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(54) **RESONANT MODE PANEL-LOUDSPEAKERS**

RESONANZ-WELLENTYP PANEELLAUTSPRECHER

HAUT-PARLEURS DU TYPE PANNEAU A MODE RESONNANT

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(56) References cited:
**WO-A-97/09840** **WO-A-97/09842**



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**Description**

TECHNICAL FIELD

**[0001]** The invention relates to loudspeakers and more particularly to panel-form loudspeakers of the kind adapted to be excited by launching bending waves into a resonant panel to cause it to resonate to produce an acoustic output. Such loudspeakers are described in our International patent application WO97/09842, and are known as distributed mode loudspeakers.

BACKGROUND ART

**[0002]** In conventional pistonic loudspeakers, a moving diaphragm, usually a cone, is held in position on a frame or chassis by at least one flexible member which forms a resilient suspension. This suspension performs at least the following functions, namely:-

1. location in the frame of an assembly comprising the diaphragm and a vibrator usually including a moving coil motor;
2. allows motion of the diaphragm in an axial direction but restrains motion in directions normal to the axis, and
3. provides a degree of damping to vibration of the diaphragm by means of its material choice and treatment.

**[0003]** These requirements are usually met by a flexible corrugated moulded member, sometimes known as a roll surround, usually made from a rubber-like material, which is connected between the outer periphery of the diaphragm and the surrounding frame and a corrugated flexible member, sometimes known as a spider, which is connected between the region of the diaphragm apex and the frame. Although not always used, the common execution with two separate suspension members gives satisfactory performance in the three functions listed above. In the case of traditional moving coil loudspeakers the attachment of suspensions at other positions will introduce unwanted resonances and disturb the vibrational characteristics of the diaphragm.

**[0004]** It is among the objects of the invention to provide a suspension adapted to the needs of a resonant panel loudspeaker. In the case of a resonant panel loudspeaker we have discovered that a number of regions exist within the panel which have low average velocities by reason of the inherent nature of the panels and have concluded that it might be possible to locate a suspension at or near these panel positions and that the low velocity in such regions will mean that the suspension will have little or no effect on the vibrational characteristics of the panel as a whole.

DISCLOSURE OF INVENTION

**[0005]** According to one aspect of the invention there is provided a resonant panel-form loudspeaker comprising suspension means located in at least one panel region of low average velocity, the suspension means being created by incising the panel structure to form at least one cantilever member integral with the panel structure. Such suspension means may be used to suspend the panel in a support and/or to support a vibration exciter on the panel.

**[0006]** The support may comprise a surrounding area of the panel, which surrounding region may be acoustically inactive. The resonant panel-form loudspeaker may comprise a panel having an acoustically active area and panel regions of low average velocity surrounding the acoustically active area, with slots or grooves in the panel structure defining the acoustically active area. The slots or grooves may be such that they extend only partly through the panel structure.

**[0007]** Thus the idea of using low energy regions of the panel for the mechanical support of the panel itself or of an exciter on the panel may be extended to include the use of slots or through incisions in the panel for the purpose of areal definition of a desired acoustically active panel area for distributed mode operation or at least desired acoustic vibration behaviour set within, or as a part of a larger panel component. Such slotting will, for example, permit a wide range of distributed mode type vibrating panels to be produced as an integrated design with arbitrarily formed and contoured vehicle trim panels. The slots may be of any suitable form or shape consistent with the desired vibration behaviour in the required frequency range. FEA (finite element analysis) techniques facilitate the rapid design and analysis of indicated slot perimeter shape and resulting geometric forms.

**[0008]** The low vibration energy in the suspension regions has the benefit of allowing the use of stronger suspension elements than would otherwise be possible, so increasing the durability of the resulting assembly.

**[0009]** The incisions may comprise a parallel pair of slots through the panel structure. The cantilever members may be straight or otherwise, e.g. curved. As concerns a suspension for a vibration exciter, straight cantilevers might be preferred in order better to span the distance between areas of low average velocity and a region of high activity where the exciter is coupled to the panel. The suspension may consist of an array of such cantilever members. Thus the panel may be incised to form cantilever members which retain stiffness in the plane of the panel and which are compliant in the plane of a frame or the like supporting the panel. Alternatively or additionally a separate compliant suspension e.g. of a rubber-like material may be fixed, e.g. by means of an adhesive, to the panel in the said region(s) of low average velocity. Where the rubber-like suspension is used in addition to the cantilevers, the rubber-like suspension

may be mounted on the cantilevers.

**[0010]** The resonant panel-form loudspeaker may comprise a distributed mode acoustic radiator, e.g. of the kind defined in International patent application WO97/09842.

