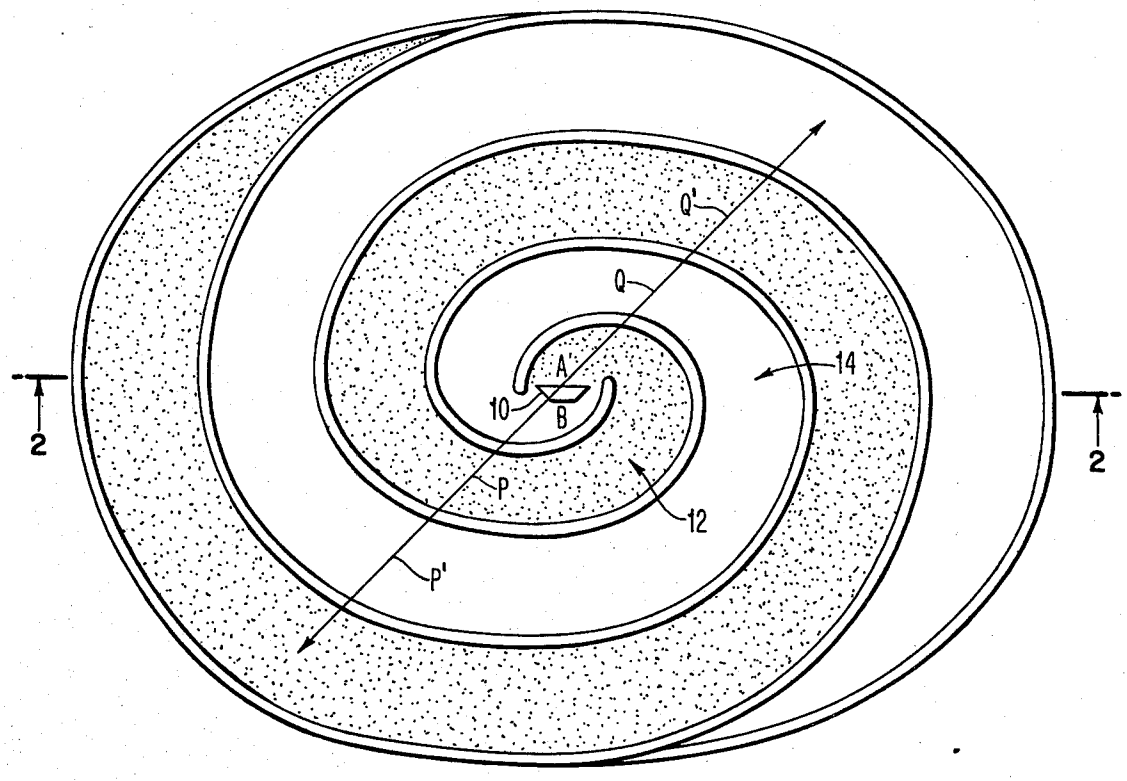


FIG. 1

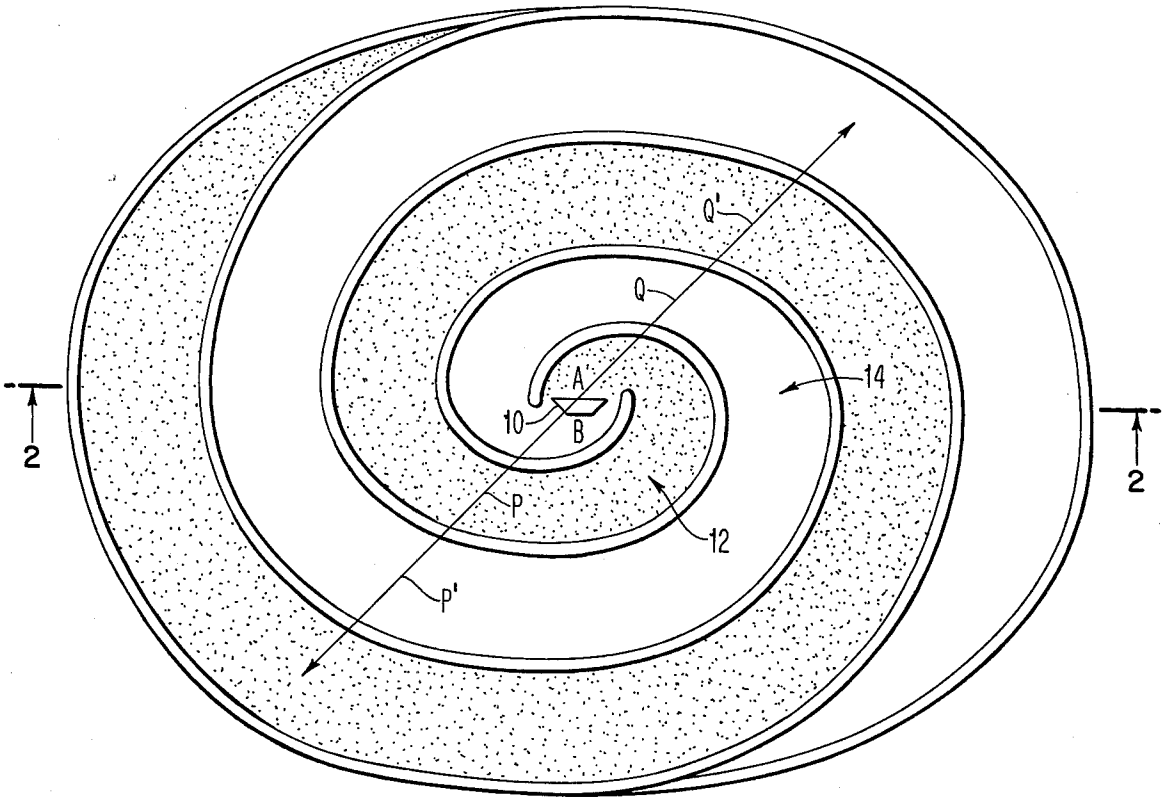
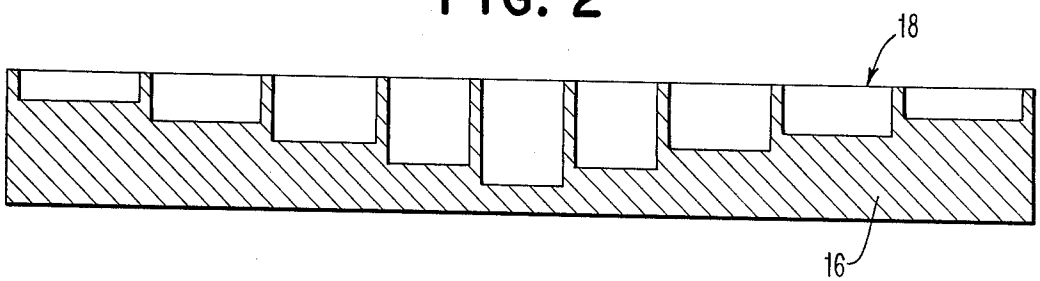


FIG. 2



SOUND RADIATING STRUCTURE

BACKGROUND OF THE INVENTION

It is well known that the familiar cone speaker with its attached voice coil moving in a magnetic field produces two sound waves simultaneously, one to the front of the cone and the other to the rear. These two sound waves are opposite in phase to each other since for a given movement of the cone, the compressional portion of a sound wave is produced on one side of the cone while simultaneously the rarification portion is produced on the opposite side. If those two anti-phase waves are allowed to interact or join together in a common space before either wave has reversed in phase (i.e., if difference in path lengths traveled by the waves enroute to interacting is less than a half-wavelength, or an appreciable portion thereof) the two waves will tend to cancel each other, resulting in little or no accoustic energy being radiated. When a cone moves without producing accoustical radiation the condition of reactive or non-dissipative input electrical power arises and poor conversion efficiency results.

Another familiar property of the cone speaker is its varying directivity with change in frequency, that is, the angle of radiation coverage is narrower for the higher frequencies than for the lower frequencies for any given size of speaker cone. In the past, the speaker cone has been used to radiate all frequencies, or in some applications where there is a need to provide radiation coverage over a broad angle and over a broad frequency range, the use of two or more speakers of different sizes has become a custom.

The use of speaker enclosures has become common practice. One type of enclosure is frequently called labyrinth enclosure and it causes one of the two sound waves generated by the speaker cone to reverse in phase before allowing the wave to enter the same environment or space occupied by the other wave. Thus, the two waves generated by a speaker cone can be made to reinforce each other, a process accomplished by passing one of the sound waves through a transmission line one-half wavelength in length at a selected frequency. This technique has a tendency to increase the level of accoustic output from the enclosure over a selected range of frequencies. The use of such an enclosure improves the electrical efficiency but only over a range of frequencies.

Another form of enclosure suppresses one of the two sound waves generated by the cone. This type of enclosure is generally much smaller than the labyrinth enclosure and is widely used for high fidelity reproduction of sound because of its relatively flat frequency response, that is, constant accoustical output vs. frequency. This type of enclosure suffers from lack of efficiency, requiring high electrical input. In addition, a single speaker cone has varying directivity as a function of frequency and therefore several cones of different size have frequently been employed.

