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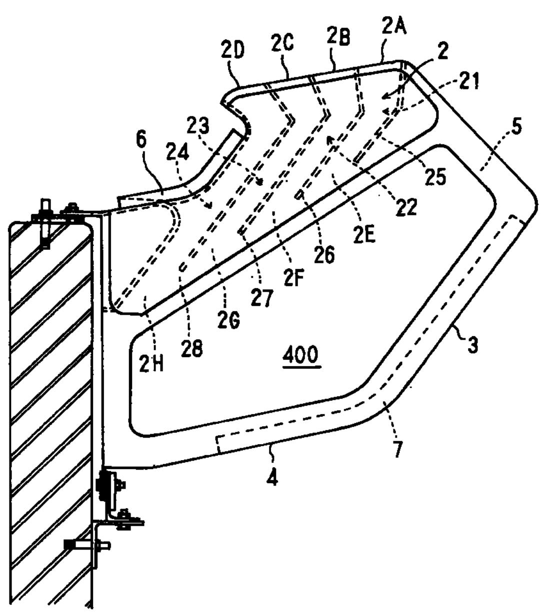
(54) **Interference noise-control unit**

(57) In the interference noise-control unit according to the present invention, the sound inlets (2A to 2D) are positioned little by little higher in a direction away from the soundproof wall (1) so that the ends thereof are on a gentle ascending slope. The channels (21 to 24) are bent toward the soundproof wall (1) on their ways from the sound inlets (2A to 2D) to the sound outlets (2E to 2H), the bending angles of the channels (21 to 24) being increased in the direction away from the soundproof wall (1). Therefore, the noise-control unit according to the present invention is highly effective against a noise from a lower source as well as against a noise from an upper source.

FIG.4

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## Description

The present invention relates to an interference noise-control unit having formed therein a plurality of channels different in length from each other and through which a part of noises coming from sources is guided, the noise-control unit having such a geometry as to yield behind it a sound interference zone where the part of the noises coming as retarded due to passing through the channels is allowed to interfere with the remainder of the noises coming directly from the sources, whereby a highly effective noise control can be attained.

Recently, the rapid-transit railways, express-highways, etc. have been provided along them with sound-insulating walls of which some has a sound-absorbent panel attached on a side thereof facing the noise sources, that is, the railway vehicles or automobiles running on the railway or highway, to reduce or control the noise from such sources. Because of the properties of sound such as diffraction, reflection, etc., however, such sound-insulating walls have been found not so effective to reduce the noise. For a higher effect of such sound-insulating walls, it has been proposed to use taller ones, which however has caused new environmental problems such as violation of the right of light, etc.

Accordingly, for suppression of a noise from a railway and road as a main noise source, it has been proposed to use, in combination of a sound-insulating wall, an interference noise-control unit having a plurality of channels different in length from each other and through which a part of the noise from the source is guided, the part of the noise coming as retarded due to passing through the channels being allowed to interfere with the noise coming directly from the source, thereby reducing the noise level as a whole.

The above-mentioned conventional interference noise-control unit will be further described herebelow with reference to the drawings. FIG. 1 is a sectional view of the interference noise-control unit, FIG. 2 is a perspective view of the stack of channels, and FIG. 3 is a sectional view of the principle of sound interference.

As illustrated in these Figures, the conventional interference noise-control unit is used as secured to a existing or main soundproof wall 1 disposed apart from a noise source. The soundproof wall 1 has secured on the upper portion of a side thereof opposite to the noise source a stack 100 of a plurality (only four pieces are shown by way of example) of channels 101 to 104 laid parallel to the soundproof-wall surface and also to each other. The channels 101 to 104 are different in length from each other. The noise-control unit further comprises a sound-insulating bottom wall 105 and sound-insulating rear wall 106.

The sound inlets of the channels 101 to 104 are open at a sound inlet end 200 of the stack 100, and the sound outlets are open at a sound outlet end 300.

Thus, a part of a noise coming from the noise source located at the side of the sound inlet end 200 is allowed to enter the plurality of channels 101 to 104 at the sound inlets opening at the sound inlet end 200. Guided through the channels 101 to 104, the noise is refracted and thus retarded. It goes out of the sound outlet end 300. This noise will be called "refraction-retarded wave". On the other hand, the rest of the noise arrives directly from the source without passing through the channels 101 to 104. This will be called "direct wave". There takes place a phase difference between these refraction-retarded and direct waves and so the retarded and direct waves will interfere with each other in a zone where they meet each other. In the interference zone, the noise is thus reduced as a whole because the retarded and direct waves cancel each other due to the interference between them.

The above-mentioned interference noise-control unit having such stack 100 utilizes the above-mentioned phenomenon of sound interference, which is evidently different from the conventional sound-absorption or sound-insulation type noise-control unit. Owing to the sound interference, this example noise-control unit can also effectively reduce the noise which is diffracted as it travels. Its effect of sound reduction goes over a wider range than could be covered by the conventional noise-control units such as sound-insulating wall, sound-absorbent wall, etc. Also it provides a effective sound reduction against a noise source which could not be fully shielded in practice. Furthermore, this noise-control unit is advantageously permeable to heat and air. Moreover, it is another advantage that, in addition to a highly water-resistant or highly weatherable metallic material such as stainless steel, etc. or an inorganic lightweight material, a plastic material such as polypropylene or rubber-like elastic material may he used to attain a further compactness and lighter weight of this noise-control unit.

Thus, for control of a noise developed from the railway vehicle such as Shinkansen-Line, it has been proposed to use an interference noise-control unit having a stack 100 comprising a plurality of channels 101 to 104 and which is bent as shown in FIG. 2. As shown in FIG. 3, it is secured on the upper portion of a soundproof wall 1 made of concrete or the like. In this configuration, a "direct" wave (1) coming as diffracted over the soundproof wall 1 from a noise source is allowed to interfere with a "refraction-retarded" (2) having arrived as refracted through the channels 101 to 104 different in length, resulting in a sound reduction due to the interference/cancellation between the waves in an interference zone (3) (shown as smudged), which effectively reduces the noise as a whole. Thus, even if the soundproof wall 1 is relative low, the noise-control unit assures a sufficient effect of sound reduction at a sound receiving point located apart from the soundproof wall 1. As illustrated in FIG. 3, in case the interference noise-control unit having the bent stack 100 of channels 101 to 104 is used as secured on the upper portion of the soundproof wall 1, a part of the refraction-retarded wave (2) will come out down from a sound outlet end 300 of the stack 100 to the rear side of the stack 100 opposite to a noise source. It will go down as indicated with a arrow (4) without any sufficient interference with the direct wave (1). As a result, the refraction-retarded wave (2) will cause a noise problem in the lower zone at the back of the soundproof wall 1. For a best possible sound reduction by the interference noise-control unit having the bent stack 100, when used as secured on the upper portion of the soundproof wall 1, a sound-insulating wall 106 taller than the top of the sound outlet end 300 is disposed in a position appropriately spaced from the sound outlet end 300 as shown in FIG. 1. The sound-insulating wall 106 thus serves to prevent the non-interfered, refracted wave (4) from going down backward and shields the space behind the bent stack 100, thereby defining with the bent stack 100 an interference space 400. The sound-insulating wall 106 may be provided separately from or integrally with the bent stack 100. Such conventional interference noise-control unit assures a superb effect of sound reduction and can effectively control noise even with a relatively low soundproof wall. So, it is used for practical noise control at many traffic sites such as railway, road or around various machines.

