FIG. 1a

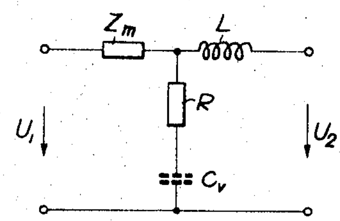

FIG. 1b

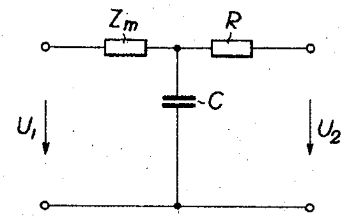

FIG. 2

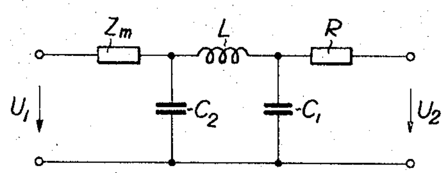

FIG. 3a

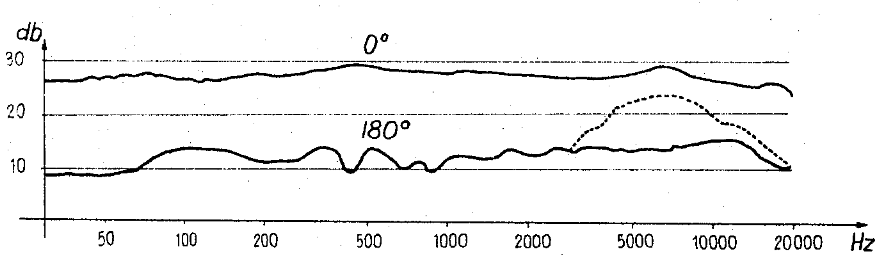

FIG. 3b

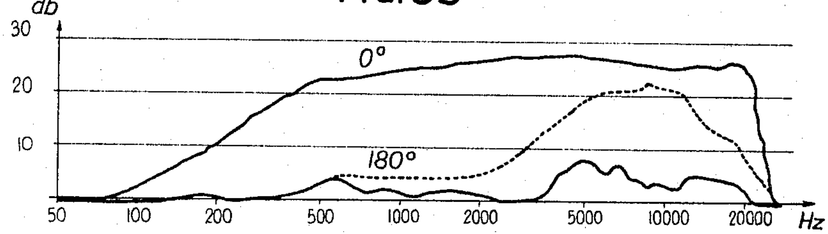

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FIG. 4

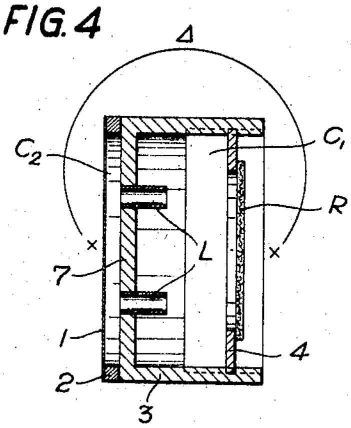
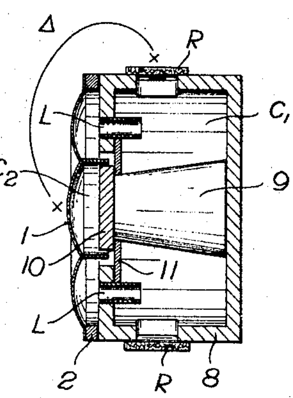


FIG. 5



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ELECTROACOUSTIC TRANSDUCER WITH UNILATERAL DIRECTIONAL CHARACTERISTIC

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Int. Cl. H04r *9/00, 1/04*
U.S. Cl. 179—115.5 14 Claims

ABSTRACT OF THE DISCLOSURE

An electroacoustic transducer includes a diaphragm having forward and rear surfaces and a phase-shifting arrangement for transmitting sound to the rear surface of the diaphragm. The phase-shifting arrangement includes a first phase-shifting system consisting of a resistance and a compliance and effective in a lower sound frequency range and includes a second phase-shifting system consisting of a mass and a compliance and effective in a higher sound frequency range, the two systems being connected in series with each other between a common rear sound inlet, for both lower and higher sound frequency ranges, and the rear surface of the diaphragm.