**[0011]** From another the invention is a decorative trim panel, e.g. for a vehicle or the like and incorporating a loudspeaker as defined above.

**[0012]** From a further aspect, the invention is a vehicle, e.g. an automobile, comprising a loudspeaker as defined above or a decorative trim panel as defined above.

**[0013]** From yet another aspect the invention is a method of making a resonant panel acoustic device characterised by identifying the location of at least one panel region of low average velocity, defining an acoustically active area of the panel by locating said panel region(s) surrounding the acoustically active area, positioning suspension means within the said region(s) and disrupting the panel structure in the said regions to form the suspension means.

**[0014]** The method may comprise defining the acoustically active area by slotting the panel structure. The slots may be such that they extend only partly through the panel structure.

**[0015]** Where the suspension is intended for supporting a vibration exciter, the method may further comprise identifying the desired panel location, e.g. an anti-node, for coupling the vibration exciter to drive the panel, and identifying one or more nodal regions adjacent to the drive location in which to position the exciter suspension.

**[0016]** The method may comprise incising the panel material to define cantilevers forming the suspension means. The suspension means may be such as to have at least three cantilevers.

## BRIEF DESCRIPTION OF DRAWINGS

**[0017]** The invention is diagrammatically illustrated, by way of example, in the accompanying drawings, in which:-

Figure 1 is a cross-sectional side view through part of a resonant panel-form loudspeaker and showing a suspension for a vibration exciter;

Figure 2 is an underneath plan view to smaller scale of the resonant loudspeaker panel of Figure 1;

Figure 3 is an underneath plan view of a resonant loudspeaker panel showing three embodiments of vibration exciter suspension;

Figure 4 is a plan view of a panel incorporating a resonant panel-form loudspeaker;

Figure 5 is a scrap plan view, to an enlarged scale, of detail 'A' of Figure 4, and

Figures 6 and 7 are alternative scrap cross-sectional views on the line A-A of Figure 5.

## BEST MODES FOR CARRYING OUT THE INVENTION

**[0018]** In the drawings, and referring more particularly to Figures 1 and 2, there is shown a resonant panel-form loudspeaker 14 e.g. of the general kind described in International patent application WO97/09842 and comprising a resonant generally rectangular flat panel 1 usually of a stiff lightweight material forming an acoustic radiator and an inertial vibration exciter 4 mounted on the panel 1 to induce bending wave vibration in the panel to cause it to resonate to produce an acoustic output. The panel may be of monolithic construction, but as shown comprises a cellular core 2 sandwiched between opposed face skins 3.

**[0019]** The inertial vibration exciter 4 comprises a voice coil/tubular coil former assembly 13 mounted, e. g. by bonding in a circular aperture 12 in the panel 1 whereby the assembly 13 extends from one face of the panel (the upper face as shown in Figure 1) and projects into an annular gap 15 in a magnet assembly 5,6,7 and defined between a disc-like pole piece 7 and a pole cap 6 which together sandwich a disc-like magnet 5.

**[0020]** The assembly comprising the magnet 5 and poles 6 and 7 is mounted on the panel 1 for axial movement relative to the coil/former assembly 13, when the coil is energised with a signal, on a compliant suspension attached to an annular flange 8 projecting from the cup 6 and comprising three equi-spaced rubber-like pads 9, only one of which is visible in Figure 1. In turn the pads 9 are mounted on finger-like cantilevers 10 formed by incising U-shaped slots 11 through the panel and equi-spaced round and concentric with the aperture 12 as best can be seen in Figure 2 in panel regions of low average velocity, such that the inner ends 16 of the cantilevers are free for movement normal to the plane of the panel 1.

**[0021]** The pads 9 are attached near to the free ends 16 of the cantilevers 10. It will be understood that, if desired, the pads 9 might be omitted and the magnet assembly 5,6,7 might instead be mounted directly on the cantilevers 10.

**[0022]** Figure 3 of the drawings show various alternative embodiments of cantilever for suspending a vibration exciter on the panel 1. These include a single straight finger-like cantilever 10 defined by a U-shaped slot or incision 11 of the kind shown in Figures 1 and 2, a curved cantilever 17 defined by a spiral slot 18, and a resilient suspension comprising a cantilever member 19 defined between an opposed pair of arcuate slots 20 and having a central part circular portion 21 and an opposed pair of projections 22 attached at their distal ends to the panel, with the magnet system connected at a central position 23 of the portion 21.

