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(56) References cited:
WO-A-92/03024 **WO-A-97/09842**
US-A- 3 247 925 **US-A- 3 347 335**

- **PATENT ABSTRACTS OF JAPAN vol. 010, no. 228 (E-426), 8 August 1986 (1986-08-08) & JP 61 061598 A (MATSUSHITA ELECTRIC IND CO LTD), 29 March 1986 (1986-03-29)**

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Description

FIELD OF THE INVENTION

[0001] This invention relates to active acoustic devices and more particularly to panel members for which acoustic action or performance relies on beneficial distribution of resonant modes of bending wave action in such a panel member and related surface vibration; and to methods of improving such active acoustic devices.

[0002] It is convenient herein to use the term "distributed mode" for such acoustic devices, including acoustic radiators or loudspeakers; and for the term "panel-form" to be taken as inferring such distributed mode action in a panel member unless the context does not permit.

[0003] In or as panel-form loudspeakers, such panel members operate as distributed mode acoustic radiators relying on bending wave action induced by input means applying mechanical action to the panel member; and resulting excitation of resonant modes of bending wave action causing surface vibration for acoustic output by coupling to ambient fluid, typically air. Revelatory teaching regarding such acoustic radiators (amongst a wider class of active and passive distributed mode acoustic devices) is given in our International patent application WO97/09842; and various of our later patent applications concern useful additions and developments.

BACKGROUND TO THE INVENTION

[0004] Hitherto, transducer locations have been considered as viably and optimally effective at locations in-board of the panel member to a substantial extent towards but offset from its centre, at least for panels that are substantially isotropic as to bending stiffness and exhibit effectively substantially constant axial anisotropy of bending stiffness(es). Aforementioned WO97/09842 gives specific guidance in terms of optimal proportionate co-ordinates for such in-board transducer locations, including alternatives; and preference for different particular co-ordinate combinations when using two or more transducers.

[0005] Various advantageous applications peculiar to the panel-form of acoustic devices have been foreshadowed, including carrying acoustically non-intrusive surfacing sheets or layers. For example, physically merging or incorporating into trim or cladding is feasible, including as visually virtually indistinguishable. Also, functional combination is feasible with other purposes, such as display, including pictures, posters, write-on/erase boards, projection screens, etc. The capability effectively to hide in-board transducers from view is enough for many applications. However, there are potential practical applications where it could be useful to leave larger, particularly central, panel regions unobstructed even by hideable transducers. For example, for video or other see-through display use, pursuit of translucence, even transparency, of panel members is not worthwhile with such in-board intrusions of transducers, though a panel-form acoustic device would be highly attractive if it could afford large medial areas of unobstructed visibility.

SUMMARY OF THE INVENTION

[0006] According to one device aspect of this invention, there is provided a distributed mode active acoustic device according to claim 1.

[0007] According to a second device aspect of this invention, there is provided a distributed mode active acoustic device according to claim 2.

[0008] According to one method aspect of this invention, there is provided a method of improving the acoustic operation of a distributed mode active acoustic device as set out in claim 13.

[0009] According to a second method aspect of this invention, there is a method according to claim 14.

[0010] From the relevant background teaching as of the time of this invention, availability of successful such marginal locations is, to say the least, unexpected. Indeed, main closest prior art cited against WO97/09842, is the start-point for its invention and revelatory teaching, namely WO92/03024 from which progress was made particularly in terms of departing from in-corner excitation thereof. Such progress involved appreciating that distributed resonant mode bending wave action as required for viable acoustic performance results in high vibrational activity at panel corners; as is also a factor for panel edges generally. At least intuitively, and as greatly reinforced by practical success with somewhat off-centre but very much in-board transducer locations, such high vibrational activity compounds strongly with panel margins self-evidently affording limited access, thus likely available effect upon, panel member material as a whole; this compounding combination contributing to previously perceived non-viability of edge excitation.

[0011] For application of this invention, a suitable acoustic panel member, or at least region thereof, may be transparent or translucent. Typical panel members may be generally polygonal often substantially rectangular. The transducer may be piezo-electric, electrostatic or electro-mechanical. The transducer may be arranged to launch compression waves into the panel edge, and/or to deflect the panel edge laterally to launch transverse bending waves along a panel edge, and/or to apply torsion across a panel corner, and/or to produce linear deflection of a local region of the panel.

[0012] Assessment of acoustic output from panel members may be relative to suitable criteria for acoustic output include as to amount of power output thus efficiency in converting input mechanical vibration (automatically also customary causative electrical drive) into acoustic output, smoothness of power output as measure of even-ness of excitation of resonant mode of bending wave action, inspection of power output as to frequencies of excited resonant modes including number and distribution or spread of those frequencies, each up to all as useful indicators. Such assessments of viability of locations for transducer means constitute method aspects of this invention individually and in combination.

