(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 043 382 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
05.03.2014 Bulletin 2014/10

(21) Application number: **08016414.8**

(22) Date of filing: **18.09.2008**

(51) Int Cl.:
H04R 1/28 *(2006.01)*

(54) **Sound system**

Tonanlage

Système sonore

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MT NL NO PL PT RO SE SI SK TR

(30) Priority: **25.09.2007 EP 07018861**

(43) Date of publication of application:
01.04.2009 Bulletin 2009/14

(73) Proprietor: **Harman International Industries Ltd.**
Potters Bar, Hertfordshire EN6 3JN (GB)

(72) Inventors:
- **Harris, Mike**
Cardiff CF 14 2FJ (GB)
- **Svobodnik, Alfred**
1020 Wien (AT)
- **Jones, Gavin**
Carmarthenshire SA 148AX (GB)

(74) Representative: **Patentanwälte**
Westphal, Mussgnug & Partner
Herzog-Wilhelm-Strasse 26
80331 München (DE)

(56) References cited:
WO-A-99/59840
DE-A1- 10 353 578
DE-A1-102004 002 957

EP 2 043 382 B1

Printed by Jouve, 75001 PARIS (FR)

Description

BACKGROUND

1. Field of Technology

[0001] The invention relates to a sound system having a low-frequency loudspeaker, and in particular to a sound system for a vehicle.

2. Related Art

[0002] One problem when installing low-frequency loudspeakers in motor vehicles is that low-frequency loudspeakers require a large resonant volume. However, there is generally limited space for such a large resonant volume. In addition, the candidate locations with large resonant volumes are often not suitable for the installation of low-frequency loudspeakers, since the low-frequency loudspeakers require a large, substantially flat surface for installation. In a motor vehicle, there are few locations that offer both a large flat surface for the mounting of the loudspeaker, and a large resonant volume.

[0003] Documents DE 10 2004 002 957 A1 and DE 103 53 578 A1 disclose a loudspeaker system wherein a loudspeaker cabinet is coupled to a second enclosed volume via a duct or a base reflexed tube.

[0004] Arrangements are known in which the low-frequency loudspeaker is fitted under a vehicle seat. However, with these arrangements, the space for the installation of a low-frequency loudspeaker is extremely small since the loudspeaker should be covered by the seat in all the positions of the seat. In addition, space is often required under the seat to ensure that rear seat passengers have sufficient foot room. Accordingly, the room for a box carrying the loudspeaker is very limited to the effect that the sound quality of such arrangements is poor.

[0005] Therefore, there is a need for improving the sound quality of a loudspeaker arranged in a motor vehicle.

SUMMARY OF THE INVENTION

[0006] A novel sound system comprises a tube-like cavity with an opening, the tube-like cavity is hermetically sealed and divided into tube-like sub-cavities by a wall having a hole. The sound system further comprises a low-frequency loudspeaker and a hermetically sealed enclosure with two openings, through one of which the loudspeaker is acoustically coupled to the enclosure and through the other the enclosure is acoustically coupled to the opening of the tube-like cavity; where the hole in the wall has a size and a position such that a resonance of the sound system deteriorating its sound quality is reduced.

[0007] Other systems, methods, features and advantages of the invention will be, or will become, apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the following claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention can be better understood with reference to the following drawings and description. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. Moreover, in the figures, like reference numerals designate corresponding parts throughout the different views.

FIG. 1 is a perspective view of an enclosure carrying a loudspeaker to be applied in a novel vehicle loudspeaker system;

FIG. 2 is a perspective view of an arrangement comprising the enclosure of FIG. 1 coupled to a cavity established by body parts of the vehicle;

FIG. 3 is a perspective cut-off view of an acoustic model of the arrangement shown in FIG. 2.

FIG. 4 is a perspective view of the model of FIG. 3 comprising symmetrical coupling of the enclosure to the tube-like cavity;

FIG. 5 is a perspective view of the model of FIG. 3 comprising asymmetrical coupling of the enclosure to the tube-like cavity;

FIG. 6 is a perspective cut-off view of the acoustic model shown in FIG. 3 having a modified coupling of the enclosure to the cavity; and

FIG. 7 is a perspective view of an arrangement where the enclosure is coupled to a cavity established by a sill and a B-pillar of a vehicle.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0009] A novel sound system comprises a low-frequency loudspeaker 2 (e.g., woofer, sub-woofer) mounted to a hermetically sealed (or vented) enclosure 1 (e.g., box, cabinet) as shown in FIG. 1. The loudspeaker 2 may be of any suitable design but is in the present example a shallow loudspeaker that requires minimum height so that it provides maximum design freedom. The loudspeaker 2 may be supplied with electrical power via an electrical connector 3. The enclosure 1 encloses a first air volume 10 and has two openings 4 (see FIG. 2) and 5 (see FIG. 3 which is an acoustic model of the arrangement shown in FIG. 2). Through one opening 4 the enclosure 1 is acoustically coupled to the loudspeaker 2 and through the other opening 5 to a cavity 7, 17 having a corresponding opening. The opening 5 may be arranged as a flange having a certain length and diameter and, thus, increasing the first air volume of the enclosure 1.

