

EARPHONES

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This invention relates to earphones.

Open-air type earphones have a housing with a driver unit therein comprising a magnetic circuit and a vibration system formed by a diaphragm and a voice coil. In such an earphone, the response decreases at frequencies below the resonant frequency of the vibration system and, therefore, the resonant frequency needs to have a low value in order to improve the low frequency characteristic. To reduce the resonant frequency, it is necessary to increase the compliance and/or the equivalent mass of the vibration system. To increase the compliance of the vibration system, it is necessary to select a material for the diaphragm having a high compliance, and to decrease the thickness of the diaphragm. However, there are limits to the compliance of the material that can be used for the diaphragm, and to the extent to which the thickness of the diaphragm can be reduced. Moreover, increasing the equivalent mass of the vibration system causes deterioration of the sensitivity and the acoustic characteristic of the earphone in the high frequency range.

To avoid the above problems, we have previously proposed, for example, in Japanese Utility Model Application No 58/71055 (Japanese Utility Model Unexamined Publication No 59/177287) that an in-the-ear earphone or headphone be provided with a duct extending from the housing to the rear of the driver unit so that, when the earphone is in the ear, the duct projects out of the concha. The duct is formed to provide an equivalent mass added to the equivalent mass and compliance of the vibration system, so that the resonant frequency is lowered in correspondence with the added equivalent mass of the duct. Therefore, the resonant frequency can be lowered irrespective of the compliance and equivalent mass of the vibration system, with the result that the characteristic of the earphone in the low frequency range can be improved.

However, such an improvement requires that there be a significant acoustic resistance in parallel with the equivalent mass of the duct, for example, by providing acoustic resistance material in an opening or openings formed in the housing to the rear of the driver unit. In that case, a resonant

circuit is formed by the mass of the vibration system and the compliance of the housing to the rear of the driver unit, which is in parallel with the above-mentioned acoustic resistance. As a result of this resonant circuit, a peak appears in the frequency characteristic of the earphone at frequencies of 3 to 5 kHz, that is, a part of the high frequency range is emphasized, so that metallic sounds become over conspicuous and unpleasant to hear. In other words, when the low frequency range of the earphone is extended, an undesirable peak occurs in the high frequency range and, conversely, when an attempt is made to suppress this peak, reproduction in the low frequency range cannot be extended.

According to the present invention there is provided an earphone comprising:

- a driver unit including means defining a magnetic circuit, and a diaphragm and voice coil which form a vibration system;
 - a housing containing said driver unit and having a sound generation opening in front of said driver unit;
 - a duct extending from said housing behind said driver unit and communicating with the interior of said housing, said duct having a length substantially longer than its diameter;
 - a casing attached to said housing behind said driver unit; and
 - means defining a pipe communicating, at its ends, with said housing and said casing respectively, and having a length longer than its diameter;
- wherein a resonant frequency of a resonant circuit formed by an equivalent mass formed by said pipe and a compliance formed by said casing is made to be near to a resonant frequency which is determined by a mass of said vibration system and a compliance of said housing to the rear of said driver unit.

According to the present invention there is also provided an earphone comprising:

- a driver unit;
- a housing containing said driver unit and having a sound generation opening in front of said driver unit;
- a duct extending from said housing behind said driver unit and communicating with the interior of said housing, said duct having a length substantially longer than its diameter;
- a casing attached to said housing behind said driver unit; and

means defining a pipe communicating, at its ends, with said housing and said casing respectively, and having a length longer than its diameter;

wherein said driver unit includes a magnetic circuit comprising a plate extending across said housing and dividing said housing into a rear cavity and a front cavity communicating with said sound generation opening, a magnet and a yoke, and a vibration system comprising a diaphragm extending across said housing in said front cavity and a voice coil connected with said diaphragm; and

wherein a resonant frequency of a resonant circuit formed by an equivalent mass formed by said pipe and a compliance formed by said casing is made to be near to a resonant frequency which is determined by a mass of said vibration system and a compliance of said rear cavity, and said plate of the driver unit has unobstructed holes therethrough for communicating said front and rear cavities.