However, the aforementioned conventional interference noise-control unit cannot effectively control any noise originating from a turbulence aerodynamically caused around and along a railway vehicle running at a high speed, for example, 200 km/h, although it can accommodate a noise coming from the lower portion of a running vehicle.

Accordingly, the present invention has an object to provide an interference noise-control unit intended for use as installed on an existing or main soundproof wall disposed remote from a noise source or sources, which can effectively control both upper and lower noises.

The above object can be accomplished by providing a interference noise-control unit comprising, according to the present invention, a hollow soundproof compartment which is to be used as secured on the upper portion of an existing soundproof wall and has formed therein a plurality of channels different in length from each other and which extend from sound inlets opened at the front of the noise-control unit to sound outlets opened at the back of the soundproof compartment; a sound-insulating rear wall juxtaposed to the soundproof compartment, having an outlet opening formed in the upper portion thereof, and of which the upper end is located within a sound-reduction zone of the soundproof compartment; and a sound-insulating bottom wall provided as coupled between the sound-insulating rear wall and soundproof compartment; the sound inlets being positioned little by little higher in a direction away from the soundproof wall so that the ends of thereof are on a gentle ascending slope, the channels being bent toward the soundproof wall on their ways from the sound inlets to the sound outlets, and the bending angles of the channels being increased in the direction away from the soundproof wall.

In the noise-control unit according to the present invention, a noise from an upper source comes to the sound inlets and also passes above the inlets. The noise entering the channels at the sound inlets, namely, refraction-retarded wave, comes out of the outlet opening and mixes with a noise having not passed through the channels, namely, direct wave. The interference between the refraction-retarded and direct waves leads to cancellation between them, namely, a sound reduction. This is also true with the noise from a lower source.

These and other objects and advantages of the present invention will be better understood from the ensuing description made, by way of example, of the preferred embodiments of the present invention with reference to the drawings.

FIG. 1 is a schematic illustration of a conventional noise-control unit;
FIG. 2 is a perspective view of another conventional noise-control unit;
FIG. 3 is a sectional view of the principle of sound interference employed in the conventional noise-control unit;
FIG. 4 is a side elevation of a preferred embodiment of the noise-control unit according to the present invention;
FIG. 5 is a front view of the noise-control unit in FIG. 4;
FIG. 6 is a explanatory illustration showing the shapes of the hollow path;
FIG. 7 is a explanatory illustration showing the control of a noise from an upper source;
FIG. 8 is a schematic illustration of the sound-reduction zone for the upper and lower noises from a railway vehicle;
FIG. 9 is a schematic illustration of the measurement of the sound reduction by the noise-control unit according to the present invention; and
FIG. 10 is a schematic illustration of the experimental sound measurement for comparison of the effect of sound reduction of the noise-control unit according to the present invention with that of the conventional noise-control unit.

FIG. 4 is a side elevation of the preferred embodiment of the interference noise-control unit according to the present invention. The noise-control unit is used as installed on a existing or main soundproof wall 1 located apart from a noise source or sources. It comprises a hollow soundproof compartment 2 secured to the upper portion of a side of the soundproof wall 1 opposite to the noise source.

The soundproof compartment 2 has formed therein a plurality of channels 21 to 24 different in length from each other and extending from sound inlets 2A to 2D opened at the front of the soundproof compartment 2 to sound outlets 2E to 2H opened at the back of the soundproof compartment 2. The channels 21 to 24 are defined by partitions 25 to 28 within the soundproof compartment 2. As will be apparent from FIG. 4, these channels 21 to 24 are bent toward the soundproof wall 1 on their respective ways from the sound inlets 2A to 2D to the sound outlets 2E to 2H.

In addition, the noise-control unit comprises a sound-insulating rear wall 3 of which the upper end is located within the sound interference zone, and a bottom wall 4 contiguous from the sound-insulating rear wall 3 and laid between the rear 3 and soundproof wall 1. Both the sound-insulating rear wall 3 and bottom wall 4 are located at the side of the soundproof wall 1 opposite to the noise source and apart from the soundproof wall 1. The sound-insulating rear wall 3 and bottom wall 4 are formed integrally with the soundproof compartment 2. There is defined an inner space 400 between the soundproof compartment 2 and the rear and bottom walls 3 and 4 as in the conventional interference noise-control unit having been described in the foregoing.

The sound-insulating rear wall 3 has an outlet opening 5 formed at the top thereof. In the interference noise-control unit according to the present invention, the soundproof compartment 2 is opened at the bottom thereof while the sound-insulating wall 3 and bottom wall 4 extend along the length of the soundproof compartment 2, that is, the noise-control unit is open at the opposite lateral sides of the walls 3 and 4. However, when such integral moldings each comprising the soundproof compartment 2, sound-insulating wall 3 and bottom wall 4 are used as disposed side by side in line, the thus formed line of soundproof units is to be closed at both lateral sides thereof with side walls, respectively. It should be noted that each of such moldings may be closed at the lateral side thereof.

Also, the hollow soundproof compartment 2 has a sound absorbent 6 attached at a side thereof facing the noise source, and another sound absorbent 7 attached on the inner faces of the sound-insulating wall 3 and bottom wall 4. These sound absorbents 6 and 7 should preferably be made of a lightweight mortar obtainable from a mixture of a porous synthetic resin and/or inorganic porous material, foaming agent, cement and water.

The porosity of such sound absorbent should preferably be 40 to 80 %. By putting into a mortar mixer a cement in 100 parts by weight and semi-rigid urethane chips of less than 2 mm in diameter in 7.5 parts by weight, for example, agitating for 1 minute, then adding a foaming agent in 30 parts by weight and water in 45 parts by weight to the agitated mixture, and then uniformly mixing for about 20 minutes, a lightweight mortar of 56% in porosity containing foamed urethane chips can be prepared as a suitable sound absorbent for the intended use. The porosity can be controlled by adjusting the volume of foaming agent and length of mixing time. The foamed urethane chips may be soft urethane, rigid urethane or semi-rigid urethane chipped using a crusher or the like.

