Nov. 17, 1964 B. WEINGARTNER 3,157,750

DYNAMIC HEADPHONE

Filed July 6, 1961

FIG. 1

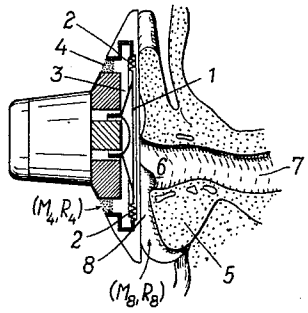


FIG. 2

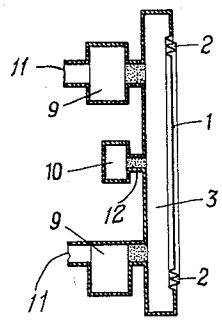
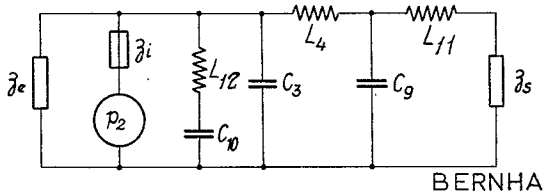


FIG. 3



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DYNAMIC HEADPHONE

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This invention relates to an electrodynamic headphone designed to exhibit good transmitting properties, i.e., to produce at the entrance to the ear a sound pressure which is as independent as possible of frequency under the different conditions arising in practice.

This aim involves substantially two difficulties:

(1) When the headphone is tightly applied to the ear, the acoustic input resistance of the ear acts as an additional mechanical impedance on the motion of the vibrating system. To a first approximation, this input resistance equals the input resistance of a tube having a rigid closure plus the resistance of the ear opening. The resistance corresponds at low frequencies substantially to a capacitance (mechanical equivalent=resilience), at medium frequencies (about 3000 cycles per second) to a strictly ohmic resistance (mechanical equivalent =damping) and at higher frequencies to an inductance (mechanical equivalent=mass). At very high frequencies, a transition to a capacitive resistance could be expected but this cannot be proved because it has superimposed thereon other phenomena. At these frequencies, the tympanum and the auditory canal can no longer be considered sound reflecting and the bend from the external ear to the auditory canal becomes effective.

It can now be shown that a piston-like exciting system driven by a constant force will produce a constant sound pressure at the entrance to the external ear when the mechanical impedance to the motion of the vibrating system is mainly determined by the acoustic loading of the ear. To enable this requirement to be fulfilled in the widest possible range, the surge impedance of the vibrating system must be as small as possible. For a given natural frequency, the conditions of which will be explained hereinafter, this necessitates that the mass of the vibrating system should be as small as possible, i.e., that in-the-present-case the diaphragm+moving coil should be as light as possible. On the other hand, in order to provide for a favorable transformation of the acoustic impedance of the external ear to the diaphragm, the area of the driving system (the diaphragm) should be larger, if possible, than the area of the entrance to the external ear (which is, on an average, 3.2 sq. cm.). When these conditions are fulfilled, the vibration of the system is elastically impeded in the low frequency range, impeded by friction in the medium frequency range and impeded by mass in the high frequency range.

(2) It is now found that the requirement of a tight fitting of the earphone to the ear can be fulfilled in practical operation only with great difficulty and is a nuisance to the wearer. As a result, there will generally be an outlet into the open between the ear and the earpiece and this outlet will have a mass and frictional resistance depending on the degree of coupling. The diaphragm of the headphone will now no longer be loaded by the input impedance of the ear but will more or less operate as a freely radiating sound transmitter. With the previously known systems this results in a considerable reduction in sound pressure particularly at low and very low frequencies.

It is now known that omnidirectional radiators produce close-range sound fields of different intensity, depending on the nature of the radiator. The pressure and velocity of these close-range fields are displaced in phase by 90°. As contrasted with the remote field, which determines the power delivered by the source, the close-range field constitutes a strictly reactive load. This close-range field can be shown, however, with the aid of pressure or velocity indicators which consume practically no power.