The invention will now be described by way of example with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which:

Figure 1 is a cross-sectional view showing an example of a previously proposed earphone;

Figure 2 is an equivalent circuit diagram of the earphone of Figure 1;

Figure 3 is a cross-sectional view showing another example of a

previously proposed earphone;

Figure 4 is a diagrammatic perspective view showing the mounting of the earphone of Figure 3 in the ear of a user;

Figure 5 is an equivalent circuit diagram of the earphone of Figure 3;

5 Figure 6 is a graph showing characteristic curves of previously proposed earphones;

Figure 7 is a cross-sectional view showing an embodiment of earphone according to the present invention;

Figure 8 is an equivalent circuit diagram of the earphone of Figure 7;

10 Figures 9 and 10 are graphs showing frequency characteristics of earphones according to the invention as compared with previously proposed earphones; and

Figure 11 is a cross-sectional view showing another embodiment of earphone according to the invention.

15 In order that the problems to be overcome by embodiments of the present invention may be fully understood, reference will first be made to Figure 1 which shows a previously proposed open-air type earphone 10. The earphone 10 comprises a housing 11 containing a driver unit 12. The driver unit 12 includes a magnetic circuit formed by a magnetic plate 13, a yoke 14 and a magnet 15, and a vibration system formed of a diaphragm 16 and a voice coil 17 which is accommodated in a gap between the yoke 14 and the magnet 15. The driver unit 12 extends across the housing 11 adjacent to a sound generation opening at the front of the housing 11 so as to divide the interior of the housing 11 into a front cavity 18a and a rear cavity 18b. A hole 19 extends through the centre of the driver unit 12, and acoustic resistance material 20, for example, polyurethane, is embedded in the hole 19. A plurality of holes 21 extend through the plate 13 and are covered by acoustic resistance material 22. A plurality of holes 23 are formed in the rear of the housing 11 and the rear cavity 18b communicates freely through
25 the holes 23 with the surrounding atmosphere. A protective cover 24 extends across the sound generation opening at the front of the housing 11 for preventing damage to the diaphragm 16, and may be formed of an inner punched metal sheet 24a having relatively large holes therein, an outer punched metal sheet 24b having relatively small holes therein and a cloth
30 sheet 24c intermediate between the metal sheets 24a and 24b for preventing the entry of dust and the like. Lead wires 25 extend from the driver unit 12

and are led out of the housing 11 through a bushing or grommet 26 in a suitable hole formed in the side of the housing 11.

An acoustic operating circuit of the open-air type earphone 10 of Figure 1 can be expressed by the equivalent circuit shown in Figure 2. More particularly, the vibration system of the driver unit 12 is represented by the series circuit of an equivalent mass M_d , a compliance C_d and an acoustic resistance R_d . A force to effect forward and backward movement of the diaphragm 16 is represented by a voltage source V_s , and R_a is the acoustic resistance to the passage of sounds through the acoustic resistance material 20 in the hole 19 and through the acoustic resistance material 22 covering the holes 21 in the driver unit 12. In the equivalent circuit of Figure 2, the back acoustic system is represented by a parallel circuit of a compliance C_b and an acoustic resistance R_b of the rear cavity 18b. Moreover, in Figure 2, the compliance, the equivalent mass, and the acoustic resistance of an ear into which the earphone 10 is inserted are represented as C_{cup} , M_{cup} and R_{cup} , respectively.

Since no resistance material covers or otherwise interferes with the passage of sound through the holes 23 in the rear of the housing 11, the acoustic resistance R_b of the rear cavity 18b is so small that it can be ignored in comparison with the acoustic resistance R_a . Similarly, the compliance C_b of the rear cavity 18b can also be ignored because of the existence of the uncovered holes 23. Therefore, the equivalent circuit of Figure 2 can be regarded as a series resonant circuit consisting of the equivalent mass M_d , the compliance C_d and the acoustic resistances R_d and R_a of the vibration system. Thus, the resonant frequency f_0 can be expressed as:

$$f_0 = 1/(2\pi\sqrt{M_d \cdot C_d}) \quad \dots(1)$$

In the open-air type earphone 10 of Figure 1, the response decreases at frequencies below the resonant frequency f_0 of the vibration system. Therefore, it is desirable that the resonant frequency f_0 be made as small as possible in order to improve the low frequency characteristic. As is apparent from equation (1) the resonant frequency f_0 may be decreased by increasing the compliance C_d and/or the equivalent mass M_d of the vibration system. In order to increase the compliance C_d of the vibration

system, it is necessary to select a material of high compliance for the diaphragm 16 and/or to decrease the thickness of the diaphragm 16. However, there are limits to the compliance of the materials that can be used for the diaphragm 16 and to the extent to which the thickness of the diaphragm 16 can be reduced. Moreover, increasing the equivalent mass M_d of the vibration system causes deterioration of the sensitivity and acoustic characteristic of the earphone 10 in the high-frequency range.