[0013] As aid to assessment at least of smoothness of power output, it is further proposed herein to use techniques based on mean square deviation from some reference. Use of the inverse of mean square deviation has the benefit of presenting smoothness for assessment according directly to positive values and/or representations. A suitable reference can be individual to each case considered, say a median-based, such as represented graphically by a smoothed line through actual measured power output over a frequency range of interest. It is significantly helpful to mean square deviation assessment for the reference to have a normalised standard format; and for the measured acoustic power output to be adjusted to fit that standard format. The standard format may be a graphically straight line, preferably a flat straight line thus corresponding to some particular constant reference value; further preferably the same line or value as found naturally to apply to a distributed mode panel member at higher frequencies where modes and modal action are more or most dense.

[0014] In this connection it is seen as noteworthy that whatever function is required for such normalising to a substantially constant reference is effectively also a basis for an equalisation function applicable to input signals to improve lower frequency acoustic output. It is the case that viable distributed mode panel members as such, and with preferential aspect ratios and bending stiffness(es) as in our above patent application, may naturally have acoustic power output characteristics relative to frequency that show progressive droops towards and through lower frequencies where resonant modes and modal action are less dense - but, as their frequency distribution as such is usually beneficial to acoustic action in such lower frequency range, such equalisation of input signal can be useful. This lower acoustic power output at lower frequencies is related to free edge vibration of the panel members as such, and consequential greater loss of lower frequency power, greater proportion of which tends to be poorly radiated and/or dissipated, including effectively short-circuited about free adjacent panel edges. As expected, these lower frequency power loss effects are significantly greater for panel members with transducer locations at or near their edges and/or lesser stiffnesses - compared with panel members using in-board transducer locations. However, and separately from any input signal equalisation, significant mitigation of these effects is available by mounting the panel members surrounded by baffles and/or by clamping at the edges of the panel members. Indeed, spaced localised edge clamps can have usefully selectively beneficial effects relative to frequencies with wavelengths greater than the spacing of the localised edge clamps.

[0015] The inventive aspect regarding corner or near-corner excitation involves suitably mass-loading or clamping substantially at a known in-board optimal or preferential drive location, where it appears that such mass-loaded optimal drive location(s) effectively behave(s) to some useful extent as "virtual" source(s) of bending wave vibrations in the member. This latter may not avoid central intrusion by the mass loading but is clearly germane to successful marginal excitation at corners.

[0016] Further investigations have been made, including of panel members having different stiffnesses, specifically again quite high but also much lower and intermediate stiffness panels, in each case of usual substantially rectangular configuration with aspect ratios and axial bending stiffnesses generally as in WO97/09842.

[0017] It appears that the resonant modal distribution of the panel is affected and altered by the transducer location, at least to some extent going with such location. Higher panel stiffnesses substantially avoid such effects. However, such in-transducer compliance and possible interaction with panel stiffness/elasticity is clearly another factor to be taken into account, including exploited usefully.

[0018] Investigations of panel members with quite high and much lower stiffnesses clearly reveal rather different cases for application of marginal excitation, including as to more and less criticality as to transducer locations, and as to less or more interaction with in-transducer compliance. It is thus appropriate to consider a panel member of intermediate stiffness.

[0019] For such intermediate stiffness panel member, and much as expected, differences relative to the much lower stiffness panel member include increase in acoustic power output available by edge clamping, markedly increased power for mid-range frequency modes, and stronger modality or peakiness for lower-frequency modes.

[0020] It is evident that differences in materials parameters of panel members beyond basic capability to sustain bending wave action are significant in determining marginal transducer locations.

[0021] At least specifically for tested substantially rectangular panel members, it has been found that many if not most, probably going on all, of edge or near-edge locations for transducer means that are unpromising as such can be significantly improved (as to bending wave dependent resonant mode distribution and excitement into acoustical response of the member) if associated with localised mass-loading or clamping at one or more selected other marginal position (s) of the panel member concerned. Inventive aspects thus includes association of a said drive means position with helpful other mass-loading or clamping position marginal of the panel member.

[0022] Use of localised marginal damping for improving performance for any given transducer marginal location is investigatable and assessable to any extent and number using the teaching hereof, whether for enhancing or reducing contributions of some resonant mode(s), otherwise deliberately interfering with other resonant mode(s), or mainly to increase output power.

[0023] It believed to be worthwhile generally to take into account the fact that lowest resonant modes are related to length of the longest natural axis of any panel member.