Also, the foaming agent should preferably be an anionic or cationic synthetic surface-active agent, hydrolysis-protein foaming agent or resin soap foaming agent.

Furthermore, the sound absorbents 6 and 7 may be made of a formed aggregate of fibers. The formed fiber aggregate should preferably contain mainly short fibers of less than 30 deniers in diameter and have a mean apparent density is 0.04 to 0.15 g/cm$^3$. Use of short fibers of less than 30 deniers in diameter and an apparent density of aggregate within the predetermined range allows an increased impermeability of the formed fiber aggregate, which provides an improved sound absorption. If an fiber aggregate is made of fibers of more than 30 deniers, it will have a lower packaging density of the fibers therein and thus a lower impermeability. Therefore, the aggregate will have a poor capability of absorbing sound. If it is tried to improve the sound absorption of this fiber aggregate only by raising the apparent density, the aggregate will be too hard and likely to reflect the incoming sound, namely, the sound absorption will be lower. The upper limit of the apparent density must be set 0.15 g/cm$^3$. Also, adoption of thin fibers of less than 30 deniers and an apparent density of less than 0.04 g/cm$^3$ will not allow the aggregate to have any increased impermeability. In this case, the aggregate of such fibers cannot show any satisfactory sound absorption. The short fiber may be selected from among synthetic fibers such as polyester, polypropylene, polyethylene, Nylon, Vinylon, etc. and natural fibers such as wool, cotton, hemp, etc. Also, short fibers obtained by splitting a cloth made of anyone of the above-mentioned fibers may be used for this purpose. In this case, a great effect of sound insulation and absorption can be attained either by a formed aggregate made from the above-mentioned short fibers and having mixed in more than 10% by weight therein fibers produced from bitumious or similar material by melt spinning or other appropriate technique or by a fiber aggregate made only of the bituminous fibers. The similar material to bituminous should be a one modified in brittleness and temperature dependence by mixing a resin or thermoplastic elastomer and containing bituminous in more than 30% by weight. The formed aggregate of such fibers made from bituminous or similar material can effectively insulate and absorb sound because the damping property of the bituminous is imparted to the fiber aggregate and enhances the sound insulation and absorption of the latter. Also, the formed fiber aggregate may be produced by placing in a mold an aggregate of short fibers containing a binder and preformed flat and then subjecting it to a hot compression molding.

FIG. 5 is a view, from the soundproof wall 1 in FIG. 4, of the noise-control unit according to the present invention, showing the hollow soundproof compartment 2, sound-insulating rear wall 3 and sound-insulating bottom wall 4. According to the present invention, a side wall 8 is provided on one side of the interference noise-control unit, and such noise-control units are to be used as coupled side by side in line.

FIG. 6 schematically illustrates the plurality of channels 21 to 24. As shown, the partitions 25 to 28 are bent on their ways from the sound inlets 2A to 2D toward the sound outlets 2E to 2H and have the straight portions thereof inclined 36° with respect to the vertical line. The sound inlets 2A to 2D are little by little higher in a direction away from the soundproof wall 1. In other words, a line "X" connecting the inlet ends of the partitions 25 to 28 is on a gentle ascending slope in that direction. The line X and horizontal line form together an angle $\alpha$ ranging from 8° to 20°. The bending angles $\beta_1$ to $\beta_4$ of the channels 21 to 24 are increased in a direction away from the soundproof wall 1. Among the channels 21 to 24, the channel 21 is the shortest while the channel 24 is the longest.

FIG. 7 explains the control of a noise from an upper source. As shown, a part of the noise from the upper source enters the noise-control unit at each of the sound inlets 2A to 2D, and goes as refracted and thus retarded out of the outlet opening 5 as indicated with a hatched arrow. The remainder of the noise from the upper source comes as direct wave and passes above the noise-control unit as indicated with a blank arrow. These direct and refraction-retarded waves mix together above the outlet opening 5, namely, they cancel each other through interference between them. An effective sound reduction is thus attainable.

FIG. 8 schematically illustrates a zone of sound reduction against noises from upper and lower sources. A running railway vehicle will develop an upper noise source (aerodynamic noise) and lower noise source (rolling noise). To control these noises, the soundproof compartment 2, sound-insulating rear wall 3 and bottom wall 4 are provided on the upper portion of a side of the soundproof wall 1 opposite to the noise sources.

FIG. 9 schematically shows an experimental measurement of the effect of sound reduction of the noise-control unit according to the present invention. As seen, the noise-control unit is installed on the soundproof wall 1 and speakers are located at possible upper and lower noise sources, respectively, to generate sounds of the frequencies as specified in Tables 1 and 2, respectively. Also an anechoic-chamber assess point is set in relation to the location of the noise-control unit. In this configuration, sounds are generated from the respective speakers and measured at the assess point. Of course, sound reduction by the soundproof wall 1 is also measured without the noise-control unit according to the present invention. In comparison with the sound reduction attained only by the soundproof wall 1, it is determined how much the noise-control unit according to the present invention can control the noises. In Tables 1 and 2, the measurements of sound reduction obtained without the sound absorbents 6 and 7 shown In FIG. 4 are shown in the column A while those obtained using the sound absorbents 6 and 7 are shown in the column B (in decibels). The sound absorbents used in this experiment is a formed aggregate made of fibrous material. Table 1 shows the results of sound reduction measurement with respect the upper noise source, while Table 2 shows those with respect the lower noise source.

Table 1

| | A | B |
|---|---|---|
| 63 Hz | 1 | 0 |
| 125 Hz | 2 | 3 |
| 250 Hz | 2 | 2 |
| 500 Hz | 10 | 11 |
| 1 kHz | 13 | 13 |
| 2 kHz | 11 | 12 |
| 4 kHz | 11 | 11 |

Table 2

| | A | B |
|---|---|---|
| 63 Hz | 1 | 1 |
| 125 Hz | 1 | 1 |
| 250 Hz | 1 | 2 |
| 500 Hz | 6 | 8 |
| 1 kHz | 13 | 14 |
| 2 kHz | 10 | 10 |
| 4 kHz | 9 | 9 |

FIG. 10 shows the comparison in effect of noise control between the conventional noise-control unit shown in FIG. 1 and the noise-control unit according to the present invention. Table 3 shows the measurements of sound reduction by only the soundproof wall 1 with respect to the upper noise source, while Table 4 shows those with respect to the lower noise source. The measurements of the sound reduction by the conventional unit are shown in the column C of these Tables while those by the unit according to the present invention are shown in the column D.