Referring now to Figure 3, it will be seen that, in order to avoid the above problems, we have previously proposed in Japanese Utility Model Unexamined Publication No 59/177287 an earphone 10' with a duct 27 extending from the housing 11' and communicating with the rear cavity 18'b of the housing 11'. As shown in Figure 4, the earphone 10' is intended to be inserted in the external ear E of the user in such a manner that a terminal portion of the duct 27 projects outwardly from the concha. Those parts of the earphone 10' which are similar to parts of the earphone 10 previously described with reference to Figure 1 are identified by the same reference numerals and the detailed description thereof will not be repeated.

It will be noted that, in the earphone 10', the holes 21 in the plate 13 are uncovered, that is, the acoustic resistance material 22 of Figure 1 is omitted, so that the acoustic resistance R_a is substantially zero. However, an acoustic resistance material 28 is applied to each of the holes 23 at the substantially frusto-conical rear of the housing 11', so that the acoustic resistance R_b is thereby set to a sufficient value for a reason hereinafter described in detail.

An elastic ring 29 of rubber or the like is provided around the sound generating opening at the front of the housing 11' for preventing leakage of sound between the plate 13 and the housing 11' and between the plate 13 and the protective cover 24. Openings 30 are provided in the end portion of the duct 27 remote from the housing 11'. The duct 27 has a length substantially larger than its diameter, for example, a length of 12 mm and a diameter of 2.2 mm, in which case the duct 27 can be represented by an equivalent mass M_{duct} added to the series circuit of the equivalent mass M_d , the compliance C_d and the acoustic resistance R_d and R_a of the vibration system. Therefore, the resonant frequency f_0 is reduced by an amount corresponding to the added equivalent mass M_{duct} . Such reduction of the resonant frequency f_0 is achieved irrespective of the compliance C_d

and the equivalent mass M_d of the vibration system for improving the characteristic of the earphone 10' in the low-frequency range.

It is to be noted that the lowest resonant frequency f_0 of the earphone 10' can be reduced by providing the duct 27, as described above, only if the acoustic resistance R_b which is in parallel with the equivalent mass M_{duct} of the duct 27, is substantially greater than zero. In other words, in order to realize the effect of the equivalent mass M_{duct} , the acoustic resistance R_b needs to be increased by the provision of acoustic resistance material 28 over the openings 23. For example, as shown in Figure 6, as the acoustic resistance R_b is increased by suitably changing the material, thickness or the like of the acoustic resistance material 28 associated with the openings 23, the characteristic curve of the earphone changes, as indicated by the curves A, B and C. However, when the acoustic resistance R_b is increased, a resonant circuit is formed by the compliance C_b , which is in parallel with the acoustic resistance R_b , and the mass m_d of the vibration system. As a result of such a resonant circuit, a peak appears in the frequency characteristic of the earphone at frequencies of 3 to 5 kHz, that is, a part of the high-frequency range is emphasized, as shown in Figure 6, so that metallic sounds become over conspicuous and unpleasant to hear. Thus, in the case of the earphone 10' of Figure 3, as the low frequency range of the earphone is extended downwardly, an undesirable peak occurs in the high frequency range, whereas, when the peak is suppressed, the reproducible low-frequency range cannot be extended.

Referring now to Figure 7, it will be seen that the first embodiment of earphone 10A according to the present invention is generally similar to the earphone 10' of Figure 3, and has its corresponding parts identified by the same reference numerals. As before, the housing 11' has an approximately frusto-conical rear portion and, in the case of the earphone 10A, an approximately cylindrical casing 31 is suitably attached at the centre of the frusto-conical rear portion of the casing 11'. The casing 31 and the rear cavity 18'b of the housing 11' communicate with each other through a pipe 32 which extends centrally into the casing 31. An opening 33 is provided through the centre of the rear wall of the casing 31, and an acoustic resistance material 34, for example, polyurethane, extends across the opening 33.

In a practical example of the earphone 10A, the magnet 15 of the

driver unit 12' is formed of samarium cobalt, and the diaphragm 16 is of a polyurethylene film having a thickness of $6\mu\text{m}$. The duct 27 has a diameter of 2.2 mm and a length of 12 mm, while the pipe 32 also has a length longer than its diameter, for example, a length of 1.5 mm, and a diameter of 1 mm. Finally, the casing 31 is provided with an internal volume of 70 mm^3 .