**[0023]** Figures 4 to 7 disclose an embodiment of resonant panel-form loudspeaker 14 of the general kind described above and having a resonant panel 1 forming part of a larger panel 24, which may, for example, be a decorative trim panel in an automobile or the like vehi-

cle. In this embodiment the loudspeaker 14 has a rectangular resonant 5 panel 1 defined within the larger panel 24 by grooves or slots 25, the panel 1 being suspended in the panel 24 by suspension cantilevers 27 defined by opposed parallel slots 26 arranged to bridge the slot 25 in regions round the panel 1 of low average velocity. One cantilever is disposed on each side of the panel 1. The vibration exciter 4 may be suspended as described above or conveniently as desired. As shown in Figure 6, the slot 25 may extend only partly through the panel 1. As shown, the slot 25 extends through the upper skin 3 and through the core 2 of the panel 1 to leave the lower skin intact and covering the slot. Alternatively as shown in Figure 7, the slot 25 may extend completely through the panel 1.

**[0024]** In regard to the application of the present invention to automobile trim panels and the like decorative structures, the slotting may be made at an early stage of manufacture, e.g. with laser or water jet cutting and the slots need only be wide enough to achieve a stable clearance for the vibrating component. In practice a width of 1mm or 2mm may generally be sufficient. The width of the suspension component depends upon the effective cantilever length, the toughness and linear stiffness of the panel in that region and the acceleration forces which the whole assembly might be reasonably required to sustain. Values of about 4 to about 25mm have proved effective for cantilever width.

**[0025]** Another benefit concerns durability in respect of lateral acceleration forces. A relatively narrow slot width allow for a safe grounding of the panel in contrast to surface configurations using adhesive bonding to compliant suspension components. In this later case the suspension may suffer damage due to de-bonding.

**[0026]** Where the acoustic arrangement suggests that separation of the radiation is required between front and rear panel faces, the larger general panel may act as a baffle, generally augmented by local structures such as vehicle door frame or some overall framing and support. In an architectural application the structural panel will be augmented by the design of the room or building. Acoustic leakage via the narrow slots is likely to be negligible between front and back. Such low leakage is also beneficial in respect of stray noise isolation from the back to the front of the panel which may be important in some applications.

**[0027]** In connection with vehicle trim panels a later stage of manufacture concerns the lamination of a lightweight relatively flexible decorative film of cloth on a thin layer of soft open cell polyurethane foam. This structure may be applied over the slots without significant impairment of the operating principle. As regards the user, no witness of the slots is then apparent. Some small further improvement in acoustic isolation may result from the finite acoustic resistance of the foam and cloth covered slots.

INDUSTRIAL APPLICABILITY

**[0028]** The advantages of arrangements as shown in the drawings are as follows, namely:-

1. suspension can use same material as panel, so cost is low;
2. suspension may be located within the panel thickness, or with only a small increase of thickness;
3. a number of such suspension positions can be found either to suspend the panel to the relatively stationary part of a vibration exciter, e.g. a magnet assembly, and/or to suspend the panel to a frame or other support, and,
4. simple cantilever/beam calculations readily provide the desired value of the compliance.

**Claims**

1. A resonant panel-form loudspeaker (14) **characterised by** suspension means located in at least one panel region of low average velocity, the suspension means being created by incising the panel structure to form at least one cantilever member (10,17,19,27) integral with the panel structure.

2. A resonant panel-form loudspeaker according to claim 1, **characterised in that** the incisions comprise a parallel pair of slots (26) through the panel structure.

3. A resonant panel-form loudspeaker according to claim 1 or claim 2, **characterised in that** the suspension means comprises an array of the cantilever members.

4. A resonant panel-form loudspeaker according to claim 1, **characterised in that** the cantilever members (10,17,19,27) are such as to retain stiffness in the plane of the panel (1) and to create compliance in a plane normal to the plane of the panel (1).

5. A resonant panel-form loudspeaker according to any one of the preceding claims, **characterised by** a compliant suspension (9) fixed to the panel (1).

6. A resonant panel-form loudspeaker according to claim 5, **characterised in that** the compliant suspension (9) is fixed to the cantilever member.

7. A resonant panel-form loudspeaker according to any one of the preceding claims, **characterised by** a distributed mode acoustic radiator.

8. A resonant panel-form loudspeaker (14) according to any one of the preceding claims, **characterised in that** the panel (24) comprises an acoustically ac-

tive area (1) and regions of low average velocity surrounding the acoustically active area, and **characterised by** slots (25) or grooves in the panel structure and defining the acoustically active area.

**9.** A resonant panel-form loudspeaker according to claim 8, **characterised in that** the slots (25) or grooves are such that they extend only partly through the panel structure.