[0010] The enclosure 1 carrying the loudspeaker 2 is arranged in a vehicle, for example, under a seat 15 of the vehicle. The vehicle body comprises a stiffener 6 which forms together with other body parts, e.g. sill 16, a cavity 7, 17. The cavity 7, 17 encloses a second volume 11 and comprises two sub-cavities 7 and 17 separated by a wall-like element which is in the present case the stiffener 6. The stiffener 6 has holes 8 that acoustically connect the two sub-cavities 7, 17. The sill 16 and the stiffener 6 form a kind of tube-in-tube structure. However, a parallel or any other arrangement of the tube-like sub-cavities 7, 17 is applicable as well.

[0011] Enclosure 1 and cavity 7, 17 form a resonator system that has a resonant volume including the first air volume 10 and second air volume 11. The holes 8 have sizes and positions such that at least one unwanted resonance of the resonator system, i.e., a resonance that deteriorates the sound quality of the sound system resonance, is reduced. The resonator system may be, e.g., of a Helmholtz resonator type or a transmission line resonator type.

[0012] Helmholtz resonance is the phenomenon of air resonance in a cavity. A so-called Helmholtz resonator comprises a cavity enclosing an air volume and a, e.g. tube-like, port (neck) venting the cavity. A well known example of Helmholtz resonance is the sound created when one blows across the top of an empty bottle.

[0013] When air is forced into a cavity, the pressure inside increases. Once the external force that forces the air into the cavity disappears, the higher-pressure air inside will flow out. However, this surge of air flowing out will tend to over-compensate, due to the inertia of the air in the port, and the cavity will be left at a pressure slightly lower than the outside, causing air to be drawn back in. This process repeats with the magnitude of the pressure changes decreasing each time. Air trapped in the cavity acts as a spring. Air, being compressible, has a definite spring constant. Changes in the dimensions of the cavity adjust the properties of the spring: a larger cavity would make for a weaker spring, and vice-versa.

[0014] The air in the port is the mass. Since it is in motion, it possess some momentum. A longer port would make for a larger mass, and vice-versa. The diameter of the port is related to the mass of air and the volume of the cavity. A port that is too small in area for the cavity volume will "choke" the flow while one that is too large in area for the cavity volume tends to reduce the momentum of the air in the port.

[0015] It can be shown that the resonant frequency is:

$$\omega_H = \sqrt{\gamma \frac{A^2}{m} \frac{P_0}{V_0}} \text{(rad/s)}$$

where γ is the adiabatic index, A is the cross-sectional area of the port, m is the mass in the cavity, P_0 is the static pressure in the cavity, and V_0 is the static volume of the cavity. By geometry,

$$A = \frac{V_0}{L}.$$

where L is the length of the port, thus:

$$\omega_H = \sqrt{\gamma \frac{A}{m} \frac{V}{L} \frac{P_0}{V_0}}$$

[0016] By the definition of density:

$$\frac{V}{m} = \frac{1}{\rho}.$$

thus:

$$\omega_H = \sqrt{\gamma \frac{P_0}{\rho} \frac{A}{V_0 L}}$$

$$f_H = \frac{\omega_H}{2\pi}.$$

where f_H is the resonant frequency (Hz).

[0017] The speed of sound in a gas is given by:

$$v = \sqrt{\gamma \frac{P_0}{\rho}}.$$

thus, the frequency of the resonance is:

$$f_H = \frac{v}{2\pi} \sqrt{\frac{A}{V_0 L}}$$

[0018] The length of the port appears in the denominator because the inertia of the air in the port is proportional to the length. The volume of the cavity appears in the denominator because the spring constant of the air in the cavity is inversely proportional to its volume. The area of the port matters for two reasons. Increasing the area of the port increases the inertia of the air proportionately, but also decreases the velocity at which the air rushes in and out.

[0019] An acoustic transmission line is the acoustic analog of the electrical transmission line, typically thought of as a rigid-walled tube that is long and thin relative to the wavelength of sound present in it. Pipe organs, woodwinds, and the like can be modeled as transmission lines.

[0020] It is known that the rear wave of the loudspeaker needs to be completely absorbed without damping the loudspeaker's motion or modulating it from internal reflections and resonance. The rear wave needs to be terminated correctly within the enclosure so that no reflections are set up over the operating bandwidth of the loudspeaker. If a rear wave resonantes the enclosure it would cause interference, which a correctly terminated line would not. If the line were sufficiently long but evenly stuffed with wadding, then the exiting wave would be relatively inaudible. The difference between a Transmission Line loudspeaker and a Reflex or Labyrinth is that the rear wave is audibly absorbed and not used for reinforcement. Also the resonance of the enclosure is virtually gone. Transmission line loudspeakers have virtually no sound emanating from the enclosure except the loudspeaker, an excellent transient response and uncompressed dynamics, and a high efficiency.