SUMMARY OF THE INVENTION

In accordance with the principles of this invention, the sound to be radiated is caused to pass through each of two totally enclosed transmission channels, or chambers, having flexible walls and those channels are formed into adjacent spirals. With such a structure there will be adjacent points in the two channels where the sound waves are in phase and the vibrating parts of the channels will produce circularly polarized transverse sound waves external to the structure.

A feature of this invention is that two separately excited, adjacent, flexible walled spirals are employed to radiate sound and therefore there is improved electrical efficiency as well as substantially uniform directivity for all frequencies.

An object of this invention is to provide an inexpensive sound radiating structure which is very efficient, produces broadband response, and has improved nondirectional characteristics.

Another object of this invention is to provide an improved sound radiating structure which is inexpensive to manufacture.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a plan view of a sound radiating structure constructed in accordance with the principles of this invention.

FIG. **2** is a cross-sectional view taken on line **2 — 2** of FIG. **1.**

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **1** and FIG. **2** there is illustrated in plan and cross-sectional view, respectively, a loudspeaker enclosure embodying the principles of this invention. A cone-type loudspeaker **10** is provided with a first spiral-shaped sound transmission chamber or channel **12** excited by the front side of the cone and a second spiral-shaped sound transmission chamber or channel **14** excited by the rear side of the cone.

The channels are preferably formed with constantly increasing width and decreasing depth from the center to the periphery so as to have a constant cross-sectional area and to provide closer spacing between corresponding mid-points of adjacent channels near the center and greater spacing between corresponding mid-points near the periphery. Corresponding mid-points are those points in adjacent channels lying approximately on a given radius from the center of the spirals. Such spirals are commonly referred to as exponential or equiangular spirals.

The extreme outer ends of the channels may be tapered or otherwise constructed to provide termination of the sound waves with minimum amount of reflection. A rigid part **16** is shaped or otherwise constructed to form three sides of each of the channels **12, 14** and a membrane **18** forms a thin, elastic fourth wall of each of the channels. The membrane **18** may be one-piece and may be glued or otherwise secured to the rigid walls of the channels. The channels are therefore totally enclosed with one side of each channel being flexible while the other sides of the channel are rigid.

A matching section A immediately in front of the cone and a matching section B immediately behind the cone have such shapes as to match the circular shape of the cone to the rectangular cross-section of each of the channels, i.e., to permit the effective driving area of the cone to be made equal to the cross-section area of each channel.

A complete analytical theory of the operation of the spiral membrane sound radiator has not yet been established conclusively. One plausible approach to an explanation of the action of the spiral membrane sound radiator would be as follows: The simultaneous sound waves produced by the cone which are anti-phase at the start are confined to their respective channels

where the transverse component of those waves exerts pressure on the walls of the channels causing the thin membrane portions of those channels to move in synchronism with the waves. As those waves progress outward in the channels they gradually become in phase by virtue of the spiral configuration of those channels. At points in adjacent channels where those waves are most nearly in phase maximum radiation will occur since the adjacent points of the flexible walls simultaneously rise from or fall into the channels, whereas, where those waves are anti-phase, a rising point on the membrane of one channel is compensated by a falling point on the membrane of the adjacent channel and no radiation will occur.

A point P in channel **12** is diametrically opposite a point Q in the other channel **14.** Similarly, a point P′ in channel **14** is diametrically opposite a point Q′ in channel **12.** If the points P, P′ are close together as compared to the distance r measured to the center of the spirals and the points Q, Q′ are likewise close together, then all points can be considered as lying on a circle centered at the cone and the arc length Q P′ or P Q′ is approximately equal to πr. Because of the difference in path length of the spiral path from A (front of cone) to point P and the spiral path from B (rear of cone) to point P′, those points P, P′ will vibrate in phase for a particular wavelength of sound produced by the cone and points Q, Q′ will also vibrate in phase for that same wavelength of sound. When points P, P′ are high pressure areas, points Q, Q′ are low pressure areas, and vice versa. The total difference in path lengths in the two channels from the cone to points P, P′ is πr and the circumference or path length on which the points lie is $2\pi r$. When r is $(\lambda/2\pi)$ the differential phase change (i.e., path length difference) is $(\lambda/2)$ and the circumference is λ. The difference in phase of the two sound waves (measured in radians) traveling in adjacent spirals at any given region (e.g., points P, P′ in adjacent channels) can be expressed as $\theta+(2\pi/\lambda)(\pi r)$ where θ, the input phase difference, is measured in radians. Thus, sound waves which start anti-phase (π radians) at matching sections A, B gradually come into phase as they travel outward along the channels and when $r=\lambda/2\pi$ those waves are precisely in phase and radiation is maximum.