**10.** A decorative trim panel **characterised by** a resonant panel-form loudspeaker according to claim 8 or claim 9.

**11.** A vehicle **characterised by** a decorative trim panel as claimed in claim 10.

**12.** A method of making a resonant panel acoustic device, **characterised by** identifying the location of at least one panel region of low average velocity, defining an acoustically active area of the panel by locating said panel region(s) surrounding the acoustically active area, positioning suspension means within the said regions(s) and disrupting the panel structure in the said region(s) to form the suspension means.

**13.** A method according to claim 12, **characterised by** defining the acoustically active area by slotting the panel structure.

**14.** A method according to claim 13, **characterised by** forming the slots (25) such that they extend only partly through the panel structure.

**15.** A method according to any one of claims 12 to 14, **characterised by** incising the panel material to define cantilever members (10,17,19,27) forming the suspension means.

**16.** A method according to any one of claims 12 to 15, **characterised by** forming a vibration exciter suspension means (10,17,19) comprising identifying a desired panel drive location for coupling the vibration exciter (4) to the panel (1) to drive the panel, and identifying one or more regions of low average velocity adjacent to the drive location in which to position the exciter suspension means (10,17,19).

**17.** A method according to any one of claims 12 to 16, **characterised by** forming a suspension means having at least three cantilever members.

**Patentansprüche**

**1.** Resonanzpaneelförmiger Lautsprecher (14), **gekennzeichnet durch** eine Aufhängungseinrichtung, die in mindestens einem Paneelbereich mit einer geringen Durchschnittsgeschwindigkeit angeordnet ist, wobei die Aufhängungseinrichtung **durch** Einschneiden der Paneelstruktur zur Bildung mindestens eines integriert mit der Paneelstruktur ausgebildeten Freiträgerelements (10, 17, 19, 27) hergestellt ist.

**2.** Resonanzpaneelförmiger Lautsprecher nach Anspruch 1, **dadurch gekennzeichnet, dass** die Einschnitte ein paralleles Paar von Schlitzen (26) durch die Paneelstruktur umfassen.

**3.** Resonanzpaneelförmiger Lautsprecher nach Anspruch 1 oder Anspruch 2, **dadurch gekennzeichnet, dass** die Aufhängungseinrichtung ein Array der Freiträgerelemente umfasst.

**4.** Resonanzpaneelförmiger Lautsprecher nach Anspruch 1, **dadurch gekennzeichnet, dass** die Freiträgerelemente (10, 17, 19, 27) so ausgebildet sind, dass sie die Steifigkeit in der Ebene des Paneels (1) erhalten und eine Nachgiebigkeit in einer zur Ebene des Paneels (1) normalen Ebene erzeugen.

**5.** Resonanzpaneelförmiger Lautsprecher nach einem der vorhergehenden Ansprüche, **gekennzeichnet durch** eine an dem Paneel (1) befestigte nachgiebige Aufhängung (9).

**6.** Resonanzpaneelförmiger Lautsprecher nach Anspruch 5, **dadurch gekennzeichnet, dass** die nachgiebige Aufhängung (9) an dem Freiträgerelement befestigt ist.

**7.** Resonanzpaneelförmiger Lautsprecher nach einem der vorhergehenden Ansprüche, **gekennzeichnet durch** einen akustischen Abstrahler mit verteilten Moden.

**8.** Resonanzpaneelförmiger Lautsprecher (14) nach einem der vorangehenden Ansprüche, **dadurch gekennzeichnet, dass** das Paneel (24) einen akustisch aktiven Bereich (1) und den akustisch aktiven Bereich umgebende Bereiche mit einer geringen Durchschnittsgeschwindigkeit umfasst, und **gekennzeichnet durch** Schlitze (25) oder Rillen in der Paneelstruktur, die den akustisch aktiven Bereich festlegen.

**9.** Resonanzpaneelförmiger Lautsprecher nach Anspruch 8, **dadurch gekennzeichnet, dass** die Schlitze (25) oder Rillen so ausgebildet sind, dass sie sich nur

teilweise durch die Paneelstruktur erstrecken.

**10.** Dekorverkleidungspaneel,
**gekennzeichnet durch** einen resonanzpaneelförmigen Lautsprecher nach Anspruch 8 oder Anspruch 9.