[0021] A duct containing some medium, such as air, that supports sound propagation for sound propagation behaves like a transmission line. Its length is normally of a similar order to the wavelengths of the sound it will be used with, but the dimensions of its cross-section are normally smaller than one quarter of a wavelength. Sound is introduced, e.g., at one end of the tube by forcing the pressure across the whole cross-section to vary with time. A plane wave will travel down the line at the speed of sound. When the wave reaches the end of the transmission line, behaviour depends on what is present at the end of the line. There are three possible scenarios:

a) A low impedance load (e.g. leaving the end open in free air) will cause a reflected wave in which the sign of the pressure variation reverses, but the direction of air displacement remains the same.

b) A load that matches the characteristic impedance (defined below) will completely absorb the wave and the energy associated with it. No reflection will occur.

c) A high impedance load (e.g. by plugging the end of the line) will cause a reflected wave in which the direction of air displacement is reversed but the sign of the pressure remains the same.

[0022] Since a transmission line behaves like a four terminal model, one cannot really define or measure the impedance of a transmission line component. One can however measure its input or output impedance. It depends on the cross-sectional area and length of the line, the sound frequency, as well as the characteristic impedance of the sound propagating medium within the duct. Only in the exceptional case of a closed end tube (to be compared with electrical short circuit), the input impedance could be regarded as a component impedance. Where a transmission line of finite length is mismatched at both ends, there is the potential for a wave to bounce back and forth many times until it is absorbed. This phenomenon is a kind of resonance and will tend to attenuate any signal fed into the line.

[0023] The application of transmission line theory is however seldom used in acoustics. An equivalent four terminal model which splits the downstream and upstream waves is used. This eases the introduction of physically measurable acoustic characteristics, reflection coefficients, material constants of insulation material, the influence of air velocity on wavelength (Mach number), etc. This approach also circumvents unpractical theoretical concepts, such as acoustic impedance of a tube, which is not measurable because of its inherent interaction with the sound source and the load of the acoustic component.

[0024] Transmission lines may be also used to channel sound away from the back of the loudspeaker such that at the other, end of the transmission line, low frequencies are in phase with the front of the loudspeaker, which improves irradiation of bass frequencies. The disadvantage of this design, that the transmission line causes certain frequencies to be suppressed, can be alleviated by judiciously tuned Helmholtz resonators.

[0025] FIG. 4 is a perspective view from the opposite side of the model shown in FIG. 3. The model comprises enclosure 1, stiffener 6 with holes 8, closed tube ends 9, and a symmetrical coupling to the tube-like cavity which is achieved by positioning the opening 5 of the enclosure (and a corresponding opening in the body part 6) in the middle of the tube-like body parts 6 such that the distances from the opening 5 (see FIG. 3) to each one of the tube ends 9 are the same.

[0026] The model shown in FIG. 5 is similar to the model shown in FIG. 4 but comprises an asymmetrical coupling to the tube-like cavity, i.e., the lengths of the branches extending from the opening 5 to each one of the tube ends 9 are different. In the examples shown in FIGS. 4 and 5, the holes 8 are only arranged in one branch but may be arranged in both branches as well.

[0027] The model shown in FIG. 6 is similar to the one of FIG. 3 except that the enclosure 1 is not coupled to sub-cavity 7 (as in FIG. 3) but is coupled to sub-cavity 17.

[0028] FIG. 7 is a perspective view of an arrangement comprising a sill 16 and a B-pillar 12. The sill 6 is divided in two sub-volumes 7, 17 by a stiffener 6 as shown in FIG. 2, and both sub-volumes 7, 17 are acoustically connected with each other by holes 8. The B-pillar 12 also encloses a sub-volume 13 that is connected to the other sub-volumes through an opening 14 forming together the second volume.

[0029] While various embodiments of the invention have been described, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible within the scope of the invention. Accordingly, the invention is not to be restricted except in light of the attached claims.

Claims

1. A sound system comprising:

   a hermetically sealed tube-like cavity with an opening;
   a low-frequency loudspeaker (2); and
   an enclosure (1) with two openings (4, 5), one of which acoustically couples the loudspeaker to the enclosure and the other acoustically couples the enclosure to the opening of the tube-like cavity; **characterised in that**
   the tube-like cavity is divided into tube-like sub-cavities by a wall (6) having at least one hole (8), whereby
   the hole in the wall has a size and a position such that a resonance of the sound system deteriorating its sound quality is reduced.

2. The sound system of claim 1 where the wall comprises at least one further hole; each hole having a size and a position such that different resonances of the sound system deteriorating its sound quality are reduced.