The spiral membrane enclosure produces radiation of a transverse wave which rotates with time (circular polarization) from the membrane. Radiation from the membrane is in the form of concentric apertures of one wavelength mean circumference. Since the radius is $\lambda/2\pi$ when radiation occurs, the radiating area is $\pi r^2 = \pi(\lambda/2\pi)^2 = \lambda^2/4\pi$ and the ratio of radiating area to wavelength is, therefore, $\lambda/4\pi$, a variable which is linearly proportional to wavelength only. This property makes the spiral membrane enclosure an inherently broadband structure, the basic requirement being only that the radius be large enough to allow a half wavelength of phase shift. Also, because the radiation occurs within an aperture of one wavelength circumference for all frequencies over which the spiral operates, a constant accoustical pressure and beam width is maintained.

Radiation from the one-wavelength aperture as described above may be termed the first mode of radiation since this represents the first occasion that the sound waves in the two transmission lines are made to be in-phase, a condition giving rise to radiation. It can be reasoned that sound waves existing in adjacent transmission lines beyond the one-wavelength aperture continue experiencing relative phase changes as they progress outward. Assuming that the spiral structure is large enough, these sound waves will be out-of-phase again at a radius when the aperture circumference is two wavelengths and in-phase at the three wavelength circumference. No radiation occurs from the two-wavelength aperture because the sound waves in adjacent channels are anti-phase. At the three wavelength aperture radiation can occur if sound waves exist, giving rise to the third mode of radiation. It follows that sound waves which are anti-phase at the input of the channels can excite only the odd modes of radiation.

The exponential-type spirals can be expressed by $r=e^{\alpha\theta}$ where r is the radius, α is a constant which determines the opening rate of the spiral, and θ is the angular measure in radians. The valve for α is chosen such that the spacing between adjacent channels in the region of maximum radiation

$$\left(\text{where } r=\frac{\lambda}{2\pi}\right)$$

is small compared to the wavelength of the sound to be radiated at that region, that is, the value of α should be such as to cause a half-wavelength differential phase shift within a radius equal to $\lambda/2\pi$.

The length of the channels of the exponential type measured from the cone is given by

$$s=\frac{r\sqrt{1+\alpha^2}}{\alpha}.$$

If it is assumed that all input energy is radiated by the time it passes through the one-wavelength circumference, i.e., when $r=(\lambda/2\pi)$, then the total distance traveled by a given wave is

$$s=\frac{\lambda\sqrt{1+\alpha^2}}{2\pi\alpha}.$$

This distance in terms of wavelength s/λ is then constant, given by

$$\frac{s}{\lambda}=\frac{\sqrt{1+\alpha^2}}{2\pi\alpha}.$$

Since the cross-sectional area of the channels is held constant throughout their length, the total volume, as a function of wavelength, as seen by the cone (air driving piston) at the center is constant for all frequencies of excitation, thus providing a constant loading factor for the piston contributing to the broadband characteristic of the structure.

An exponential spiral enclosure designed to radiate a frequency range of about 38 Hz – 20 kHz from a high compliance speaker cone having an effective driving area of about 6 square inches may have the following approximate dimensions:

Channel width at matching section — 1.3 inches
channel width at termination — 6 inches
thickness of walls shared by adjacent channels — three-eighths inch

channel depth at matching section — 4.7 inches
value of opening constant α of spirals — 0.157
length of major axis overall eliptical-shape enclosure — 28 inches
length of minor axis of overall eliptical-shape enclosure — 22 inches
thickness of membrane — 0.0005 inch (mylar)

Such a design provides a distance between channel mid-points P, P' at regions of maximum radiation which is about 0.1λ for all frequencies for which the enclosure functions and is virtually a pure resistive input impedance for all frequencies in the range 38 Hz–20 kHz.

What is claimed is:

1. A sound radiating structure comprising:

a. a first spiral shaped totally enclosed sound transmission chamber having a flexible portion,

b. a second spiral shaped totally enclosed sound transmission chamber having a flexible portion and concentrically disposed about said first chamber, and

c. sound producing means positioned adjacent said first chamber and said second chamber to cause sound waves to pass through said first and said second transmission chambers whereby said flexible portions will vibrate to produce secondary sound waves.

2. a sound radiating structure according to claim **1** wherein said spiral shapes are of the exponential type.

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