**11.** Fahrzeug,
**gekennzeichnet durch** ein Dekorverkleidungspaneel nach Anspruch 10.

**12.** Verfahren zur Herstellung einer akustischen Resonanzpaneeleinrichtung,
**gekennzeichnet durch** Identifizieren der Position mindestens eines Paneelbereichs mit einer geringen Durchschnittsgeschwindigkeit, Festlegen eines akustisch aktiven Bereichs des Paneels **durch** Anordnen dieses Paneelbereichs/dieser Paneelbereiche um den akustisch aktiven Bereich, Positionieren einer Aufhängungseinrichtung in dem/den Bereich(en) und Unterbrechen der Paneelstruktur in diesem/diesen Bereich(en) zur Bildung der Aufhängungseinrichtung.

**13.** Verfahren nach Anspruch 12,
**gekennzeichnet durch** Festlegen des akustisch aktiven Bereichs **durch** Schlitzen der Paneelstruktur.

**14.** Verfahren nach Anspruch 13,
**gekennzeichnet durch** Ausbilden der Schlitze (25) derart, dass sie sich nur teilweise **durch** die Paneelstruktur erstrecken.

**15.** Verfahren nach einem der Ansprüche 12 bis 14,
**gekennzeichnet durch** Einschneiden des Paneelmaterials zur Festlegung von Freiträgerelementen (10, 17, 19, 27), die die Aufhängungseinrichtung bilden.

**16.** Verfahren nach einem der Ansprüche 12 bis 15,
**gekennzeichnet durch** Ausbilden einer Schwingungsanreger-Aufhängungseinrichtung (10, 17, 19) mittels Identifizieren einer gewünschten Paneelantriebsposition zur Kopplung des Schwingungsanregers (4) an das Paneel (1), um das Paneel anzutreiben, und Identifizieren eines Bereichs oder mehrerer Bereiche mit einer geringen Durchschnittsgeschwindigkeit benachbart zu der Antriebsposition, in der die Anreger-Aufhängungs-einrichtung (10, 17, 19) angeordnet werden soll.

**17.** Verfahren nach einem der Ansprüche 12 bis 16,
**gekennzeichnet durch** Ausbilden einer Aufhängungseinrichtung mit mindestens drei Freiträgerelementen.

**Revendications**

**1.** Un haut-parleur en forme de panneau résonnant (14), **caractérisé par** un moyen de suspension placé dans au moins une région de panneau ayant une faible vitesse moyenne, le moyen de suspension étant créé en incisant la structure du panneau pour former au moins un élément en porte-à-faux (10, 17, 19, 27) intégré à la structure du panneau.

**2.** Un haut-parleur en forme de panneau résonnant selon la revendication 1, **caractérisé en ce que** les incisions comprennent une paire de fentes (26) traversant la structure du panneau.

**3.** Un haut-parleur en forme de panneau résonnant selon la revendication 1 ou la revendication 2, **caractérisé en ce que** le moyen de suspension comprend un réseau d'éléments en porte-à-faux.

**4.** Un haut-parleur en forme de panneau résonnant selon la revendication 1, **caractérisé en ce que** les éléments en porte-à-faux (10, 17, 19, 27) sont conçus pour conserver une rigidité dans le plan du panneau (1) et pour créer une souplesse dans un plan normal au plan du panneau (1).

**5.** Un haut-parleur en forme de panneau résonnant selon l'une quelconque des revendications précédentes, **caractérisé par** une suspension souple (9) fixée au panneau (1).

**6.** Un haut-parleur en forme de panneau résonnant selon la revendication 5, **caractérisé en ce que** la suspension souple (9) est fixée à l'élément en porte-à-faux.

**7.** Un haut-parleur en forme de panneau résonnant selon l'une quelconque des revendications précédentes, **caractérisé par** un radiateur acoustique à mode réparti.

**8.** Un haut-parleur en forme de panneau résonnant (14) selon l'une quelconque des revendications précédentes, **caractérisé en ce que** le panneau (24) comprend une zone active au point de vue acoustique (1) et des régions de faible vitesse moyenne entourant la zone active au point de vue acoustique, et **caractérisé par** des fentes (25) ou des rainures formées dans la structure du panneau et définissant la zone active au point de vue acoustique.

**9.** Un haut-parleur en forme de panneau résonnant selon la revendication 8, **caractérisé en ce que** les fentes (25) ou les rainures sont telles qu'elles s'étendent seulement partiellement à travers la structure du panneau.

**10.** Un panneau de garniture décoratif **caractérisé par** un haut-parleur en forme de panneau résonnant selon la revendication 8 ou la revendication 9.