3. The sound system of claim 1 or 2 where at least some of the holes have different sizes.

4. The sound system of one of claims 1-4 where the tube-like sub-cavities are arranged parallel to each other.

5. The sound system of one of claims 1-4 where the tube-like cavity is a B-pillar of a vehicle.

6. The sound system of one of claims 1-4 where the tube-like cavity is a sill of a vehicle.

7. The sound system of one of claims 1-4 where the tube-like cavity is established by both a B-pillar and a sill.

8. The sound system of one of claims 1-7 where the enclosure comprises a flange coupling the enclosure to the cavity.

9. The sound system of one of claims 1-8 where the cavity forms a Helmholtz type resonator.

10. The sound system of one of claims 1-8 where the cavity forms a transmission line type resonator.

11. The sound system of one of claims 1-10 where the enclosure is coupled to the tube-like cavity symmetrically.

12. The sound system of one of claims 1-10 where the enclosure is coupled to the tube-like cavity asymmetrically.

13. The sound system of one of claims 1-12 where the holes in the wall are in line along the tube-like cavity.

14. The sound system of one of claims 1-13 where the enclosure is acoustically coupled to one of the sub-cavities.

15. The sound system of one of claims 1-14 where the tube-like sub-cavities are arranged as a tube-in-tube structure.

16. The sound system of one of claims 1-15 where the enclosure is located under one of the seats of a vehicle.

17. The sound system of one of claims 1-17 where the enclosure is hermetically sealed.

Patentansprüche

1. Tonsystem, umfassend:

   einen hermetisch verschlossenen röhrenartigen Hohlraum mit einer Öffnung;
   einen Niederfrequenzlautsprecher (2); und
   ein Gehäuse (1) mit zwei Öffnungen (4, 5), von denen eine den Lautsprecher akustisch an das Gehäuse koppelt und der andere das Gehäuse akustisch an die Öffnung des röhrenartigen Hohlraums koppelt; **dadurch gekennzeichnet, dass**
   der röhrenartige Hohlraum durch eine Wand (6) mit wenigstens einem Loch (8) in röhrenartige Unterhohlräume unterteilt ist, wobei
   das Loch in der Wand eine Größe und eine Position aufweist, derart, dass eine Resonanz des Tonsystems, die seine Tonqualität verschlechtert, reduziert wird.

2. Tonsystem nach Anspruch 1, wobei die Wand wenigstens ein weiteres Loch umfasst; wobei jedes Loch eine Größe und eine Position aufweist, derart, dass Resonanzen des Tonsystems, die seine Ton-

qualität verschlechtern, reduziert werden.

3. Tonsystem nach Anspruch 1 oder 2, wobei wenigstens einige der Löcher unterschiedliche Größen aufweisen.

4. Tonsystem nach einem der Ansprüche 1 bis 4, wobei die röhrenartigen Unterhohlräume parallel zueinander angeordnet sind.

5. Tonsystem nach einem der Ansprüche 1 bis 4, wobei der röhrenartige Hohlraum eine B-Säule eines Fahrzeugs ist.

6. Tonsystem nach einem der Ansprüche 1 bis 4, wobei der röhrenartige Hohlraum ein Schweller eines Fahrzeugs ist.

7. Tonsystem nach einem der Ansprüche 1 bis 4, wobei der röhrenartige Hohlraum sowohl durch eine B-Säule als auch ein Schweller ausgebildet ist.

8. Tonsystem nach einem der Ansprüche 1 bis 7, wobei das Gehäuse einen Flansch umfasst, der das Gehäuse an den Hohlraum koppelt.

9. Tonsystem nach einem der Ansprüche 1 bis 8, wobei der Hohlraum einen Resonator des Helmholtz-Typs bildet.

10. Tonsystem nach einem der Ansprüche 1 bis 8, wobei der Hohlraum einen Resonator des Übertragungsleitungstyps bildet.

11. Tonsystem nach einem der Ansprüche 1 bis 10, wobei das Gehäuse symmetrisch an den röhrenartigen Hohlraum gekoppelt ist.

12. Tonsystem nach einem der Ansprüche 1 bis 10, wobei das Gehäuse asymmetrisch an den röhrenartigen Hohlraum gekoppelt ist.

13. Tonsystem nach einem der Ansprüche 1 bis 12, wobei die Löcher in der Wand entlang dem röhrenartigen Hohlraum in einer Linie liegen.

14. Tonsystem nach einem der Ansprüche 1 bis 13, wobei das Gehäuse akustisch an einen der Unterhohlräume gekoppelt ist.

15. Tonsystem nach einem der Ansprüche 1 bis 14, wobei die röhrenartigen Unterhohlräume als eine Röhre-in-Röhre-Struktur angeordnet sind.

16. Tonsystem nach einem der Ansprüche 1 bis 15, wobei das Gehäuse unter einem der Sitze eines Fahrzeugs angeordnet ist.

17. Tonsystem nach einem der Ansprüche 1 bis 16, wobei das Gehäuse hermetisch verschlossen ist.

Revendications

1. Système acoustique comprenant :

> une cavité de type tube scellé hermétiquement avec une ouverture ;
> un haut-parleur basse-fréquence (2) ; et
> une enceinte (1) avec deux ouvertures (4, 5), dont une couple acoustiquement le haut-parleur à l'enceinte et dont l'autre couple acoustiquement l'enceinte à l'ouverture de la cavité de type tube ; **caractérisé en ce que**
> la cavité de type tube est divise en sous-cavités de type tubes par une paroi (6) comportant au moins un trou (8), moyennant quoi
> le trou dans la paroi a une taille et une position telles qu'une résonance du système acoustique dégradant sa qualité sonore est réduite.

