

PATENT SPECIFICATION

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(54) ELECTRO-ACOUSTIC TRANSDUCER

(71) We, KABUSHIKI KAISHA DAINI SEIKOSHA, a Japanese Company of 6-31-1, Kameido, Koto-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

5 This invention concerns an electro-acoustic transducer and, although the invention is not so restricted, it is more particularly concerned with an electro-acoustic transducer for use as a sound source in portable equipment such as a wrist watch or a pocket bell.

10 In the case of an electro-acoustic transducer which is used in such portable equipment, in order to limit power consumption, it is known to operate the transducer at its resonance frequency. This however has the disadvantage that the transducer has only a very narrow frequency band and it is the object of the present invention to provide an electro-acoustic transducer having a broad frequency band.

15 According to the present invention, there is provided an electro-acoustic transducer comprising a sealed air chamber spaced apart walls of which are respectively constituted by first and second oscillatable unapertured plates, electrical means for oscillating the first oscillatable plate so that the second oscillatable plate is oscillated by way of the air in the sealed air chamber to produce audible sound, and a resonator chamber one wall of which is constituted by the second oscillatable unapertured plate, the resonator chamber having a port therein so that the surface of the second oscillatable unapertured plate in the resonator chamber is open to the ambient air, sound produced by the oscillation of the second oscillatable unapertured plate being in operation transmitted through said port.

20 Preferably, the sealed air chamber provided with first and second oscillatable unapertured plates forms a vibratable system having two resonance frequencies, the resonator chamber having a resonance frequency between the said two resonance frequencies.

25 The resonator chamber is preferably a helmholtz resonator chamber.

30 The said electrical means is preferably an electro-magnetic means. Thus the electro-magnetic means may comprise a member of magnetically permeable material attached to the first oscillatable unapertured plate, and a coil having an end face thereof arranged adjacent to and spaced from the said member, such that the passing of a driving alternating electric current through the coil causes oscillation of the member and hence of the first oscillatable unapertured plate.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:-

35 Figures 1 and 3 are respectively elevational views in section of two different known electro-acoustic transducers,

Figures 2 and 4 show characteristic curves of sound intensity ($-P$) against frequency of oscillation (f) for the electro-acoustic transducers of Figure 1 and 3 respectively,

Figure 5 is an elevational view in section of a portion of an electro-acoustic transducer according to the present invention,

40 Figure 6 shows a characteristic curve of sound intensity ($-P$) against frequency of oscillation (f) relating to the structure shown in Figure 5,

Figure 7 is a diagrammatic view showing a simplified mechanical equivalent of the structure shown in Figure 5,

45 Figure 8 is a graph illustrating the amplitude-drive frequency characteristics of the said mechanical equivalent shown in Figure 7,

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Figure 9 is an elevational view in section of an electro-acoustic transducer according to the present invention, and

Figure 10 shows a characteristic curve of sound-intensity ($-P$) against frequency of oscillation (f) relating to the transducer of Figure 9.

Terms such as 'upper' and 'lower', as used in the description below, are to be understood to refer to directions as seen in the accompanying drawings.

In Figure 1 there is shown a known electro-acoustic transducer which comprises a base plate 1 having a central magnetic pole 1a which is integral with the base plate 1 and which extends upwardly from one side thereof, the base plate 1 and central magnetic pole 1a being composed of a magnetically permeable material. A coil 2 is wound on the central magnetic pole 1a and a magnetic ring member 3 is arranged coaxially around the coil 2. An oscillatable unapertured plate 5, having an audible resonant frequency, is mounted at its periphery on a support frame 4, or on separate supports, the lower surface of the oscillatable unapertured plate 5 being disposed adjacent to and spaced from the upper surface of the combination constituted by the base plate 1, central magnetic pole 1a, coil 2, and magnetic ring member 3. A magnetically permeable plate member 6 is fixed to the upper surface of the oscillatable unapertured plate 5. Thus a magnetic loop is formed by the plate member 6, magnetic ring member 3, base plate 1 and central magnetic pole 1a.

When an alternating current is supplied to the coil 2, the plate member 6 is alternately attracted and repelled, as a result of which the oscillatable plate 5 is oscillated.

As shown in Figure 2, the sound intensity $-P$ which is produced when the oscillatable plate 5 is oscillated varies in accordance with the frequency of oscillation f . The sound intensity $-P$ is at its maximum at the single resonance point of the oscillatable unapertured plate 5, but as will be seen from Figure 2, the frequency band Δf_1 at which one can obtain at least a predetermined acoustic pressure P_0 is very narrow. Thus the transducer of Figure 1, which is provided with only one single oscillating plate 5, can produce sound in sufficient volume within a restricted frequency band only, this restricted frequency band incorporating one single resonant frequency.