**11.** Un véhicule **caractérisé par** un panneau de garniture décoratif selon la revendication 10.

**12.** Un procédé de fabrication d'un dispositif acoustique à panneau résonnant, **caractérisé en ce qu'**on identifie l'emplacement d'au moins une région de panneau ayant une faible vitesse moyenne, on définit une zone du panneau active au point de vue acoustique en plaçant ladite ou lesdites régions du panneau de façon qu'elles entourent la zone active au point de vue acoustique, on positionne un moyen de suspension à l'intérieur de ladite ou desdites régions, et on introduit une discontinuité dans la structure du panneau dans ladite ou lesdites régions pour former le moyen de suspension.

**13.** Un procédé selon la revendication 12, **caractérisé en ce qu'**on définit la zone active au point de vue acoustique en formant des fentes dans la structure du panneau.

**14.** Un procédé selon la revendication 13, **caractérisé en ce qu'**on forme les fentes (25) de façon qu'elles s'étendent seulement partiellement à travers la structure du panneau.

**15.** Un procédé selon l'une quelconque des revendications 12 à 14, **caractérisé en ce qu'**on incise le matériau du panneau pour définir des éléments en porte-à-faux (10, 17, 19, 27) formant le moyen de suspension.

**16.** Un procédé selon l'une quelconque des revendications 12 à 15, **caractérisé en ce qu'**on forme un moyen de suspension d'excitateur de vibration (10, 17, 19) en identifiant un emplacement d'excitation de panneau désiré pour coupler l'excitateur de vibration (4) au panneau (1) pour exciter le panneau, et on identifie une ou plusieurs régions ayant une faible vitesse moyenne, adjacentes à l'emplacement d'excitation, pour positionner le moyen de suspension d'excitateur (10, 17, 19).

**17.** Un procédé selon l'une quelconque des revendications 12 à 16, **caractérisé en ce qu'**on forme un moyen de suspension ayant au moins trois éléments en porte-à-faux.