2. Système acoustique selon la revendication 1, où la paroi comprend au moins un autre trou ; chaque trou ayant une taille et une position telles que différentes résonances du système acoustique dégradant sa qualité sonore sont réduites.

3. Système acoustique selon la revendication 1 ou 2, où au moins une partie des trous ont différentes tailles.

4. Système acoustique selon l'une des revendications 1 à 4, où les sous-cavités de type tube sont disposées en parallèle les unes par rapport aux autres.

5. Système acoustique selon l'une des revendications 1 à 4, où la cavité de type tube est un pilier B de véhicule.

6. Système acoustique selon l'une des revendications 1 à 4, où la cavité de type tube est un bas de marche de véhicule.

7. Système acoustique selon l'une des revendications 1 à 4, où la cavité de type tube est établie par un pilier B et par un bas de marche.

8. Système acoustique selon l'une des revendications 1 à 7, où l'enceinte comprend une bride couplant l'enceinte à la cavité.

9. Système acoustique selon l'une des revendications 1 à 8, où la cavité forme un résonateur de type Helmholtz.

10. Système acoustique selon l'une des revendications

1 à 8, où la cavité forme un résonateur de type ligne de transmission.

11. Système acoustique selon l'une des revendications 1 à 10, où l'enceinte est couplée symétriquement à la cavité de type tube.

12. Système acoustique selon l'une des revendications 1 à 10, où l'enceinte est couplée à la cavité de type tube de manière asymétrique.

13. Système acoustique selon l'une des revendications 1 à 12, où les trous présents dans la paroi sont alignés le long de la cavité de type tube.

14. Système acoustique selon l'une des revendications 1 à 13, où l'enceinte est couplée acoustiquement à l'une des sous-cavités.

15. Système acoustique selon l'une des revendications 1 à 14, où les sous-cavités de type tube sont disposées sous la forme d'une structure tube dans tube.

16. Système acoustique selon l'une des revendications 1 à 15, où l'enceinte est située sous l'un des sièges d'un véhicule.