This invention relates to electroacoustic transducers, such as microphones, and, more particularly, to an electroacoustic transducer including a phase-shifting acoustic arrangement effective over a wide frequency range.

In microphones, particularly of the electrostatic or electrodynamic type, it is known to use a phase-shifting acoustic arrangement which is disposed in the sound path from the outside air to the rear surface of the diaphragm. This phase-shifting acoustic arrangement serves to impart a unilateral directional pattern, such as a cardioid pattern, for example, to the microphone. The phase-shifting arrangement comprises acoustic elements representing masses, compliances, frictional resistances and sound lines, and the combination of these elements has a delaying or phase-shifting effect. The delay is equal to the time required for the sound waves to traverse, exteriorily of the microphone, the distance between the center of the forward surface of the diaphragm and the effective sound inlet of the phase-shifting arrangement. This time is almost constant up to very high sound frequencies, so that the delay which is effected by this phase-shifting arrangement disposed inside the microphone is highly independent of frequency, and the phase increases with frequency in a linear relation.

A large number of such phase-shifting arrangements are known, but all have the disadvantage that they do not have a constant transit time throughout the frequency range to be transmitted. This results in disturbances in the unilateral directional pattern, and the differences between the external and internal transit times result in phase difference. Thus, sound waves reaching the microphone from the rear are also converted into electrical oscillations within a certain frequency range, where the microphone has poor directional discriminating properties.

An object of the invention is to provide an electroacoustic transducer including a phase-shifting arrangement in which the above-mentioned disadvantages are minimized so that the directional pattern is maintained throughout all the frequencies to be transmitted.

Another object of the invention is to provide an electroacoustic transducer comprising a phase-shifting arrangement including a first phase-shifting system consisting of

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a resistance and a compliance and effective in a lower frequency range, and a second phase-shifting system consisting of a mass and a compliance and effective in a higher frequency range, the transducer having a common rear inlet for both sound frequency ranges.

A further object of the invention is to provide an electroacoustic transducer including a phase-shifting arrangement and in which the systems forming the phase-shifting arrangement comply with the relations $RC_1=\tau/3$, $LC_2=\tau^2/3$, and $C_2/C_1=2$, where $\tau=\Delta/c$ is the transit time of sound from the center of the forward surface of the diaphragm to the effective sound inlet of the phase-shifting arrangement, R is the value of the resistance, C_1 is the value of the compliance associated with the resistance, L is the value of the mass, C_2 is the value of the compliance associated with the mass, Δ is the length of the shortest sound path exteriorly of the microphone from the center of the forward face of the diaphragm to the effective sound inlet of the phase-shifting arrangement, and c is the velocity of the sound in air.

In the formulae mentioned hereinbefore and hereinafter, the parameters are expressed in the following units: resistance R in grams per second, compliance C in centimeters per dyne, length of sound path Δ in centimeters, velocity of sound in air c in centimeters per second, mass L in grams, and transit time τ in seconds. In the electrical analogy, the resistance R is expressed in ohms, the capacitance C in farads and the inductance L in henries. The other parameters are expressed in the units mentioned above.

While the invention is not restricted to a specific type of electroacoustic transducers, it is particularly suitable for condenser microphones and dynamic treble microphones. The latter may be combined with a second microphone for the bases, to constitute a so-called two-range transmitter for high requirements.

Still another object of the invention is to provide a condenser microphone in combination with a phase-shifting arrangement and in which the resistance serving for the frictional control of the vibratory system also constitutes the resistance for a phase-shifting system including a resistance and a capacitance.