[0024] Also relevant as a general matter is the fact that the operating frequency range of interest should be made part of assessment of location for transducer means , i.e. could be different for ranges wholly above and extending below such as 500 Hz. Another influencing factor could be presence of an adjacent surface, say behind the panel member at a spacing affecting acoustic performance.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Specific implementation for the invention is now diagrammatically illustrated and described in and with reference to by way of example, in the accompanying drawings, in which:-

Figure 1 shows a distributed mode acoustic panel with a fitted transducer as generally described in the above PCT application;
Figure 2 shows outline indication of four different ways of marginal or edge excitation an acoustic panel;
Figure 3 shows possible placements of transducers marginally of an acoustic panel to achieve actions shown in Figure 2, and Figure 3A shows transparent such panel;
Figure 4 shows corner drive position and helpful mass-loading at an in-board preferential drive location;
Figures 5 and 5A show four normally unfavoured marginal drive transducer locations together with many marginal mass-loading or clamping positions and how test masses and drive transducers were associated with the panel; and
Figure 6 shows in-board area unobstructed within marginal positions for drive transducer(s), clamp termination(s) and resilient suspension/mounting
Figures 7A, B are bar charts for power assessment without normalisation for the low stiffness panel member with three edge clamping of seven-point and full edge nature, respectively, and for position of another local clamp along the other edge at which transducer means has an unfavourable position;
Figure 8 indicates seven- and thirteen- point localised clamping as applied above, and
Figure 9 is a schematic diagram useful in explaining impact of in-transducer compliance.

DESCRIPTION OF ILLUSTRATED EMBODIMENTS

[0026] In Figure 1, distributed mode acoustic panel loud-speaker 10 is as described in WO97/09842 with panel member 11 having typical optimal near- (but off-) centre location for drive means transducer 12. The sandwich structure shown with core 14 and skins 15, 16 is exemplary only, there being many monolithic and/or reinforced and other structural possibilities. In any event, normal in-board transducer placement potentially limits clear area available, e.g. for such as transmission of light in the case of a transparent or translucent panel.

[0027] Mainly transparent or translucent resonant mode acoustic panel members might use known transparent piezoelectric transducers, e.g. of lanthanum doped titanium zirconate. However these are relatively costly, hence the alternative approach thereof by which it is possible to leave the resonant mode acoustic panel member 10 mainly clear and unobstructed by optimising loudspeaker design from a choice of four types of excitation shown in Figure 2 directed to the margins or perimeter of the panel, and labelled as types T1 - T4, as follows:-

T1 - launching compression waves into an edge (shown along 18A) of the panel member 11 - as available by inertial action or reference plane related drive transducers
T2 - launching transverse bending waves along an edge (also shown along 18A) of the panel member 11 - as available by laterally deflecting the panel edge using bender action drive transducers
T3 - applying torsion to the panel member 11 as shown across a corner between edges 18A, B - available by action of either of bender or inertial type drive transducers
T4 - producing linear deflection directly at an edge of the panel member 11 as shown at edge 18B - available at local region of contact by inertial action drive transducers.

[0028] Figure 3 is a scrap view of composite panel 11 showing high tensile skins 15, 16 and structural core 14 with drive transducers/exciters 31 - 34 for the above-mentioned four types T1 - T4 of edge/marginal drive. An optimised panel may be driven by any one of the different drive types.

[0029] A transparent or translucent edge-driven acoustic panel could be monolithic, e.g. of glass, or of skinned core structure using suitable translucent/transparent core and skin materials. Interpretation with a a visual display unit (VDU) may enable the screen also to be used as a loudspeaker, can have suitably high bending stiffness along with low mass if comprising a pair of skins 15A, 16A sandwiching a lightweight core of aerogel material 14A using transparent adhesive 15B, 16B. Aerogel materials are extremely light porous solid materials, say of silica. Transparent or translucent skin or skins may be of laminated structure and/or made from transparent plastics material such a polyester, or from glass. Conventional transparent VDU screens may be replaced by such a transparent acoustic radiator panel, including with acoustic excitation outside unobstructed main screen area.

[0030] A particular suitable silica aerogel core material is (RTM) BASOGEL from BASF. Other feasible core materials could include less familiar aerogel-forming materials including metal oxides such as iron and tin oxide, organic polymers, natural gels, and carbon aerogels. A particular suitable plastics skin laminates may be of polyethylene terephthalate (RTM) MYLAR, or other transparent materials with the correct thickness, modulus and density. Very high shear modulus of aerogels allow extremely thin composites to be made to suit miniaturisation and other physically important factors and working under distributed mode acoustic principles.

[0031] If desired, such transparent panel could be added to an existing VDU panel, say incorporated as an integral front plate. For a plasma type display the interior is held at low gas pressure, close to vacuum, and is of very low acoustic impedance. Consequently there will be negligible acoustic interaction behind the sound radiator, resulting in improved performance, and the saving of the usual front plate. For film type display technologies, again the front transparent window may be built using a distributed mode radiator while the display structures behind may be dimensioned and specified to include acoustic properties which aid the radiation of sound from the front panel. For example partial acoustic transparency for the rear display structures will reduce back wave reflection and improve performance for the distributed mode speaker element. In the case of the light emitting class of display, these may be deposited on the rear surface of the transparent distributed mode panel, without significant impediment to its acoustic properties, the images being viewed from the front side.