17. Système acoustique selon l'une des revendications 1 à 16, où l'enceinte est scellée hermétiquement.

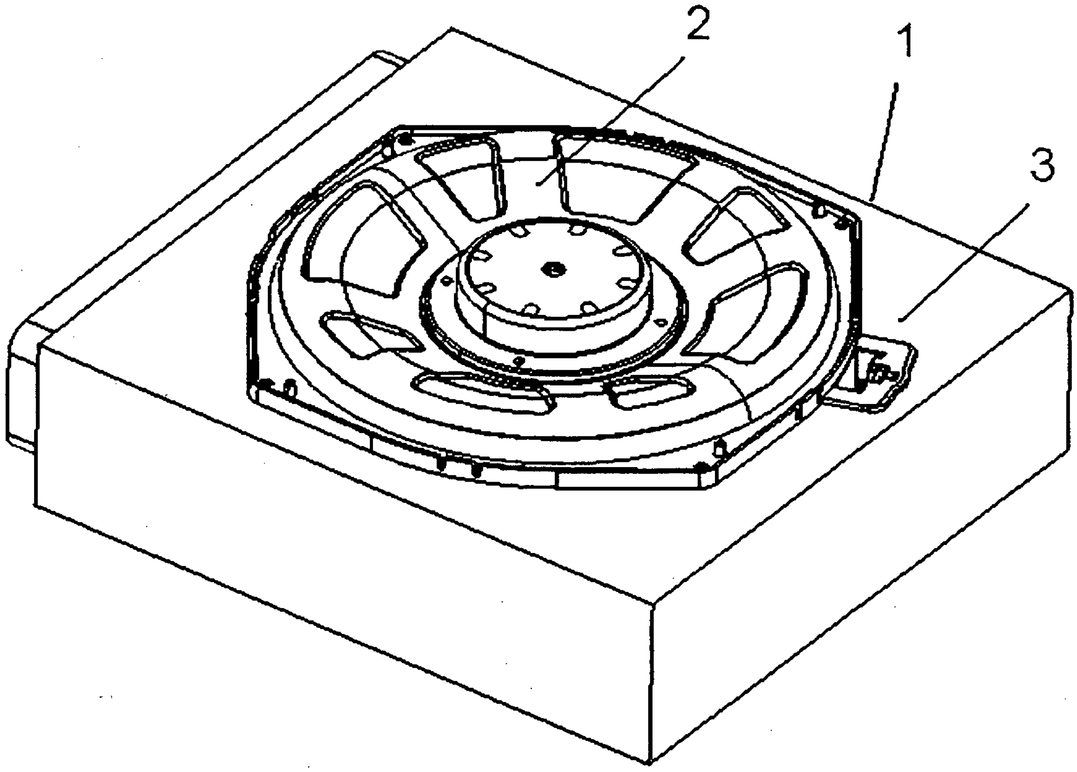

FIG. 1

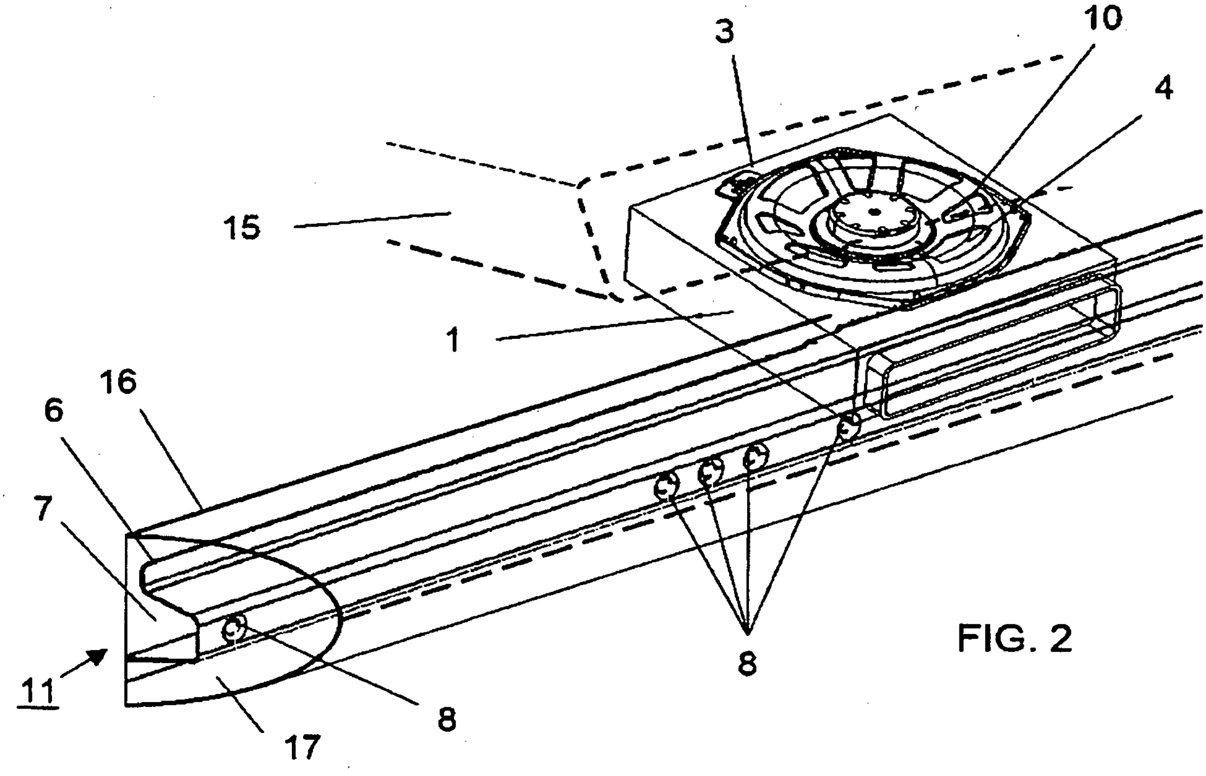