It is also known that the amplitude of pressure or velocity in the close-range field may assume very high values at a constant distance from the source at low frequencies.

This phenomenon is utilized by the invention. This relates to an electrodynamic headphone, the effective diaphragm area of which is larger than the average entrance area of the auricle, and which is characterized in that one or more openings lead into the open from a small-depth air chamber disposed on the rear side of the diaphragm to establish a close-range field corresponding to a first-order omnidirectional radiator when the headphone is operated as a free radiator. Another feature of the invention resides in that the openings have a small cross-section compared to the diaphragm area so that, because of their acoustic mass, the resonant frequency of the vibrating system is shifted into the low frequency range. When the headphone is loosely applied to the ear, the latter can be considered a virtually powerless pressure or velocity receiver in the close-range field of the radiator, so that the reduction at low frequencies observed with the previously known systems with a loose coupling can be compensated to a considerable degree.

These and other features of the invention will become more readily apparent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is a partial axial cross-sectional view through an earphone embodying the invention;

FIG. 2 is an enlarged view similar to FIG. 1 of another embodiment of the invention; and

FIG. 3 is a circuit diagram illustrating the operation of the earphone.

The illustrative embodiment shown in FIG. 1 comprises a diaphragm **1** of the vibratory system with the gripping means **2**. By means of the low-depth air chamber **3**, the acoustic impedance, which is disposed in the tubular openings **4** and comprises the frictional resistance R_4 and the mass M_4 (dimensioned to provide the desired frequency response at low and medium frequencies), is coupled to the diaphragm.

The duct **4** contains an acoustic mass, which is added to the diaphragm mass. This acoustic mass is calculated as

$$M_4=\rho\cdot l\cdot\frac{F^2}{f} \qquad (1)$$

wherein

ρ=specific gravity of air in grams per cubic centimeter
l=length of duct 4 in centimeters
F=area of diaphragm in square centimeters
f=cross-sectional area of duct **4** in square centimeters

The resulting resonant frequency of the vibrating mass is thus

$$f_{res}=\frac{1}{2\pi\sqrt{(M_m+M_4)\cdot\frac{1}{D_{tot}}}} \qquad (2)$$

wherein

M_m=diaphragm mass in grams
M_4=effective mass of air duct in grams
D_{tot}=total effective restoring force in dynes/centimeter

The entrance opening 6 of the ear is surrounded by the auricle 5 and continued by the auditory canal 7. The opening 8 having the mass M_8 and the frictional resistance R_8 connects the chamber 6 into the open air when the headphone is loosely applied.

At high and very high frequencies, the close-range field disappears and in the presence of the outlet for the sound from the rear side of the diaphragm into the open is no longer apparent. For this reason the openings to the rear may be connected as is shown in FIG. 2, to chambers 9, which have no influence at low frequencies (i.e., the mechanical equivalent of a low-pass filter), whereas they straighten the frequency response at high frequencies owing to their resonant properties. The chambers 9 are connected to the sound field by outlet tubes 11. The term "low-pass filter" is used in this specification and the appended claims as defining a filter passing all frequencies below a certain value with little attenuation and producing substantial attenuation for all frequencies above this value.

For the sake of a straight-line frequency response it is also sometimes suitable to connect to the rear side of the diaphragm, in an acoustic impedance 10 which is separated from the outer air and is also ineffective at low frequencies. The chamber 10 is connected to the low-depth air chamber by a duct 12.