Table 3

| | C | D |
|---|---|---|
| 63 Hz | 1 | 1 |
| 125 Hz | 0 | 0 |
| 250 Hz | 4 | 3 |
| 500 Hz | 4 | 8 |
| 1 kHz | 9 | 13 |
| 2 kHz | 10 | 13 |
| 4 kHz | 13 | 18 |

Table 4

| | C | D |
|---|---|---|
| 63 Hz | 1 | 1 |
| 125 Hz | 0 | 0 |
| 250 Hz | 4 | 3 |
| 500 Hz | 4 | 8 |
| 1 kHz | 9 | 13 |
| 2 kHz | 10 | 13 |
| 4 kHz | 13 | 18 |

The channels 21 to 24 are bent at angles $\beta_1$ of about 100°, $\beta_2$ of about 120°, $\beta_3$ of about 140° and $\beta_4$, of about 150°, respectively. In this embodiment, four channels 21 to 24 are provided, but more than five channels or two to three channels may be provided in practice. The noise-control unit shown in FIG. 5 can be integrally molded from a synthetic resin such as polypropylene, etc. It should be noted, however, that the soundproof compartment 2, sound-insulating rear wall 3 and bottom wall 4 may be separately.

As having been described in the foregoing, the noise-control unit according to the present invention has the sound inlets positioned little by little higher in a direction away from the soundproof wall so that the ends thereof are on a gentle ascending slope, and the channels bent toward the soundproof wall on their ways from the sound inlets to the sound outlets, the bending angles of the channels being increased in the direction away from the soundproof wall. Therefore, the noise-control unit according to the present invention can effectively control the noises from the upper and lower sources without the necessity of increasing the height of the soundproof wall. The noise-control unit according to the present invention is highly effective especially against a noise from an upper source such as aerodynamic sound.

**Claims**

1. An interference noise-control unit, intended for use as installed on an existing soundproof wall (1) disposed remote from a noise source, comprising:

   a hollow soundproof compartment (2) which is to be used as secured on the upper portion of the existing soundproof wall (1) and has formed therein a plurality of channels (21 to 24) different in length from each other and which bend from sound inlets (2A to 2D) opened at the front of the noise-control unit to sound outlets (2E to 2H) opened at the back of the soundproof compartment (2);
   a sound-insulating rear wall (3) juxtaposed to the soundproof compartment (2), having an outlet opening (5) formed in the upper portion thereof, and of which the upper end is located within a sound-reduction zone of the soundproof compartment (2); and
   a sound-insulating bottom wall (4) provided as coupled between the sound-insulating rear wall (3) and soundproof compartment (2);
   the sound inlets (2A to 2D) being positioned little by little higher in a direction away from the soundproof wall (1) so that the ends of thereof are on a gentle ascending slope; and
   the channels (21 to 24) being bent toward the soundproof wall on their ways from the sound inlets (2A to 2D) to the sound outlets (2E to 2H).

2. An interference noise-control unit as set forth in Claim 1, wherein the bending angles of the channels (21 to 24) is increased in the direction away from the soundproof wall (1).

3. An interference noise-control unit as set forth in Claim 1 or 2, wherein a sound absorbent (6) is attached at a side thereof facing the noise source and another sound absorbent (7) is attached on the inner face of the sound-insulating rear wall (3) and bottom wall (4).

4. An interference noise-control unit as set forth in any one of Claims 1 to 3, wherein the line connecting the ends of the sound inlets (2A to 2D) is inclined through an angle of 8° to 20° with respect to the horizontal direction.

5. An interference noise-control unit as set forth in any one of Claims 1 to 3, wherein the partitions (25 to 28) defining the channels (21 to 24) and extending toward the sound outlets (2E to 2H), respectively, are inclined 36° with respect to the vertical line.

FIG. 1 (PRIOR ART)

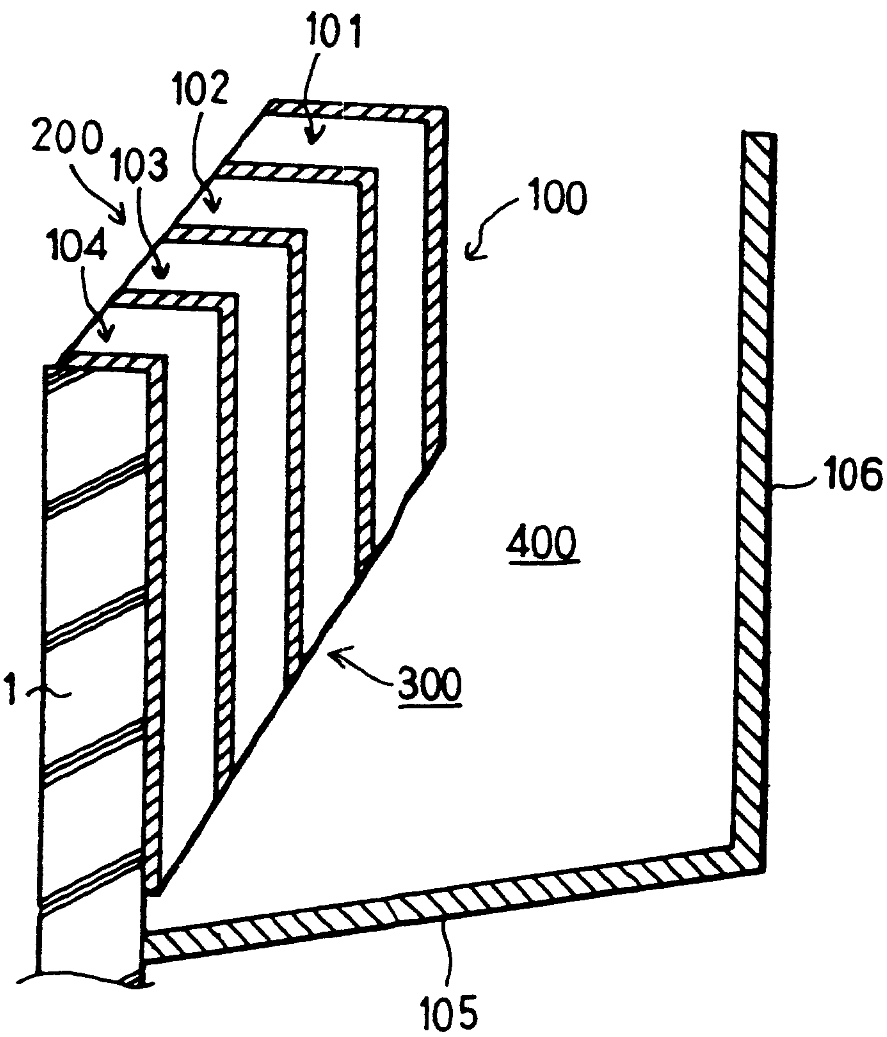


FIG. 2 (PRIOR ART)