FIG. 2

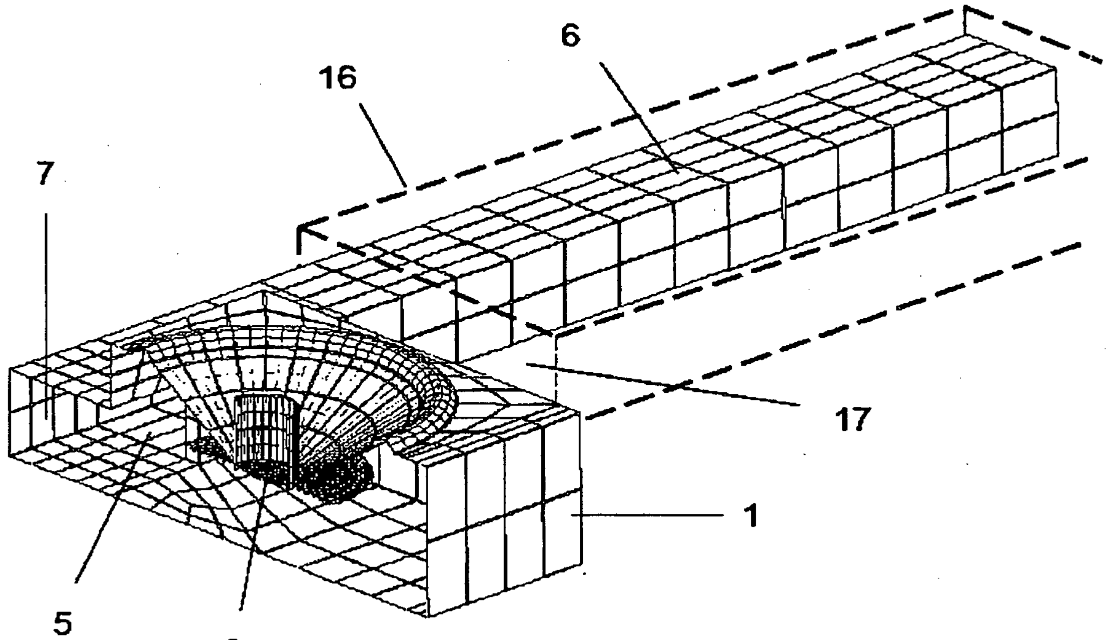

FIG. 3

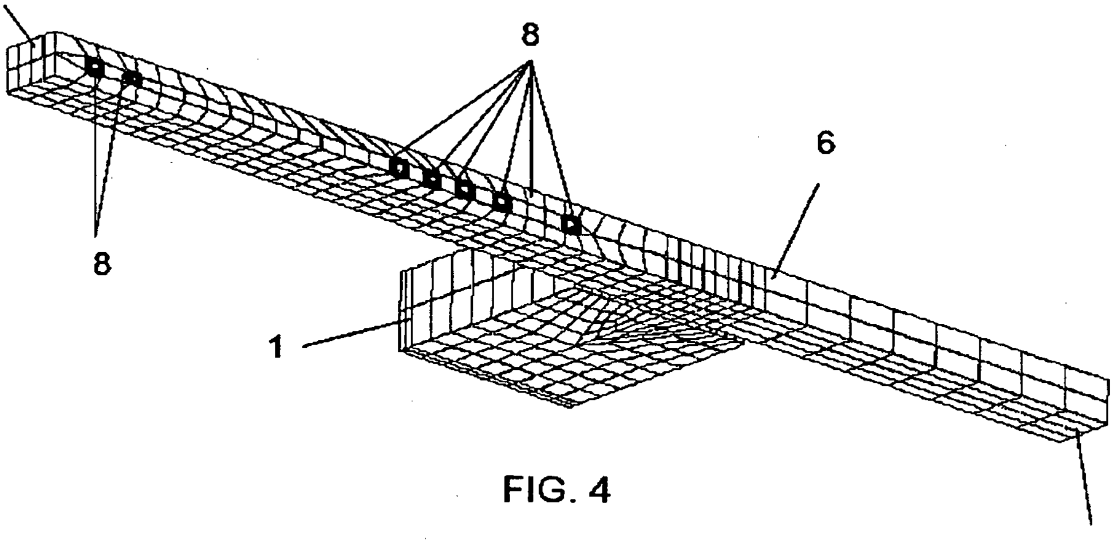

FIG. 4

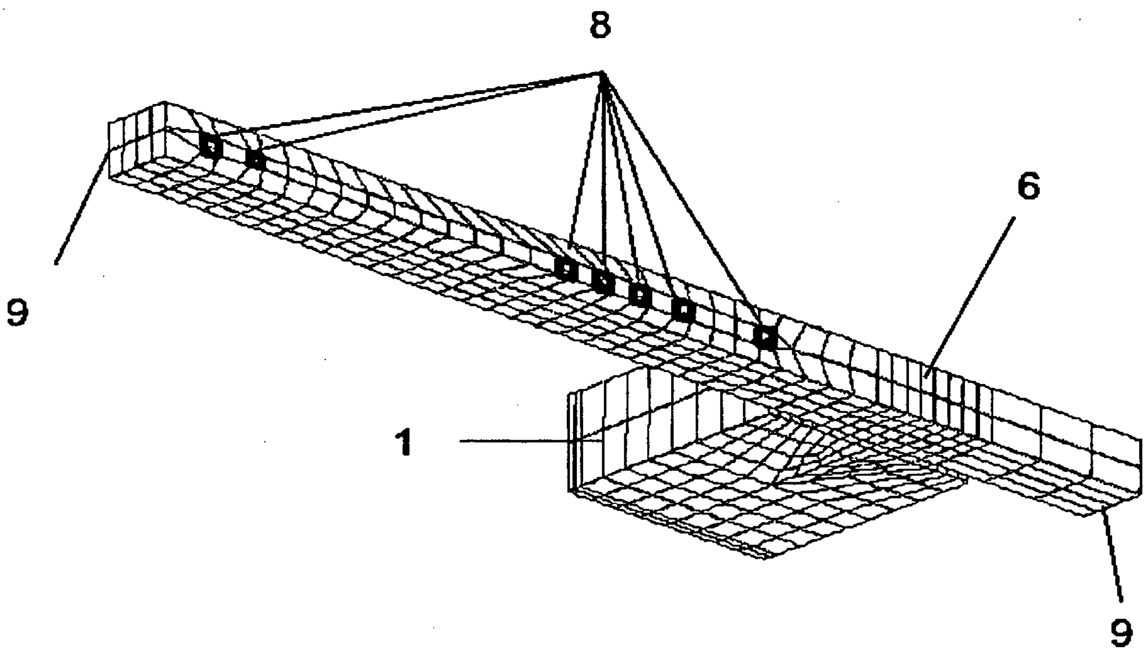

FIG. 5

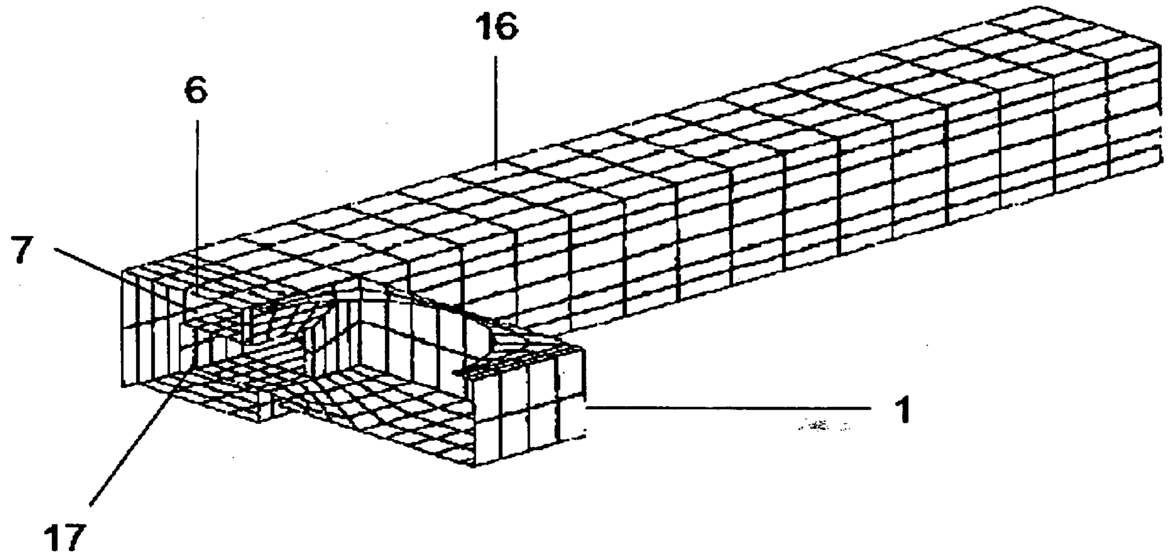