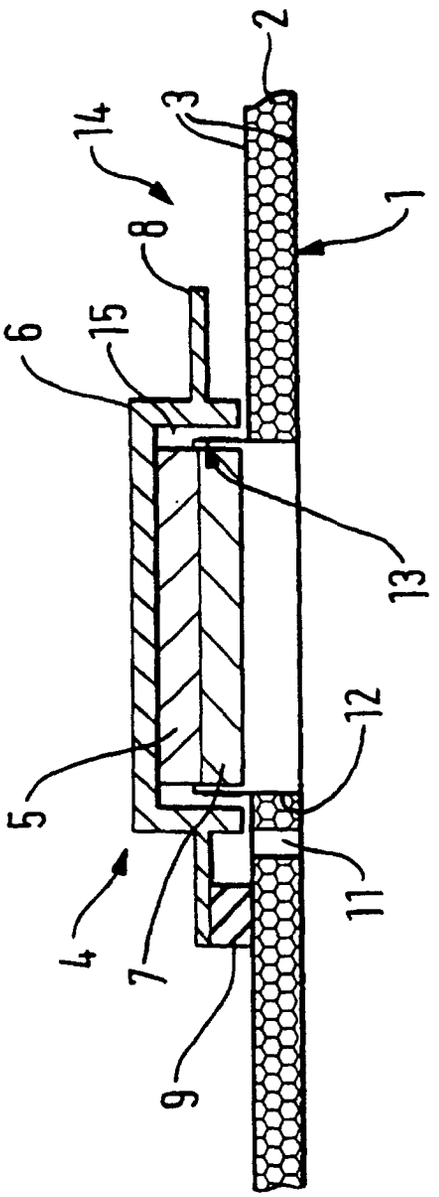


FIG. 1

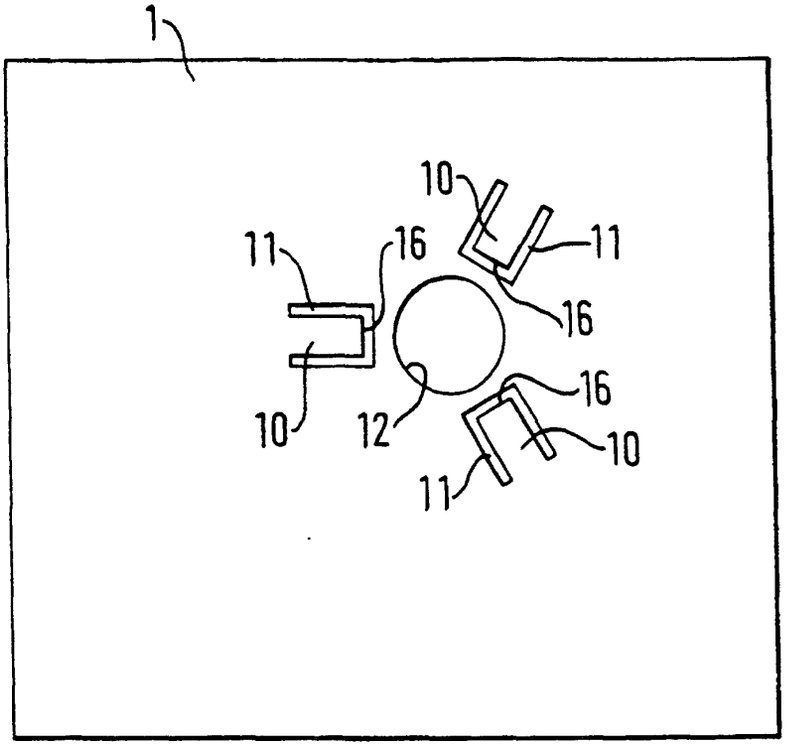


FIG. 2

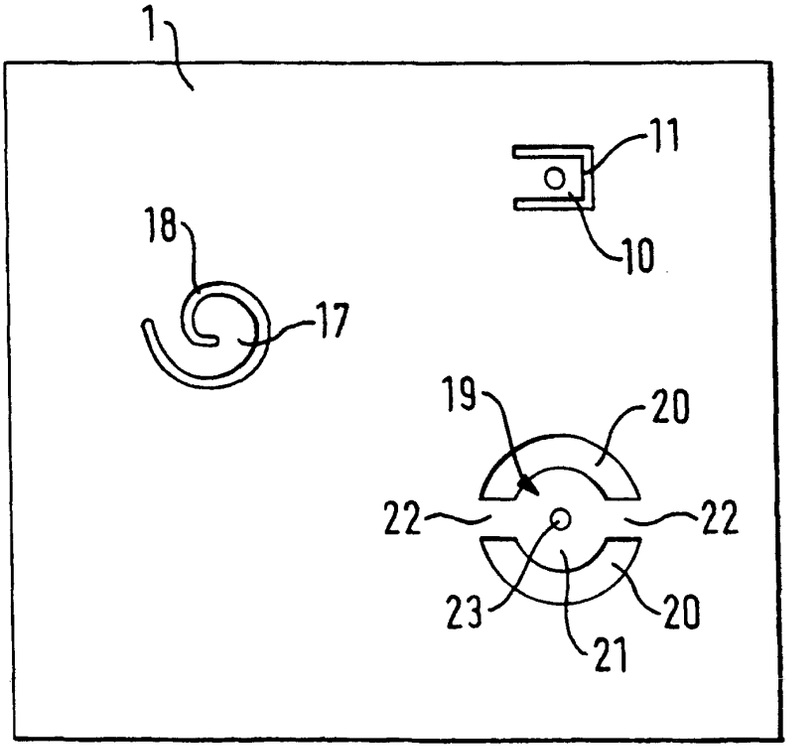


FIG. 3

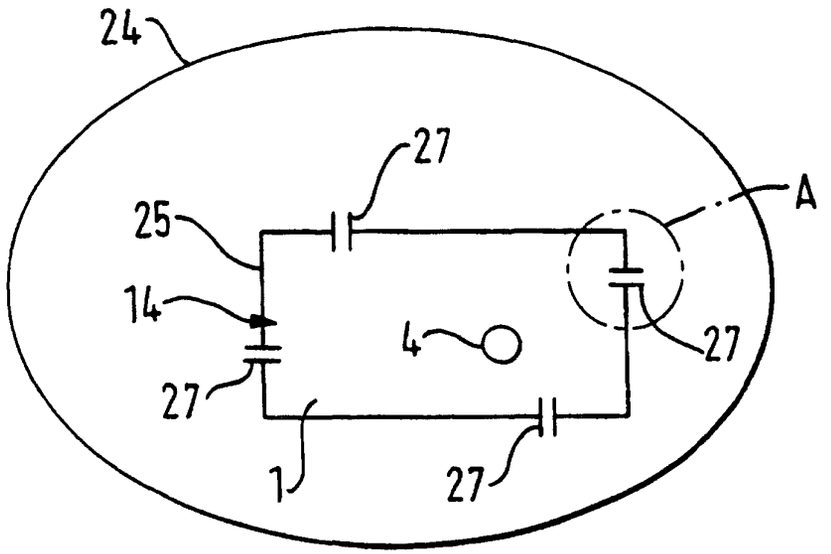