In Figure 3 there is shown another known electro-acoustic transducer which incorporates the whole of the transducer of Figure 1. Figure 3 will therefore not be described in detail, reference numerals in Figure 3 corresponding to those employed in connection with the description of Figure 1 indicating like parts.

In the Figure 3 transducer, however, the support frame 4 is mounted within an acoustic case 7 having a port 7a therein. A Helmholtz resonator chamber 8 is defined between the acoustic case 7 and the combination constituted by the support frame 4, oscillatable unapertured plate 5, and plate member 6. The characteristic curve of sound intensity against frequency of oscillation in relation to the transducer of Figure 3 is shown in Figure 4, and as will be seen therefrom, if one arranges that the resonant frequency of the oscillatable unapertured oscillating plate 5 is similar but not identical to the resonant frequency of the Helmholtz resonator chamber 8, then the characteristic curve of sound intensity against frequency of oscillation has a relatively wide frequency band Δf_2 at which one can obtain at least the predetermined acoustic pressure P_0 .

The transducer of Figure 3 is useful where only one single drive frequency is required but cannot be used to produce sounds of different frequencies, e.g. sounds whose frequencies differ by from half an octave to one octave.

In Figure 5 there is therefore shown a portion of an electro-acoustic transducer according to the present invention. This portion incorporates a transducer as shown in Figure 1, and will therefore not be described in detail, like reference numerals indicating like parts.

In the case of the construction shown in Figure 5, however, in addition to the oscillatable unapertured plate 5 there is also provided a second oscillatable unapertured plate 9 having an audible resonant frequency different from that of the plate 5, the oscillatable plates 5, 9 constituting oppositely disposed spaced apart walls of a sealed air chamber 10. The oscillatable unapertured plates 5, 9 together with the sealed air chamber 10 constitute a vibratable system. The oscillation of the first oscillatable unapertured plate 5 by the electro-magnetic means constituted by the parts 1, 2, 3, 6 causes the second oscillatable unapertured plate 9 to be oscillated by way of the air in the sealed air chamber 10 so that the second oscillatable unapertured plate 9 produces audible sound.

In the structure shown in Figure 5, therefore, when an alternating current flows through the coil 2, the first oscillatable unapertured plate 5 and its member 6 is electro-magnetically driven. However, sound is not produced from the first oscillatable unapertured plate 5 but is produced by the oscillation of the second oscillatable unapertured plate 9. As shown in Figure 6, the vibratable system of Figure 5 has two resonance points having frequency bands Δf_{s1} and Δf_{s2} , but each of these frequency bands is very narrow.

The acoustic pressure-drive frequency characteristics of the structure shown in Figure 5 is illustrated in Figures 7 and 8. Thus Figure 7 constitutes a schematic mechanical equivalent of

the structure shown in Figure 5. The reference letters M, K and x_m shown in Figure 7 respectively indicate an equivalent mass, equivalent spring constant, and the amplitude of the combination of the first oscillatable plate 5, and its plate member 6. Similarly, the reference letters m, k and x_m respectively indicate an equivalent mass, an equivalent spring constant, and the amplitude of the second oscillatable plate 9. k_a is an equivalent spring constant of the sealed air chamber 10. These factors are essential components of the oscillating system, and although attenuating resistance, acoustic impedance, etc., should also ideally be considered, these have been omitted in order to simplify the description.

If an alternating force $F \sin \omega t$, where F is the driving power, and ω is the frequency of oscillation of the second oscillatable unapertured plate 9, is applied to the mass M of an oscillating system, then the following equations can be deduced:-

$$1. x_M = \frac{F}{M} \frac{\left\{ \frac{k+k_a}{m} - \omega^2 \right\}}{\left\{ \omega^4 - \left(\frac{K+k_a}{M} + \frac{k+k_a}{m} \right) \omega^2 + \frac{Kk+Kk_a+kka}{Mm} \right\}}$$

$$2. x_m = \frac{kaF}{Mm} \frac{1}{\left\{ \omega^4 - \left(\frac{K+k_a}{M} + \frac{k+k_a}{m} \right) \omega^2 + \frac{Kk+Kk_a+kka}{Mm} \right\}}$$

It will be understood from the above equations, there are two resonance points, the amplitude-drive frequency characteristics being as shown in Figure 8.