[0032] A transparent distributed mode loudspeaker may also have application for rear projection systems where it may be additional to a translucent screen or this function may itself be incorporated with a suitably prepared surface for rear projection. In this case the projection surface and the screen may be one component both for convenience and economy but also for optimising acoustic performance. The rear skin may be selected to take a projected image, or alternatively, the optical properties of the core may be chosen for projection use. For example in the case of a loudspeaker panel having a relatively thin core, full optical transparency may not be required or be ideal, allowing the choice of alternative light transmitting cores, e.g. other grades of aerogel or more economical substitutes. Special optical properties may be combined with the core and/or the skin surface to generate directional and brightness enhancing properties for the transmitted optical images.

[0033] Where the transparent distributed mode speaker has an exposed front face it may be enhanced, for example, by the provision of conductive pads or regions, visible, or transparent, for user input of data or commands to the screen. The transparent panel may also be enhanced by optical coatings to reduce reflections and/or improve scratch resistance, or simply by anti scratch coatings. The core and skin for the transparent panel may be selected to have an optical tint, for colour shading or in a neutral hue to improve the visual contrast ratios for the display used with or incorporated in the distributed mode transparent panel speaker. During manufacture of the transparent distributed model panel, invisible wiring, e.g. in the form of micro-wires, or transparent conductive films, may be incorporated together with indicators, e.g. light emitting diodes (LED) or liquid crystal displays (LCD) or similar, allowing their integration into the transparent panel and consequent protection, the technique also minimising impairment to the acoustic performance. Designs may also be produced where total transparency is not required, e.g. where one skin only of the panel has transparency to provide a view to an integral display under that surface.

[0034] The transducer may be piezo-electric or electrodynamic according to design criteria including price and performance considerations, and are represented in Figure 3 as simple outline elements simply bonded to the panel by suitable adhesive(s). For above T1 type drive excitation, inertial transducer 31 is shown driving vertically directed compression waves into the panel 30. For above T2 type of drive excitation, bending type of transducer 32 is shown operative for directly bending regionally to launch bending waves through the loudspeaker panel 30. For above T3 type of drive excitation, inertial transducer 33 is shown serving to deflect the panel corner in driving into the diagonal and thence into the whole loudspeaker panel 30. For above type T4 drive excitation another inertial transducer 34 is shown of block or semi-circular form serving to deflect an edge of the loudspeaker panel 30.

[0035] Each type of excitation will engender its own characteristic drive to the panel 30 which is accounted for in the overall loudspeaker design including parameters of the panel 30 itself. It is envisaged that, according to the panel characteristics, including such as controlled loss for example and the location and type of marginal edge or near-edge drive, more than one audio channel may be applied to the panel 30 concerned . This multi-channel potential may be augmented by signal processing to optimise the sound quality, and/or to control the sound radiation properties and/or even to modify the perceived channel-to-channel separation and spatial effects.

[0036] Figure 4 shows a panel 70 of core 74 and skins 75, 76 structure, and having near-corner-mounted transducer

72 with mass loading 78 substantially at an otherwise normal in-board preferential transducer, actually the one or in the group furthest away from the corner of excitation by the transducer 72, which is found to be particularly effective in appearing to behave as a "virtual" source of bending wave vibrations. It can be advantageous for the transducer to avoid or at least couple outside a position with a co-ordinate location substantially centred at 5% of side dimensions from the corner as such, where it has been established that many resonant mode(s) have nodes, i.e. low vibrational activity.

[0037] Turning to Figure 5, outline is indicated for an investigation involving select single positions for one edge or edge-adjacent transducer mounting, see at ST1 - ST4 for in-corner, half-side length, quarter-side length and three-eighths side-length, respectively; and select positions for edge-clamping/mass-loading at edge positions about the panel. An exciting transducer was used, see 92 in Figure 5A relative to panel 90, along with loads/clamps by way of panel flanking/gripping 93A/B magnets.

[0038] Performance using the corner exciting transducer position ST1 was aided by mass-loading as in Figure 5A at positions Pos. 13, 14, 18, 19 - including in further combination with other positions. For exciting transducer position ST2, good single mass-loading positions are Pos. 6, 7, 8 perhaps 9, 11 particularly, 12, 15 - again including combinations with other positions. Combinations 5 = 11 and 6 + 11 were of particular value, including in further combinations. For exciting transducer position ST3, good single mass-loading positions are Pos. 5, 6, 7, 13, especially the combinations 5 + 13 and 10 + 13, the combination 6 + 18, and combinations/further combinations. For exciting transducer position ST4, best positions appear to be 6, 18 but neither was as good as those for the other exciter positions ST1 - ST3.

[0039] Figure 6 shows a panel-form loudspeaker 80 having an in-board unobstructed region 81 extending throughout and beyond normal in-board preferential drive transducer locations, and a marginally located transducer 82. The region 81 may serve for display purposes directly, or represent something carried by the panel 80 without affecting acoustic performance, or something behind which the loudspeaker panel 80 passes, say in close spacing and/or transparent or translucent. Both of loudness and quality are readily enhanced, the former by additional drive transducers judiciously placed (not shown), and quality by localised edge clamping(s) 83 beneficially to control particular modal vibration points effectively as panel termination(s). The panel 80 is further indicated with localised resilient suspensions 84 located neutrally or even beneficially regarding achieved acoustic performance. High pass filtering 85 is preferred for input signals to drive transducer(s) 82, conveniently to limit to range of best reproduction, say not below 100Hz for A4-size or similar panels. Then, there should not be any problematic low-frequency panel/exciter vibration.