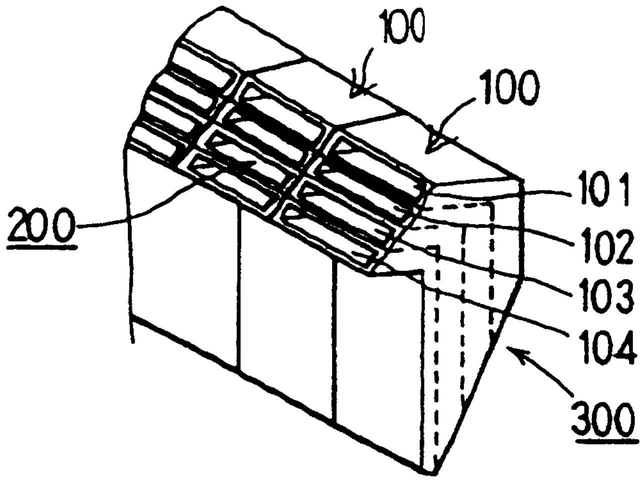



FIG. 3 (PRIOR ART)

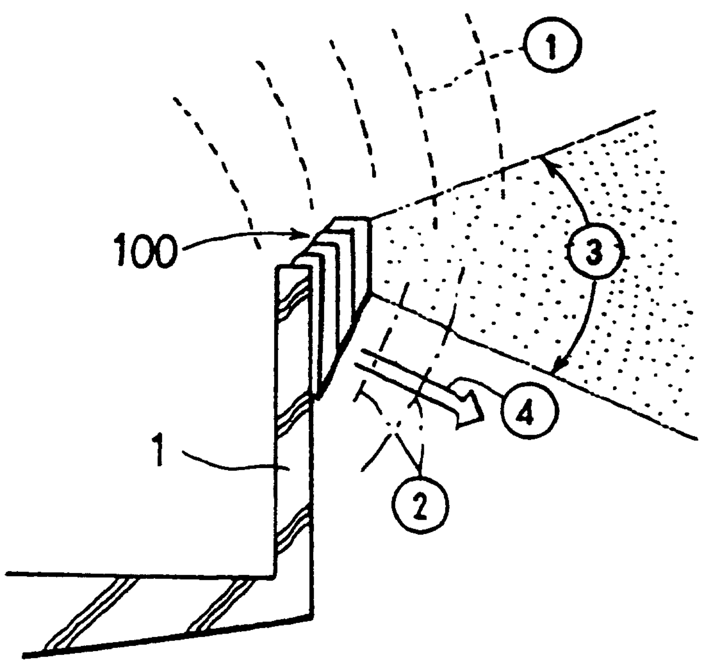


FIG. 4

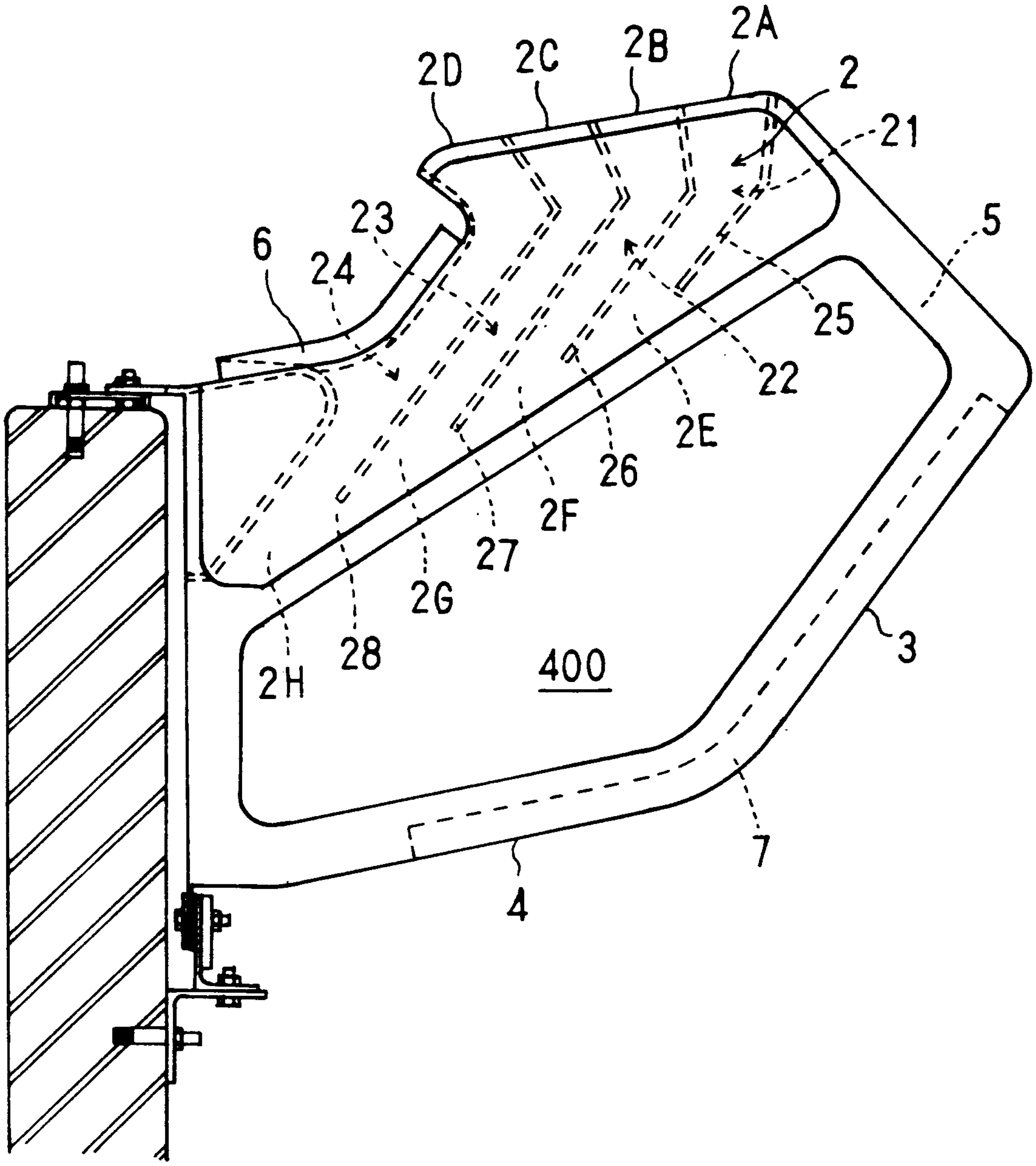


FIG. 5

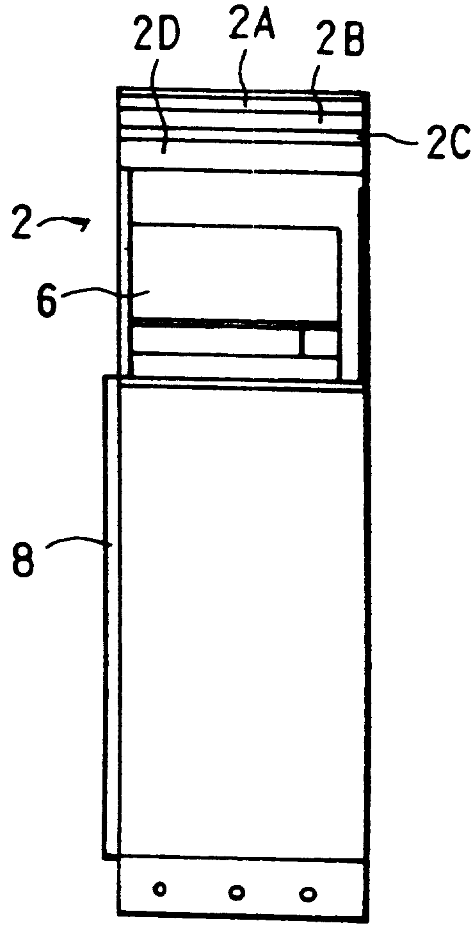