One can clearly obtain the characteristic shown in Figure 6 by appropriately selecting the amplitude x_m of the second oscillatable unapertured plate 9, in accordance with the curves shown in Figure 8. The two resonance frequencies f_1 and f_2 shown in Figure 8 can be arranged to be quite close to each other by appropriate selection of the constants of the oscillating system shown in Figure 7, but they cannot be made absolutely coincident unless the equivalent mass m is zero ($m=0$) so that in practice two resonance points are always produced. The acoustic pressure is very large at these two resonance frequencies but only the frequency bands f_{31} and f_{32} shown in Figure 6 can normally be used and these do not provide a sufficiently wide operating band.

In Figure 9 there is therefore shown a complete electro-acoustic transducer according to the present invention, the latter incorporating the structure shown in Figure 5. The transducer of Figure 9 will therefore not be described in detail, reference numerals corresponding to those used above indicating like parts.

As will be seen from Figure 9, the electro-acoustic transducer shown therein, in addition to the structure shown in Figure 5, also incorporates an acoustic case 7, having a port 7a, corresponding to the parts 7, 7a of Figure 3. Thus one wall of the resonator chamber 8 is constituted by the second oscillatable unapertured plate 9. Moreover, by reason of the provision of the port 7a of the Helmholtz resonator chamber 8, the surface of the second oscillatable unapertured plate 9 in the Helmholtz resonator chamber 8 is open to the ambient air, while sound produced by the oscillation of the second oscillatable unapertured plate 9 is in operation transmitted through the port 7a.

It is preferably arranged that the Helmholtz resonator chamber 8 has a resonance frequency which is between the two resonance frequencies f_1 , f_2 of the vibratable system constituted by re-oscillatable plates 5, 9 and the sealed air chamber. In this case, when the Helmholtz resonance frequency is intermediate the frequencies f_1 , f_2 , the acoustic pressure-drive frequency characteristic of the transducer of Figure 9 is as shown in Figure 10 in which the frequency band Δ at which one can obtain at least the predetermined acoustic pressure p_0 is very wide. Thus, as will be appreciated in the construction shown in Figure 9 this wide frequency band Δf_4 is produced both by the provision of the two oscillatable unapertured plates 5, 9 as opposed to the use of the single oscillatable plate of the prior art, and also by the use of the Helmholtz resonator chamber 8. Moreover, as will be seen from Figure 10, the frequency band Δf_4 provides a substantially constant acoustic pressure between the two resonance frequencies f_1 , f_2 .

In the specific description given above, the electrical means employed for oscillating the first oscillatable unapertured plate 5 has been constituted by electro-magnetic means 1, 2, 3, 6. However, the electrical means for effecting oscillation of the first oscillatable unapertured plate 5 can alternatively be constituted by piezo-electric means or by dynamic electrical means.

In the description given above, moreover, the resonator chamber is referred to as a Helmholtz resonator chamber but this is not essential provided that the resonator chamber incorporates an air chamber having a sound emission port therein.

An electro-acoustic transducer according to the present invention may be arranged to produce a variety of different tones with low power consumption and is suitable for use in small portable equipment such as a wrist watch or pocket bell.

WHAT WE CLAIM IS:-

1. An electro-acoustic transducer comprising a sealed air chamber spaced apart walls of which are respectively constituted by first and second oscillatable unapertured plates,



the structure shown in Figure 5. The reference letters M, K and x_M shown in Figure 7 respectively indicate an equivalent mass, equivalent spring constant, and the amplitude of the combination of the first oscillatable plate 5, and its plate member 6. Similarly, the reference letters m, k and x_m respectively indicate an equivalent mass, an equivalent spring constant, and the amplitude of the second oscillatable plate 9. k_a is an equivalent spring constant of the sealed air chamber 10. These factors are essential components of the oscillating system, and although attenuating resistance, acoustic impedance, etc., should also ideally be considered, these have been omitted in order to simplify the description.

If an alternating force $F \sin \omega t$, where F is the driving power, and ω is the frequency of oscillation of the second oscillatable unapertured plate 9, is applied to the mass M of an oscillating system, then the following equations can be deduced:-

$$1. x_M = \frac{F}{M} \frac{\{k + k_a - \omega^2\}}{m} \bigg/ \left\{ \omega^4 - \left(\frac{K + k_a}{M} + \frac{k + k_a}{m} \right) \omega^2 + \frac{Kk + Kk_a + kka}{Mm} \right\}$$

$$2. x_m = \frac{kaF}{Mm} \bigg/ \left\{ \omega^4 - \left(\frac{K + k_a}{M} + \frac{k + k_a}{m} \right) \omega^2 + \frac{Kk + Kk_a + kka}{Mm} \right\}$$

It will be understood from the above equations, there are two resonance points, the amplitude-drive frequency characteristics being as shown in Figure 8.