Still a further object of the invention is to provide an electrodynamic transducer in combination with a phase-shifting arrangement and including a gasket sealing the space accommodating a moving coil from an air chamber constituting the compliance in a phase-shifting system including a resistance and a compliance.

Yet another object of the invention is to provide an electroacoustic diaphragm in combination with a phase-shifting arrangement, and having two phase-shifting systems as mentioned above, and in which at least one of the acoustic elements in each of the phase-shifting systems is adjustable to compensate for deviations, such as due to manufacturing tolerances.

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.

In the drawings:

FIGS. 1*a* and 1*b* are schematic wiring diagrams illustrating electric circuits equivalent to conventional phase-shifting arrangements;

FIG. 2 is a schematic wiring diagram of the electric circuit equivalent to the phase-shifting arrangement of the invention;

FIGS. 3*a* and 3*b* are frequency response curves of different types of microphones with and without the phase-shifting arrangements of the invention;

FIG. 4 is a simplified cross sectional view of a condenser microphone embodying the invention; and

FIG. 5 is a simplified cross sectional view of an electrodynamic microphone embodying the invention.

For a better understanding of the invention, the following explanation is based on the first kind of mechanical-electrical analogy, wherein current value is analogous to the sound particle velocity, voltage analogous to differential sound pressure, inductance analogous to mechanical mass, capacitance analogous to mechanical compliance, and electrical resistance analogous to mechanical frictional resistance.

FIG. 1*a* shows an electrical circuit equivalent to a known system including a resistance and mass, and which meets only partially the requirement for a phase-shifting effect having a linear relation to frequency. FIG. 1*b* shows such a system including a resistance and a compliance. In FIGS. 1*a* and 1*b*, Z_m is the impedance of the vibratory diaphragm, and $L-R$ in FIG. 1*a*, and $R-C$ in FIG. 1*b*, are phase-shifting arrangements. C_v is the air chamber which is acoustically necessary to define the reference pressure. u_1 and u_2 correspond to the alternating sound pressures on the forward face of the diaphragm and at the rear end of the phase-shifting arrangement, respectively. These two sound pressures have a phase displacement which equals the "external" phase angle

$$a_A=\frac{\omega\Delta}{c}\omega\theta$$

where ω is the circular frequency $2\pi f$ and Δ is the shortest path length between the center of the forward face of the diaphragm and the effective sound inlet of the phase-shifting arrangement. C is the velocity of sound and θ the angle if incidence of sound with reference to the main axis of the microphone system. The phase-shifting systems effect an internal phase displacement ψ_i which is, in the ideal case, as large as the external phase displacement.

The arrangements shown in FIGS. 1*a* and 1*b*, and consisting of a mass and a resistance, and of a resistance and a compliance, respectively, can only approximate this ideal condition because the required phase relation is provided only at relatively low frequencies and the phase-shifting effect of the arrangement is much too small at higher frequencies. The known mathematical definition of the phase relation is:

$$L/R=\Delta/c \quad (1a)$$

$$RC=\Delta/c \quad (1b)$$

In accordance with the invention, a substantial improvement of the phase-shifting properties of a delay line is provided by a known phase-shifting system consisting of a resistance and a compliance and having connected thereto a further phase-shifting system consisting of a mass and a compliance. The latter system has an effective phase-shifting effect at higher frequencies. In this system, the following relations are at least approximated: $RC_1=\tau/3$, $LC_2=\tau^2/2$, $C_2/C_1=2$, where R is the value of the resistance and C_1 the value of the compliance of the known phase-shifting system consisting of a resistance and a compliance. L is the value of the mass and C^2 the value of the compliance of the system provided by the invention and consisting of a mass and a compliance, and $\tau=\Delta/c$ is the sound transit time from the forward surface of the microphone to the effective sound inlet of the phase-shifting arrangement.