Referring now to Figure 8, it will be seen that the acoustic equivalent circuit for the earphone 10A differs from that shown in Figure 5 for the earphone 10' of Figure 3 by the addition thereto of an equivalent mass M_{tt} , a compliance C_{tt} and an acoustic resistance R_{tt} corresponding to the duct 32, the casing 31 and the opening 33, respectively. In Figure 8, as in Figure 5, the equivalent mass M_{duct} of the duct 27 is added to the series circuit consisting of the equivalent mass M_d , the compliance C_d and the acoustic resistance R_d of the vibration system so that the lowest resonant frequency f_0 is decreased in accordance with the amount of the added equivalent mass M_{duct} . Such lowering of the lowest resonant frequency f_0 by the added equivalent mass M_{duct} is made possible by the substantial value of the acoustic resistance R_b resulting from the acoustic resistance material 28 covering the openings 23. However, by reason of the equivalent mass M_{tt} formed by the pipe 32, the compliance C_{tt} formed by casing 31 and the acoustic resistance R_{tt} formed by the opening 33 covered by the acoustic resistance material 34, the peak that would otherwise be caused in the frequency range of 3 to 5 kHz by the resonance between the equivalent mass M_d of the vibration system and the compliance C_b of the rear cavity 18'b is suppressed.

More specifically, a resonant circuit is formed by the equivalent mass M_{tt} of the pipe 32 and the compliance C_{tt} of the casing 31. Therefore, the impedance across the circuit consisting of the equivalent mass M_{tt} , the compliance C_{tt} and the acoustic resistance R_{tt} decreases at the resonant frequency of such resonant circuit. Thus, by selecting the resonant frequency of the resonant circuit formed by the equivalent mass M_{tt} and the compliance C_{tt} to be a value near to the resonant frequency of the circuit formed by the equivalent mass M_d of the vibration system and the compliance C_b of the rear cavity 18'b, the peak that would otherwise be caused by the equivalent mass M_d and the compliance C_b in the frequency range of 3 to 5 kHz can be suitably suppressed.

As will be apparent from Figure 9, in which the solid line curve D1

represents the frequency characteristic for the earphone 10A embodying the present invention and the broken line curve D0 represents the frequency characteristic of the previously proposed earphone 10' of Figure 3, the peak appearing in the frequency range of 3 to 5 kHz for the earphone 10' is substantially suppressed in the case of the earphone 10A. The curves D0 and D1 in Figure 9 represent the frequency characteristics of the earphones 10' and 10A, respectively, provided that the earphones 10' and 10A have substantially the same values of the acoustic resistance Rb.

However, if desired, the acoustic resistance Rb of the earphone 10A may be substantially increased relative to the acoustic resistance Rb for the earphone 10', thereby further decreasing the lowest resonant frequency f0 of the earphone 10A without increasing the peak in the frequency range of 3 to 5 kHz beyond that occurring in the frequency characteristic of the earphone 10'. Thus, for example, in Figure 10, the curve D2 indicates the frequency characteristic of an earphone 10A in which the acoustic resistance Rb has been increased beyond the corresponding acoustic resistance Rb of the earphone 10' of Figure 3, and having the frequency characteristic represented by the curve D0. It will be apparent from a comparison of the curves D0 and D2 that, if the peaks in the frequency range of 3 to 5 kHz are permitted to be nearly equal for an earphone according to the invention and as previously proposed, respectively, the lowest resonant frequency f0 can be made lower for the earphone according to the present invention than for the previously proposed earphone, for example, 100 Hz as compared with 150 Hz.

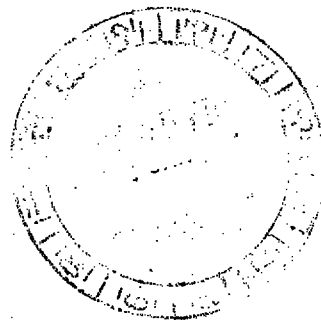
Although Figure 7 shows an embodiment in which the casing 31 has a hole 33 in the rear thereof covered by acoustic resistance material 34, it is to be understood that the invention may also be embodied in an earphone 10B as shown in Figure 11, and in which the casing 31' defines a closed chamber communicating only with the rear cavity 18'b of the housing 11' through the pipe 32. Apart from the foregoing, the earphone 10B is substantially similar to the earphone 10A.