[0040] It is advantageous in terms for acoustic performance to control acoustic impedance loading on the panel 80, say to be relatively low in the marginal or peripheral region, especially in the vicinity of the drive transducer(s) 82 where surface velocity tends to be high. Beneficial such control provision includes significant clearance to local planar members (say about 1 - 3 centimetre) and/or slots or other apertures in adjacent peripheral framing or support provision or grille elements.

[0041] It is further feasible and advantageous deliberately to arrange for such as mechanical damping to result in acoustic modification including loss in the area 81, or even also marginally thereof, not to be obstructed, at least for higher frequencies. This may be done by choice of materials, e.g. monolithic polycarbonate or acrylic and/or suitable surface coating or laminated construction. Resulting effective concentration of acoustic radiation to marginal regions about plural drive transducers particularly facilitates reproduction of more than one sound channel, at least for near-field listening as for playing computer games or like localised virtual sound stage applications. Further away, merging even of multiple as-energised sound sources need not be problematic when summed, at least for such as audio visual presentations.

[0042] The following Table gives relevant physical parameters of actual panel members used for investigation to which Figures 7A,B relate.

	Lower Stiffness Panel	Higher Stiffness Panel	Intermediate Stiffness panel
Core material	Rohacell	Al honeycomb	Rohacell
Core thickness	1.5mm	4mm	1.8mm
Skin material	Melinex	Black glass	Black glass
Skin thickness	50 μm	102 μm	102 μm
Panel Area	0.06m2	0.06m2	0.06m2
Aspect ratio	1:1.13	1:1.13	1:1.13
Bending stiffness	0.32 Nm	12.26 Nm	2.47 Nm
Mass density	0.35 kgm-2	0.76 kgm-2	0.6 kgm-2
Zm	2.7 Nsm-1	24.4 Nsm-1	9.73 Nsm-1

[0043] A higher stiffness panel member is shown in the second column, Figures 7A, B relate to the much lower stiffness panel member of the first column, and an intermediate stiffness panel member is shown in the third column.

[0044] All of the graphs have acoustic output power (dB/W) as ordinate and frequency as abscissa, thus show measured acoustic output power as a formation of frequency, typically as a truly plotted dotted line. Most of the graphs also show an upper adjustment of the true power line. As mentioned in the preamble, this adjustment is by way of applying functions that normalise to a flat straight line, and allows assessment of resonant modality free of often encountered effects of fall-off of power at lower frequencies. It is found that smoothness of power makes significant contribution to quality of sound. From such normalised value of the actual power output, it is advantageous to produce assessment of smoothness by inverse of mean square deviation, and most of the bar plots are of that type.

[0045] In the main, it is believed that the illustrated graph and bar charts are substantially self-explanatory as to showing localised clamping as feasible for improving less promising transducer locations. 7-point local edge clamping at corners and mid-points is shown as at 'X' in Figure 8. 13-point clamping is shown as at 'X' + 'O' in Figure 8.

[0046] An application for localised edge clamping is in relation to improving an unpromising transducer edge location, see bar charts Figures 7A, B showing right hand rather than left hand sides of the edge concerned as otherwise in the drawings. The cases concerned relate to the lower stiffness panel member, and are full clamping of three edges and seven point clamping, with a localised clamp varied along the same edge as the transducer means. In both cases, useful improvement results at about the quarter length position from the corner more remote from the exciter - see reference bar at right hand side of Figure 7B for no clamping condition. The spread is greater for the full edge clamping case, see Figure 7A.

[0047] Where there is disagreement between assessments based on power efficiency and power smoothness, it is worth bearing in mind that any panel member with clamping of corners to the edge with which the transducer is associated effectively has forced nulls at the corner. There thus must be up to half wavelengths distance for resonant modes concerned before vibrational activity can reach anti-nodal peaks. If preference for a close-to-corner transducer location is indicated by power smoothness assessment, it should be treated with caution as it could be of low power/efficiency, even though smooth by reason of coupling to all resonant mode waveform concerned at may be quite small rises in their waveforms. Checking with the corresponding power/efficiency assessment is thus recommended. Indeed, best is always likely to be where there is substantial agreement between the two bases of assessment, or some compromise particularly suited to a specific application; and preferably further taking account of skilled inspection of power/frequency graphs perhaps advantageously with as well as without any normalisation for assessment purposes.

[0048] Reverting to the case of the much less stiff panel member, two effects are seen as contributing to much less well-defined best/near best exciter position. One is that the panel modes for the range of frequencies of the optimisation are higher than for stiffer panel members. The panel member is therefore a closer approximation to a continuum, and smoothness of output power is less dependent on transducer position, particularly second transducer positions.