FIG. 6

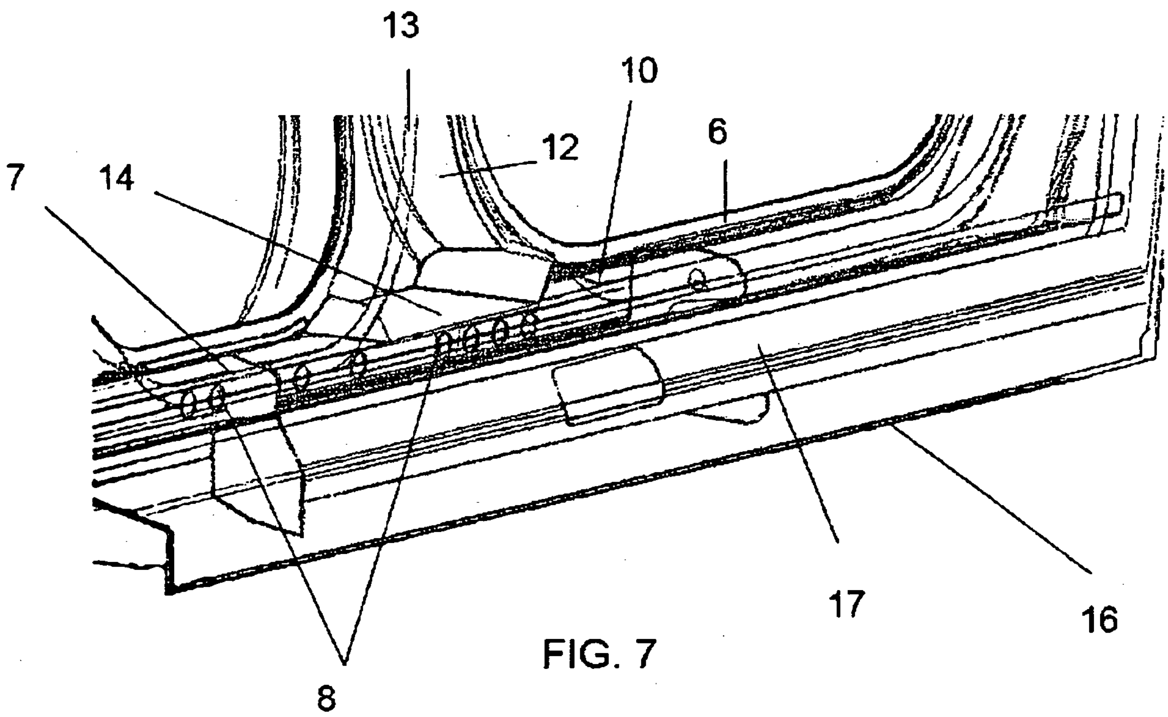

FIG. 7

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- DE 102004002957 A1 **[0003]**
- DE 10353578 A1 **[0003]**