One can clearly obtain the characteristic shown in Figure 6 by appropriately selecting the amplitude x_m of the second oscillatable unapertured plate 9, in accordance with the curves shown in Figure 8. The two resonance frequencies f_1 and f_2 shown in Figure 8 can be arranged to be quite close to each other by appropriate selection of the constants of the oscillating system shown in Figure 7, but they cannot be made absolutely coincident unless the equivalent mass m is zero ($m=0$) so that in practice two resonance points are always produced. The acoustic pressure is very large at these two resonance frequencies but only the frequency bands f_{31} and f_{32} shown in Figure 6 can normally be used and these do not provide a sufficiently wide operating band.

In Figure 9 there is therefore shown a complete electro-acoustic transducer according to the present invention, the latter incorporating the structure shown in Figure 5. The transducer of Figure 9 will therefore not be described in detail, reference numerals corresponding to those used above indicating like parts.

As will be seen from Figure 9, the electro-acoustic transducer shown therein, in addition to the structure shown in Figure 5, also incorporates an acoustic case 7, having a port 7a, corresponding to the parts 7, 7a of Figure 3. Thus one wall of the resonator chamber 8 is constituted by the second oscillatable unapertured plate 9. Moreover, by reason of the provision of the port 7a of the Helmholtz resonator chamber 8, the surface of the second oscillatable unapertured plate 9 in the Helmholtz resonator chamber 8 is open to the ambient air, while sound produced by the oscillation of the second oscillatable unapertured plate 9 is in operation transmitted through the port 7a.

It is preferably arranged that the Helmholtz resonator chamber 8 has a resonance frequency which is between the two resonance frequencies f_1 , f_2 of the vibratable system constituted by reoscillatable plates 5, 9 and the sealed air chamber. In this case, when the Helmholtz resonance frequency is intermediate the frequencies f_1 , f_2 , the acoustic pressure-drive frequency characteristic of the transducer of Figure 9 is as shown in Figure 10 in which the frequency band Δ at which one can obtain at least the predetermined acoustic pressure p_0 is very wide. Thus, as will be appreciated in the construction shown in Figure 9 this wide frequency band Δf_4 is produced both by the provision of the two oscillatable unapertured plates 5, 9 as opposed to the use of the single oscillatable plate of the prior art, and also by the use of the Helmholtz resonator chamber 8. Moreover, as will be seen from Figure 10, the frequency band Δf_4 provides a substantially constant acoustic pressure between the two resonance frequencies f_1 , f_2 .

In the specific description given above, the electrical means employed for oscillating the first oscillatable unapertured plate 5 has been constituted by electro-magnetic means 1, 2, 3, 6. However, the electrical means for effecting oscillation of the first oscillatable unapertured plate 5 can alternatively be constituted by piezo-electric means or by dynamic electrical means.

In the description given above, moreover, the resonator chamber is referred to as a Helmholtz resonator chamber but this is not essential provided that the resonator chamber incorporates an air chamber having a sound emission port therein.

An electro-acoustic transducer according to the present invention may be arranged to produce a variety of different tones with low power consumption and is suitable for use in small portable equipment such as a wrist watch or pocket bell.

WHAT WE CLAIM IS:-

1. An electro-acoustic transducer comprising a sealed air chamber spaced apart walls of which are respectively constituted by first and second oscillatable unapertured plates,

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5 electrical means for oscillating the first oscillatable plate so that the second oscillatable plate is oscillated by way of the air in the sealed air chamber to produce audible sound, and a resonator chamber one wall of which is constituted by the second oscillatable unapertured plate, the resonator chamber having a port therein so that the surface of the second oscillatable unapertured plate in the resonator chamber is open to the ambient air, sound produced by the oscillation of the second oscillatable unapertured plate being in operation transmitted through said port. 5

10 2. A transducer as claimed in claim 1 in which the sealed air chamber provided with first and second oscillatable unapertured plates forms a vibratable system having two resonance frequencies, the resonator chamber having a resonance frequency between the said two resonance frequencies. 10

3. A transducer as claimed in claim 1 or 2 in which the resonator chamber is a Helmholtz resonator chamber.

15 4. A transducer as claimed in any preceding claim in which the said electrical means is an electro-magnetic means. 15

5. A transducer as claimed in claim 4 in which the electro-magnetic means comprises a member of magnetically permeable material attached to the first oscillatable unapertured plate, and a coil having an end face thereof arranged adjacent to and spaced from the said member, such that the passing of a driving alternating electric current through the coil causes oscillation of the member and hence of the first oscillatable unapertured plate. 20

6. An electro-acoustic transducer substantially as hereinbefore described with reference to and as shown in Figures 9 and 10 of the accompanying drawings.

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