[0049] The other effect concerns the much lower mechanical impedance of the panel member, which leads to a less strong dependence on transducer position for energy transfer. The mechanism involved is now explained.

[0050] The mechanical impedance (Zm) of a panel member determines the movement resulting for an applied point force, see 100, 101 in Figure 9. An object associated with the panel with a mechanical impedance put very much less than, even approaching comparable to, the panel impedance will strongly offset panel motion where the object is located. Associating an exciting transducer of moving coil type with the panel is equivalent to connecting the panel to a grounded mass (the magnet cup of the transducer, see 102) via a spring (the voice coil suspension of the transducer, see 108). When the impedance of such spring is too close to the panel impedance, it will in some part determine the panel motion at the transducer. In the limit of this spring wholly determining the point motion at the transducer, there would be no dependence of input power on exciter position.

[0051] In practice the ratio of spring impedance to panel impedance can so profoundly affect best transducer location, and results are no longer so clear for best/near best transducer locations.

[0052] This low mechanical impedance has more effect for edge transducer location than for in-board transducer location as mechanical impedance is yet lower at the panel edge, which means that a transducer, voice coil suspension has a larger effect. Specifically, for the lower stiffness panel of the above Table:

mechanical impedance in the body of the panel is
Zmbody=2.7 Nsm-1
mechanical impedance at the panel edge is approximately half Zmbody, i.e.
Zmedge=1.3 Nsm-1
Compliance of the voice coil suspension of the transducer used is:
Cms=0.52x10-3 mN-1

[0053] The mechanical impedance at each of modal frequencies can be an order of magnitude lower than the average impedance, Zmedge. It is therefore feasible to estimate a typical frequency, below which the exciter has a strong effect on the panel member, say where impedance of the voice coil suspension is about one-fifth of the average impedance at the panel edge. Then,

$$\frac{1}{\omega \times Cms} = \frac{1}{5} \times Zmedge$$

and gives an estimate of 1200 Hz, below which the transducer and panel are intendedly coupled, which is within the frequency range of optimisation.

[0054] Considering the transducer and such low mechanical impedance, panel member as one coupled system the transducer in part determines the impedance of the panel member, and smoothness of the output power is less dependent on the position of the transducer.

[0055] Repeating such analysis for the high stiffness panel gives a corresponding frequency of 130Hz, which is outside the frequency range of the optimisation.

Claims

1. A distributed mode active acoustic device comprising a plural sided panel member (11) and a transducer (31, 32, 33, 34) coupled thereto, the panel member (11) having a distribution of resonant modes of bending wave action determining acoustic performance in conjunction with the transducer (31, 32, 33, 34), **characterised in that** the transducer (31, 32, 33, 34) is located at a first marginal position of the panel member not itself selected for best operative interaction with said panel member, and wherein mass is coupled to the edge of the panel (11) at at least one further discrete position distinct from the first position and chosen to improve acoustic operation of the device in conjunction with the transducer (31, 32, 33, 34).

2. A distributed mode active acoustic device comprising a plural sided panel member (11) and a transducer (31, 32, 33, 34) coupled thereto, the panel member (11) having a distribution of resonant modes of bending wave action determining acoustic performance in conjunction with the transducer (31, 32, 33, 34), **characterised in that** the transducer (31, 32, 33, 34) is located at a first marginal position of the panel member (11) not itself selected for best operative interaction with said panel member, and wherein edge clamping means (83) is coupled to the edge of the panel at at least one further discrete position distinct from the first position and chosen to improve acoustic operation of the device in conjunction with the transducer (31, 32, 33, 34).

3. Active acoustic device according to any preceding claim, further comprising baffle means extending about and beyond said panel member.

4. Active acoustic device according to any preceding claim, wherein said panel member (11) is at least partially transparent or translucent.

5. Active acoustic device according to any preceding claim, wherein said transducer means (31, 32, 33, 34) is of electro-mechanical type.

6. Active acoustic device according to any preceding claim, wherein said transducer means (31, 32, 33, 34) is operative to launch compression waves into edge of said panel member (11) and/or to deflect edge of said panel member (11) laterally to launch transverse bending waves along said panel member (11) and/or to apply torsion across a corner of said panel member and/or to produce linear deflection of a local edge region of said panel member (11).

7. Active acoustic device according to claim 2 or any one of claims 3-6 when dependent on claim 2, wherein said panel member is of rectangular form having adjacent sides of lengths in the ratio 1:1.13; wherein said transducer is located at a marginal position on one of the longer of said sides; and wherein edge clamping means (X) are coupled to the edge of the panel at all four corners of said panel and at mid-points of all three sides of said panel other than said one of the longer of said sides.

8. Active acoustic device according to claim 7, wherein said transducer is located at marginal position approximately one quarter of the way along one of the longer of said sides of the panel.

9. Active acoustic device according to claim 7, wherein further edge clamping means are coupled to said one of the longer of said sides.