FIG. 2 is an electric circuit diagram equivalent to the invention arrangement. The improvements due to the provision of the delay line of the invention are apparent from FIGS. 3*a* and 3*b*. By way of example, FIG. 3*a* shows the frequency response curve of a condenser microphone in the case of sound coming from a source directly in front of the microphone, or zero angle of sound incidence, and in the case of sound coming from a source directly at the rear of the microphone, wherein the angle of sound incidence is 180°. In the curve designated 0°, representing the sound source in front of the microphone, it is not apparent that there is a substantial difference between a condenser microphone without the phase-shifting arrangement of the invention and one with such phase-shifting. However, there is a distinct difference in the curve designated 180° and representing the frequency response curve for sound coming from a source at the rear of the microphone. The dotted branch of this latter curve applies to a microphone which has only a simple phase-shifting system consisting of a resistance and a compliance. The solid curve represents the frequency response in the case of sound falling from the rear on the condenser microphone, in accordance with the invention. It is readily apparent, that, without the delay line of the invention, the back attenuation is very poor above about 3000 cycles per second. Thus, the microphone has virtually no directional discrimination in this frequency range. On the other hand, the curve for the transducer designed in accordance with the invention continues substantially in the horizontal direction, so that the invention transducer has an excellent unilateral directional pattern throughout the frequency range.

As will be noted by FIG. 3*b*, a similar improvement can be obtained with an electrodynamic transducer incorporating the principles of the invention. In FIG. 3*b*, the solid line 180° represents the frequency response for sound coming from a source at the rear of an electrodynamic treble microphone embodying the invention. The dotted line indicates the response of a known arrangement.

FIG. 4 is a highly simplified cross sectional view of a condenser microphone embodying the invention. This microphone includes a diaphragm **1** comprising, for example, a polyester sheet with a vapor-deposited gold layer. Diaphragm **1** is secured to a microphone housing **3** with the interposition of a spacing ring **2**. Housing **3** defines a cavity including an air chamber C_1 which may be adjustable in volume by means of an annular disc **4** screw threaded in housing **3**. Air chamber C_1, and a resistance R mounted on disc **4** and covering the opening thereof, form a known phase-shifting system R, C_1. The second system in accordance with the invention is formed by the mass L and the compliance C_2. Mass L is formed by a vibratory air column in one or more tubes and which may be adjustable. Compliance C_2 is formed by the air cushion enclosed between diaphragm **1** and a counter electrode **7**. Δ is the sound path from the center of the forward surface of diaphragm **1** to the rear sound inlet at the entrance of resistance R. When this sound path is given, one of the four elements of the phase-shifting arrangement may be freely selected. The other elements will then be determined by the relations mentioned above. Generally, the frictional resistance will be chosen as the freely selectable value because it is of great importance also for the frequency response of the transmission lever at 0° sound incidence.

FIG. 5 illustrates, in highly simplified form, an electodynamic transducer embodying the invention. A diaphragm **1** is secured by a retaining ring **2** to the head of the magnetic system **8**. The magnetic system defines a housing, and the magnetic circuit is closed by magnet **9** having the pole piece **10**, which defines an air gap including a moving coil. The frictional resistance is shown at R and an air chamber at C_1. A mass L and air chamber C_2 must be selected, in accordance with the invention, with reference to Δ, R and C_1, and these constitute the additional phase-shifting system. Mass L may be formed, for example, by one or more tubes which may be adjustable. Compliance C_2 is formed by the air chamber between diaphragm **1** and the magnet system **8**. This air chamber is sealed by a gasget or washer **11**, which in particular separates the air chamber C_2 from the air chamber C_1.

In another variation, mass L was formed by the mass of the air column vibratable in the air gap. This arrangement is difficult to adjust, because the design of the air gap is determined mainly in respect to magnetic aspects. The elements of FIG. 5 are adjusted in the same manner as in FIG. 4.

It will be obvious that the invention is not limited to the illustrated example, as other designs may be used. In any case, however, it is essential to have present the acoustic elements mentioned above, and to select their values with relation to each other and with relation to the external sound path.