FIG. 4

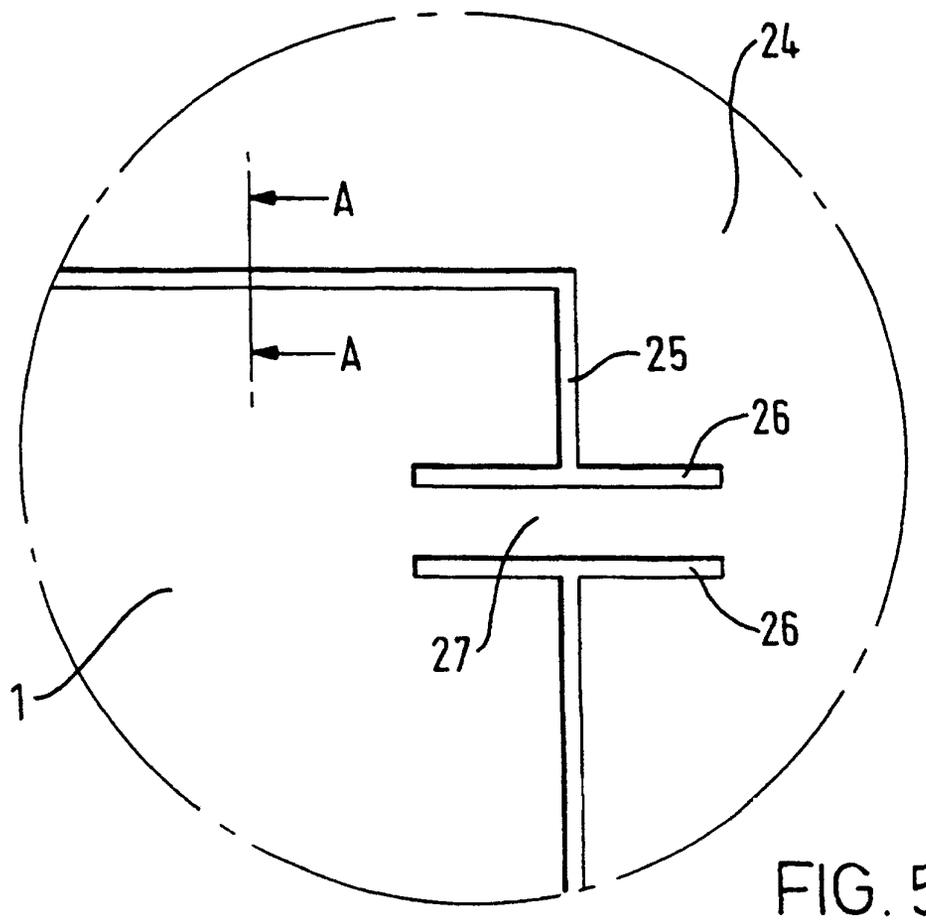


FIG. 5

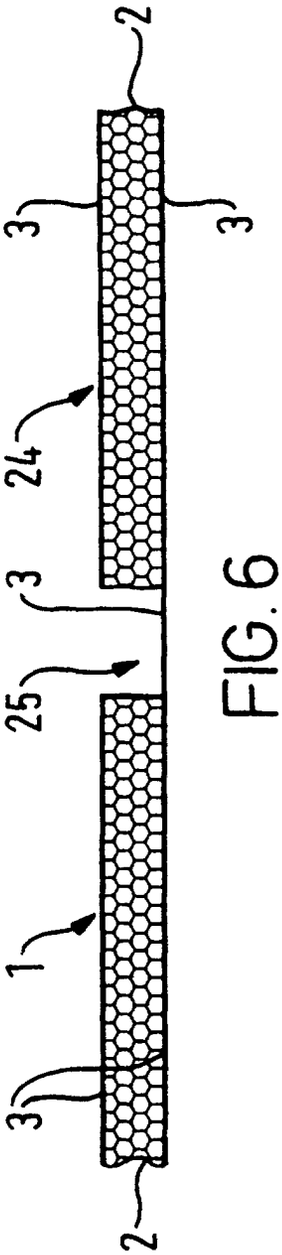


FIG. 6

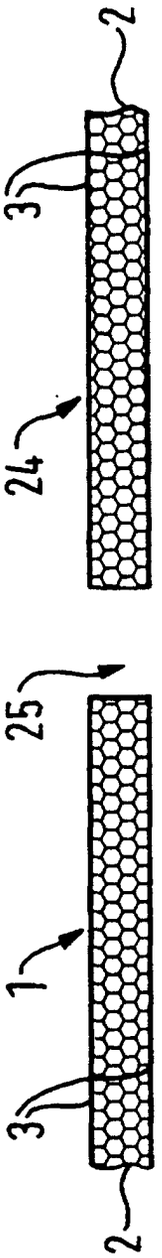


FIG. 7