10. Active acoustic device according to claim 9, wherein said further edge clamping means is coupled to said one of the longer of said sides at a point approximately one quarter along said side from the corner of said panel more remote from the exciter.

11. Active acoustic device according to claim 7, wherein edge clamping means (O) are further coupled to the edge of the panel at points approximately one quarter and three-quarters along each of all three sides of said panel other than said one of the longer of said sides.

12. Active acoustic device according to claim 11, wherein said transducer is located at marginal position approximately 0.42 of the way along one of the longer of said sides of the panel.

13. Method of improving the acoustic operation of a distributed mode active acoustic device comprising a plural sided panel member (11) and a transducer (31, 32, 33, 34) coupled thereto, the panel member having a distribution of resonant modes of bending wave action determining acoustic performance in conjunction with the transducer (31, 32, 33, 34), **characterised in that** the transducer (31, 32, 33, 34) is located at a first marginal position of the panel member (11) not itself selected for best operative interaction with said panel member and **in that** the method comprises the step of:

coupling mass (93) to the edge of the panel at a further discrete position distinct from the first position and chosen to improve acoustic operation of the device in conjunction with the transducer (31, 32, 33, 34).

14. Method of improving the acoustic operation of a distributed mode active acoustic device comprising a plural sided panel member (11) and a transducer (31, 32, 33, 34) coupled thereto, the panel member (11) having a distribution of resonant modes of bending wave action determining acoustic performance in conjunction with the transducer (31, 32, 33, 34)**characterised in that** the transducer (31, 32, 33, 34) is located at a first marginal position of the panel member (11) not itself selected for best operative interaction with said panel member (11); and **in that** the method comprises the step of:

clamping the edge of the panel at a further discrete position (83) discrete from the first position and chosen to improve acoustic operation of the device in conjunction with the transducer (31, 32, 33, 34).

Patentansprüche

1. Aktive akustische Einrichtung mit verteilten Moden mit einem mehrseitigen Paneelelement (11) sowie einem damit gekoppelten Wandler (31, 32, 33, 34), wobei das Paneelelement (11) eine Resonanzmodenverteilung einer Biegewellenwirkung hat, die in Verbindung mit dem Wandler (31, 32, 33, 34) die akustische Leistung bestimmt, **dadurch gekennzeichnet, dass** der Wandler (31, 32, 33, 34) an einer ersten Randposition des Paneelelements angeordnet ist, die selbst nicht zur besten betrieblichen Wechselwirkung mit dem Paneelelement ausgewählt ist, und dass an mindestens einer weiteren separaten Position, die sich von der ersten Position unterscheidet und so gewählt ist, dass sie den akustischen Betrieb der Einrichtung in Verbindung mit dem Wandler (31, 32, 33, 34) verbessert, eine Masse mit dem Rand des Paneels (11) gekoppelt ist.

2. Aktive akustische Einrichtung mit verteilten Moden mit einem mehrseitigen Paneelelement (11) und einem damit gekoppelten Wandler (31, 32, 33, 34), wobei das Paneelelement (11) eine Resonanzmodenverteilung einer Biegewellenwirkung hat, die in Verbindung mit dem Wandler (31, 32, 33, 34) die akustische Leistung bestimmt, **dadurch gekennzeichnet, dass** der Wandler (31, 32, 33, 34) an einer ersten Randposition des Paneelelements (11) angeordnet ist, die selbst nicht zur besten betrieblichen Wechselwirkung mit dem Paneelelement ausgewählt ist, und dass an mindestens einer weiteren separaten Position, die sich von der ersten Position unterscheidet und so gewählt ist, dass sie den akustischen Betrieb der Einrichtung In Verbindung mit dem Wandler (31, 32, 33, 34) verbessert, eine Randklemmeinrichtung (83) mit dem Rand des Paneels gekoppelt ist.

3. Aktive akustische Einrichtung nach einem der vorhergehenden Ansprüche, die ferner eine Ablenkeinrichtung umfasst, die sich um und über das Paneelelement hinaus erstreckt.

4. Aktive akustische Einrichtung nach einem der vorhergehenden Ansprüche, bei der das Paneelelement (11) zumindest teilweise transparent oder transluzent ist.

5. Aktive akustische Einrichtung nach einem der vorhergehenden Ansprüche, bei der die Wandlereinrichtung (31, 32, 33, 34) vom elektromechanischen Typ ist.

6. Akustische Einrichtung nach einem der vorhergehenden Ansprüche, bei der die Wandlereinrichtung (31, 32, 33, 34) betrieben wird, um Druckwellen in den Rand des Paneelelements (11) einzutragen und/oder um den Rand des Paneelelements (11) seitlich auszulenken, um Transversalbiegewellen entlang des Paneelelements (11) auszulösen und/oder um eine Torsion über eine Ecke des Paneelelements aufzubringen und/oder um eine lineare Auslenkung eines lokalen Randbereichs des Paneelelements (11) zu erzeugen.