In the embodiment illustrated in the drawings and described hereinabove, the phase-shifting arrangement comprises a mass element which is nearest to the rear surface of the diaphragm, and a friction element which is nearest to the sound inlet of the phase-shifting arrangement in the sound path from such inlet to the rear surface.

What is claimed is:

1. An electroacoustic transducer comprising, in combination, a diaphragm having forward and rear surfaces; a phase-shifting arrangement for transmitting sound to said rear surface of said diaphragm to impart a unilateral directional pattern to said transducer; said phase-shifting arrangement including a first phase-shifting system consisting of a resistance and a compliance and effective in a lower sound frequency range, and a second phase-shifting system consisting of a mass and a compliance and effective in a higher sound frequency range; and means defining a common rear sound inlet, for both lower and higher sound frequency ranges, to said phase shifting arrangement.

2. An electroacoustic transducer as claimed in claim 1 in which the phase-shifting arrangement is designed to comply with the relations $RC_1=\tau/3$, $LC_2=\tau^2/2$ and $C_2/C_1=2$, where $\tau=\Delta/c$ in seconds is the transit time of sound from the center of the forward surface of the diaphragm to the effective sound inlet of said phase-shifting arrangement, R in grams per second is the value of the resistance, C_1 is centimeters per dyne is the value of the compliance associated with the resistance, L in grams is the value of the mass, C_2 in centimeters per dyne is the value of the compliance associated with the mass, Δ in centimeters is the length of the shortest sound path on the outside of the microphone from the center of the forward face of the diaphragm to the effective sound inlet of the phase-shifting arrangement, and c in centimeters per second is the velocity of sound in air.

3. An electroacoustic transducer, as claimed in claim 1, in which said transducer is an electrostatic transducer having friction-controlled vibratory system including said diaphragm; said resistance being included in said vibratory system and effecting friction control thereof.

4. An electroacoustic transducer, as claimed in claim 1, in which said transducer is an electrodynamic transducer including means defining an air space; a moving coil disposed in said air space; and means defining an air chamber separated from said air space and constituting a compliance of said first phase-shifting system.

5. An electroacoustic transducer, as claimed in claim 1, in which said transducer is an electrodynamic transducer including means defining an air gap; a moving coil disposed in said air gap; means defining an air chamber constituting said compliance of said first phase-shifting system; and a gasket separating said air gap from said air chamber.

6. An electroacoustic transducer, as claimed in claim 1, in which one element of each of said first and second phase-shifting systems in an adjustable acoustic element.

7. An electroacoustic transducer, as claimed in claim 6, in which the adjustable acoustic element of said first phase-shifting system comprises the compliance thereof.

8. An electroacoustic transducer, as claimed in claim 7, in which said last-named compliance comprises an air chamber defined, in part, by a disc adjustable to change the volume of said air chamber.

9. An electroacoustic transducer, as claimed in claim 8, in which said disc comprises the resistance of said first phase-shifting system.

10. An electroacoustic transducer, as claimed in claim 6, in which one of said adjustable acoustic elements comprises the mass of said second phase-shifting system.

11. An electroacoustic transducer, as claimed in claim 10, in which said mass comprises adjustable tube means.

12. An electroacoustic transducer, as claimed in claim 1, in which said phase-shifting arrangement includes a mass in the sound path between said common rear sound inlet and said diaphragm, and nearer said rear surface of said diaphragm.

13. An electroacoustic transducer, as claimed in claim 1, in which said phase-shifting arrangement includes a friction acoustic element adjacent the sound inlet of said phase-shifting arrangement and in the sound path from said inlet to said rear surface of said diaphragm.

14. An electroacoustic transducer, as claimed in claim 1, in which said phase-shifting arrangement comprises a mass acoustic element and a friction acoustic element in series in the sound path from said inlet to said rear surface of said diaphragm; said mass acoustic element being nearer said rear surface of said diaphragm, and said friction acoustic element being adjacent said sound inlet.

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U.S. Cl. X.R.

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