FIG. 6

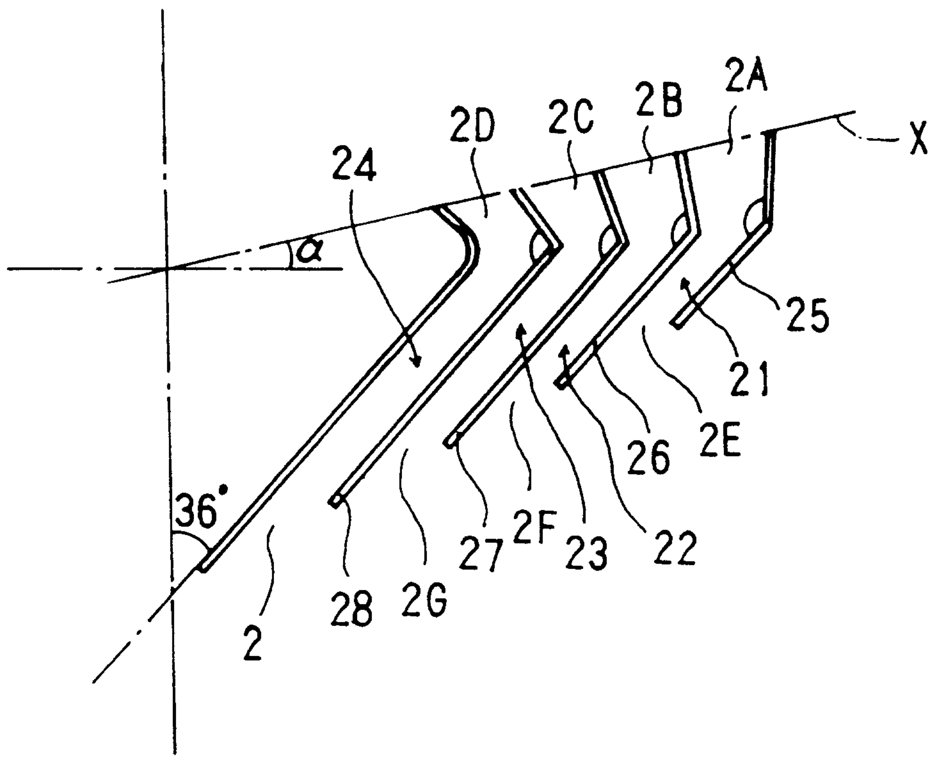


FIG. 7

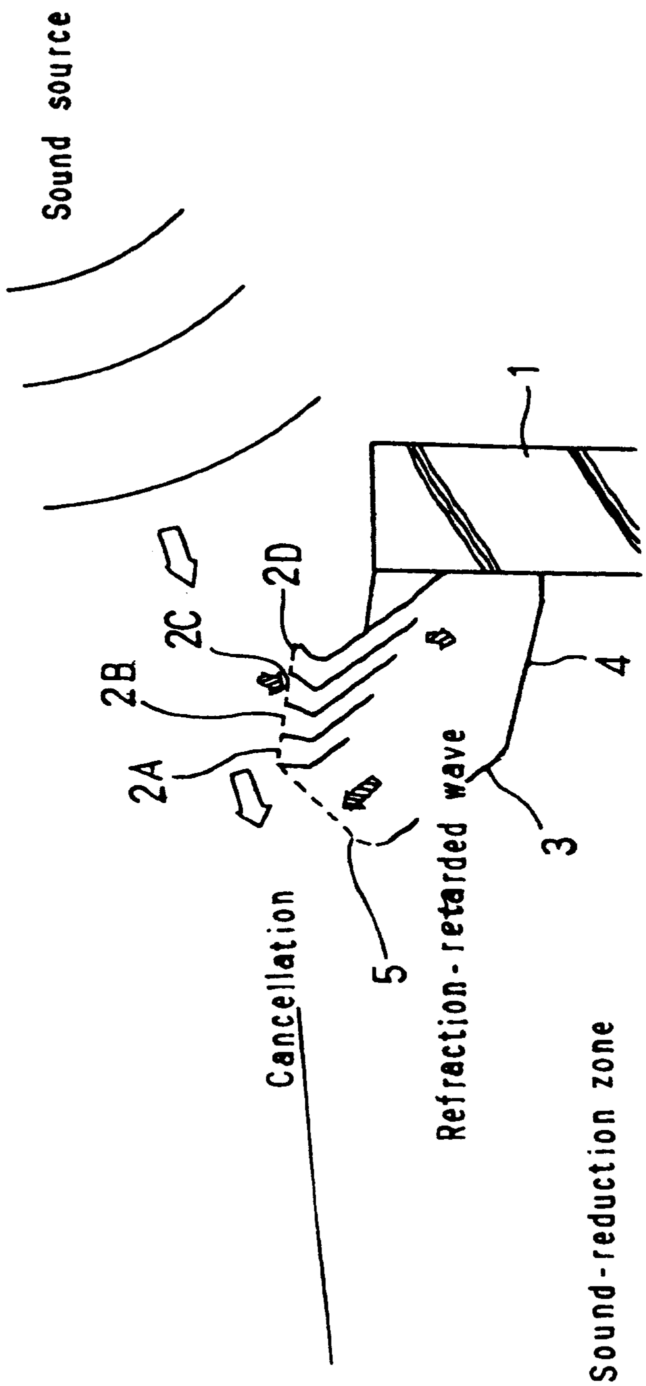

Sound source
1
2D
2C
2B
2A
4
3
5
Cancellation
Refraction-retarded wave
Sound-reduction zone