The action of the several elements is apparent from the equivalent circuit diagram shown in FIG. 3. p_2 is the driving force which drives the diaphragm. The latter has the mechanical motion impedance Z_1. Z_e is the input impedance of the ear. The elements L_4, L_{11}, L_{12}, C_3, C_9, C_{10} correspond to the acoustic elements 4, 11, 12, 3, 9 and 10, respectively, of FIG. 2. Z_s is the very small radiation resistance at the end of duct 11. It is obvious that the combination L_4, L_{11}, C_3, C_9 constitutes a low-pass filter, the limiting frequency of which is toward the higher frequencies. This limiting frequency can be calculated from the value of the inductance (masses) determined in accordance with the above teachings and the capacitances (mechanical equivalent=resiliency).

The latter corresponds to

$$C_n=\frac{1}{D_n}=\frac{V_n}{\rho\cdot c^2\cdot f^2} \qquad (3)$$

wherein, in addition to the meanings stated above,

c=velocity of sound in air in centimeters per second.
V_n=volume of chamber 3, 9, 10.

Since the effectiveness of these low-pass filters is not terminated at their surge impedance, they exhibit at their limiting frequency a resonance-like hump, which is adapted to compensate troughs in the frequency response. The inductance (mechanical equivalent=mass) L_{12} forms together with the capacitance restoring force C_{10} a series resonant circuit, the resonant frequency of which is calculated from Equations 1 and 3 as

$$f_s=\frac{c}{2\pi}\cdot\sqrt{\frac{f}{l.V}}$$

wherein

c=velocity of sound in centimeters per second
f=cross-sectional area of duct 11 in square centimeters
l=length of duct 11 in centimeters
V=volume of cavity 10

These resonant circuits are preferably provided for straightening the frequency response at high frequencies. All resonant circuits and low-pass filters described are damped by frictional acoustic resistances (mechanical equivalent=damping material), which have not been considered in the calculations and are employed to obtain a smooth frequency response.

I claim:

1. An electrodynamic headphone which comprises a vibratory system including a diaphragm having an effective area larger than the average entrance area of a human ear and means defining a small-depth air chamber with the rear side of said diaphragm, said headphone further comprising means defining at least one opening leading into the open from said air chamber for presenting to said vibratory system an impedance which is more dependent mass than friction substantially down the lower end of the bass range and causing an air mass in said opening to be at resonance in conjunction with the restoring force of said small-depth air chamber, at a frequency in the range of 800–5000 cycles per second, whereby the air in said opening constitutes vibrating mass means virtually in phase with the diaphragm throughout a substantial low-frequency range and the headphone when loosely applied to the ear establishes a close-range sound field corresponding to a first-order omnidirectional radiator.

2. An electrodynamic headphone as claimed in claim 1, in which said openings have a small cross-section compared to the diaphragm area and have an acoustic mass which causes the resonant frequency of said vibratory system to lie in a low-frequency range.

3. An electrodynamic headphone as claimed in claim 1, in which said opening comprises an end portion having a relatively small cross section and an intermediate portion having a relatively large cross section to form a low-pass filter.

4. An electrodynamic headphone as claimed in claim 1, which comprises means defining cavities communicating with the small-depth air chamber and separated from the outer air, said cavities constituting acoustic impedances forming series-resonant circuits having resonant frequencies in the high and very high frequency range.

5. An electrodynamic headphone juxtaposable with a human ear, comprising a vibratile diaphragm having an effective area larger than the average entrance area of an ear and facing the latter; means defining with a surface of said diaphragm remote from said ear an air chamber of small depth; and means defining at least one opening communicating between said chamber and the ambient atmosphere, said opening containing an air mass and presenting to a vibratory system consisting of said diaphragm, said mass and air within said chamber an impedance which is determined by said mass to a greater extent than by friction over a frequency range extending substantially to the lower-bass region whereby said air mass is at resonance with respect to restoring force due to compression of air within said chamber at a frequency between substantially 800 and 5,000 cycles per second, whereby the air in said opening constitutes mass means vibrating virtually in phase with the diaphragm throughout a substantial low-frequency range and the headphone when loosely applied to the ear establishes a close-range sound field corresponding to a first-order onnidirectional radiator.

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