In the case of the earphone 10B of Figure 11, when the volume of the casing 31' is 70 mm^3 , and the value of the acoustic resistance Rb is increased similarly to that in the earphone represented by the curve D2 in Figure 10, the frequency characteristic of the earphone 10B is represented by the curve D3. In other words, removal of the hole 33 from the casing 31

of the earphone 10A has the effect of shifting the peak from the frequency range of 3 to 5 kHz to a frequency near 2 kHz. Such shifting of the peak in the frequency characteristic tends to make the metallic sounds less conspicuous. If the volume of the casing 31' in the earphone 10B is increased to 300 mm³, the frequency characteristic becomes that indicated by the curve D4 in Figure 10. In such case, the peak is less pronounced, and the frequency characteristic is somewhat flattened. However, the casing 31' is undesirably enlarged to provide a volume of 300 mm³.

Although the invention has been described above in its application to earphones of the in-the-ear type which are positioned near the inlet of the external acoustic meatus, it will be appreciated that the invention can be similarly applied to closed-type earphones. Further, the desirable effects of the invention are particularly obtained when the invention is applied to stereophonic earphones which are associated with both the right and left ears of the listener.

By way of summary, it will be noted that the resonant circuit consisting of the equivalent mass Mtt formed by pipe 32 and the compliance Ctt formed by the casing 31 or 31' has its resonance frequency set to a value near the resonant frequency of the compliance Cb of the rear cavity 18'b and the mass Md of the vibration system. By reason of the foregoing, the peak in the frequency characteristic caused by the resonance between the rear cavity 18'b and the mass of the vibration system is relatively suppressed. Thus, the high frequency characteristic can be improved and the acoustic resistance Rb can be increased for reducing the lowest resonant frequency f0.



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CLAIMS

1. An earphone comprising:
a driver unit including means defining a magnetic circuit, and a diaphragm and voice coil which form a vibration system;
a housing containing said driver unit and having a sound generation opening in front of said driver unit;
a duct extending from said housing behind said driver unit and communicating with the interior of said housing, said duct having a length substantially longer than its diameter;
a casing attached to said housing behind said driver unit; and
means defining a pipe communicating, at its ends, with said housing and said casing respectively, and having a length longer than its diameter;
wherein a resonant frequency of a resonant circuit formed by an equivalent mass formed by said pipe and a compliance formed by said casing is made to be near to a resonant frequency which is determined by a mass of said vibration system and a compliance of said housing to the rear of said driver unit.
2. An earphone according to claim 1 wherein said housing has an opening therefrom to the rear of said driver unit, and said opening from said housing has acoustic resistance material extending thereacross for lowering the lowest resonant frequency determined by said mass of the vibration system and said compliance of said housing to the rear of said driver unit while said resonant circuit formed by said pipe and said casing suppresses a relatively high frequency peak that would otherwise be formed in the frequency characteristic of the earphone.
3. An earphone according to claim 2 wherein said casing has an opening to the atmosphere, and said opening has acoustic resistance material extending thereacross.
4. An earphone according to claim 2 wherein said casing defines a closed chamber communicating only with said housing through said pipe.
5. An earphone comprising:



a driver unit;

a housing containing said driver unit and having a sound generation opening in front of said driver unit;

a duct extending from said housing behind said driver unit and communicating with the interior of said housing, said duct having a length substantially longer than its diameter;

a casing attached to said housing behind said driver unit; and

means defining a pipe communicating, at its ends, with said housing and said casing respectively, and having a length longer than its diameter;

wherein said driver unit includes a magnetic circuit comprising a plate extending across said housing and dividing said housing into a rear cavity and a front cavity communicating with said sound generation opening, a magnet and a yoke, and a vibration system comprising a diaphragm extending across said housing in said front cavity and a voice coil connected with said diaphragm; and

wherein a resonant frequency of a resonant circuit formed by an equivalent mass formed by said pipe and a compliance formed by said casing is made to be near to a resonant frequency which is determined by a mass of said vibration system and a compliance of said rear cavity, and said plate of the driver unit has unobstructed holes therethrough for communicating said front and rear cavities.

6. An earphone according to claim 5 wherein said housing has an opening from said rear cavity with acoustic resistance material extending thereacross for lowering the lowest resonant frequency determined by said mass of the vibration system and said compliance of said rear cavity while said resonant circuit formed by said pipe and said casing suppresses a relatively high frequency peak that would otherwise be formed in the frequency characteristic of the earphone.

7. An earphone according to claim 6 wherein said casing has an opening to the atmosphere in which acoustic resistance material is disposed.

8. An earphone according to claim 6 wherein said casing defines a closed chamber communicating only with said rear cavity of the housing through said pipe.



9. A earphone substantially as hereinbefore described with reference to Figure 7 of the accompanying drawings.

10. An earphone substantially as hereinbefore described with reference to Figure 11 of the accompanying drawings.