FIG. 8

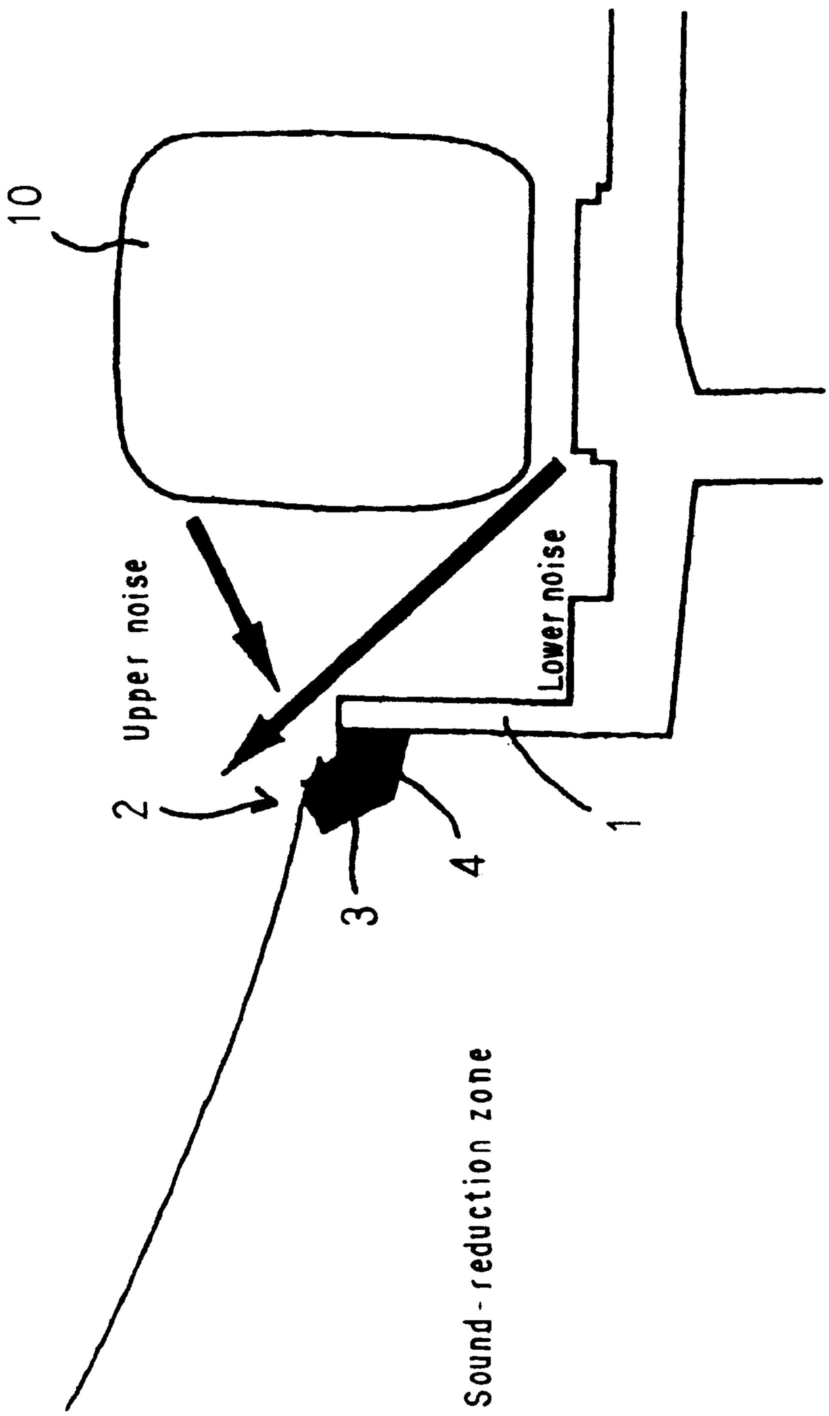


FIG. 9

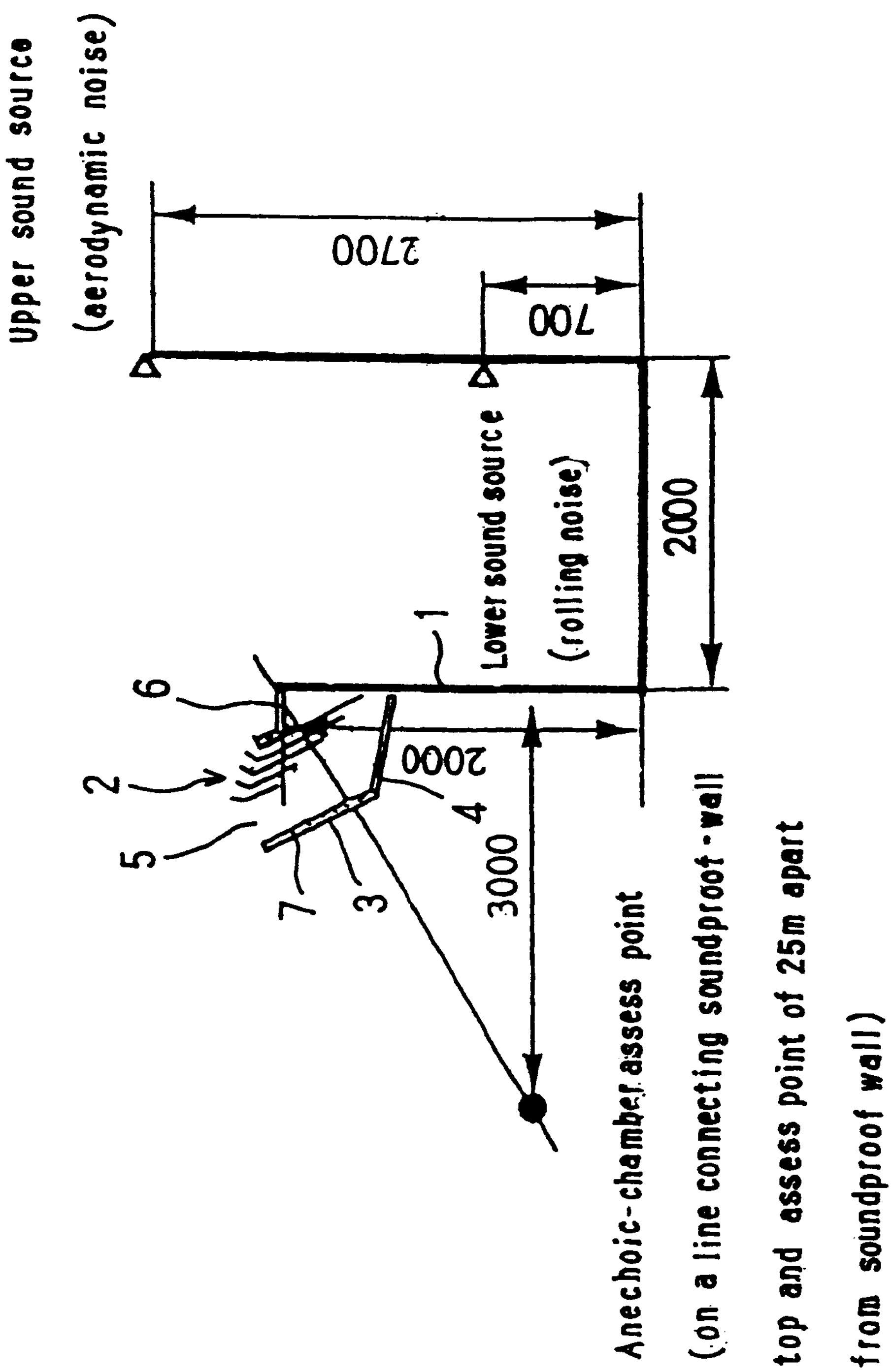
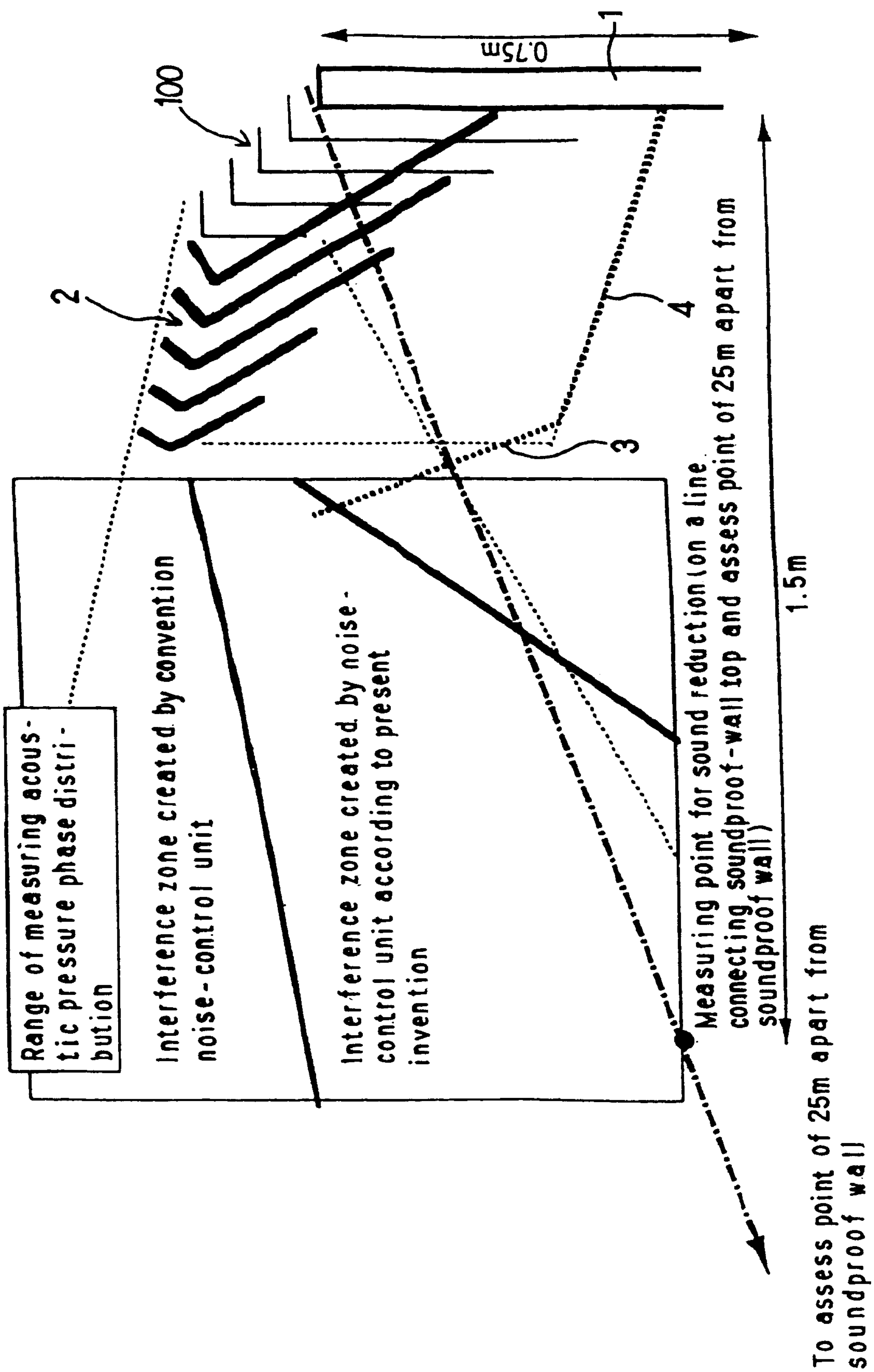

Upper sound source
(aerodynamic noise)
2700
700
Lower sound source
(rolling noise)
2000
1
6
2
5
4
7
3
2000
3000
Anechoic-chamber assess point
(on a line connecting soundproof-wall
top and assess point of 25m apart
from soundproof wall)

FIG. 10


0.75m
1
100
2
3
4
1.5m
Range of measuring acoustic pressure phase distribution
Interference zone created by convention noise-control unit
Interference zone created by noise-control unit according to present invention
Measuring point for sound reduction (on a line connecting soundproof-wall top and assess point of 25m apart from soundproof wall)
assess point of 25m apart from
To assess point of 25m apart from soundproof wall