7. Aktive akustische Einrichtung nach Anspruch 2 oder einem der Ansprüche 3 bis 6 in ihrer Abhängigkeit von Anspruch 2, bei der das Paneelelement eine rechteckige Form mit benachbarten Seiten mit einem Längenverhältnis von 1: 1,13 aufweist, wobei der Wandler an einer Randposition an einer der längeren Seiten angeordnet ist, und bei der eine Randklemmeinrichtung (X) an allen vler Ecken des Paneels und an Mittelpunkten aller drei Selten des Paneels mit Ausnahme einer der längeren Seiten mit dem Rand des Paneels gekoppelt ist.

8. Aktive akustische Einrichtung nach Anspruch 7, bei der der Wandler an einer Randposition angeordnet ist, die sich bei ungefähr einem Viertel des Weges entlang einer der längeren Seiten des Paneels befindet.

9. Aktive akustische Einrichtung nach Anspruch 7, bei der eine weitere Randklemmeinrichtung mit einer der längeren Seiten gekoppelt ist.

10. Aktive akustische Einrichtung nach Anspruch 9, bei der die weitere Randklemmeinrichtung mit einer der längeren Seiten an einer Stelle gekoppelt ist, die sich bei ungefähr einem Viertel längs der Seite von der Ecke des Paneels befindet, die weiter entfernt von dem Anreger ist.

11. Aktive akustische Einrichtung nach Anspruch 7, bei der eine Randklemmeinrichtung (0) ferner an Stellen mit dem Rand des Paneels gekoppelt ist, die sich bei ungefähr einem Viertel und drei Vierteln entlang jeder der drei Seiten des Paneels mit Ausnahme einer der längeren Seiten befinden.

12. Aktive akustische Einrichtung nach Anspruch 11, bei der der Wandler an einer Randposition bei ungefähr 0,42 des Weges entlang einer der längeren Seiten des Paneels angeordnet ist.

13. Verfahren zur Verbesserung des akustischen Betriebs einer aktiven akustischen Einrichtung mit verteilten Moden, die ein mehrseitiges Paneelelement (11) und einen damit gekoppelten Wandler (31, 32, 33, 34) umfasst, wobei das Paneelelement eine Resonanzmodenverteilung einer Biegewellenwirkung hat, die in Verbindung mit dem Wandler (31, 32, 33, 34) die akustische Leistung bestimmt, **dadurch gekennzeichnet, dass** der Wandler (31, 32, 33, 34) an einer ersten Randposition des Paneelelements (11) angeordnet ist, die selbst nicht zur besten betrieblichen Wechselwirkung mit dem Paneelelement ausgewählt ist, und dass das Verfahren den Schritt umfasst:

- Koppeln einer Masse (93) mit dem Rand des Paneels an einer weiteren separaten Position, die sich von der ersten Position unterscheidet und so gewählt ist, dass sie den akustischen Betrieb der Einrichtung in Verbindung mit dem Wandler (31, 32, 33, 34) verbessert.

14. Verfahren zur Verbesserung des akustischen Betriebs einer aktiven akustischen Einrichtung mit verteilten Moden, die ein mehrseitiges Paneelelement (11) und einen damit gekoppelten Wandler (31, 32, 33, 34) umfasst, wobei das Paneelelement (11) eine Resonanzmodenverteilung einer Biegewellenwirkung hat, die in Verbindung mit dem Wandler (31, 32, 33, 34) die akustische Leistung bestimmt, **dadurch gekennzeichnet, dass** der Wandler (31, 32, 33, 34) an einer ersten Randposition des Paneelelements (11) angeordnet ist, die selbst nicht zur besten betrieblichen Wechselwirkung mit dem Paneelelement (11) ausgewählt ist, und dass das Verfahren den Schritt umfasst:

- Klemmen des Rands des Paneels an einer weiteren separaten Position (83), die separat von der ersten Position und so gewählt ist, dass sie den akustischen Betrieb der Einrichtung in Verbindung mit dem Wandler

(31, 32, 33, 34) verbessert.

Revendications

1. Un dispositif acoustique actif à modes répartis comprenant une structure de panneau (11) à plusieurs côtés et un transducteur (31, 32, 33, 34) qui lui est couplé, la structure de panneau (11) ayant une répartition de modes résonnants d'action d'ondes de flexion déterminant des performances acoustiques conjointement au transducteur (31, 32, 33, 34), **caractérisé en ce que** le transducteur (31, 32, 33, 34) est placé à une première position marginale de la structure de panneau qui n'est pas en elle-même sélectionnée pour la meilleure interaction fonctionnelle avec la structure de panneau, et dans lequel une masse est couplée au bord du panneau (11) à au moins une position discrète supplémentaire distincte de la première position, et choisie pour améliorer le fonctionnement acoustique du dispositif en association avec le transducteur (31, 32, 33, 34).

2. Un dispositif acoustique actif à modes répartis comprenant une structure de panneau (11) à plusieurs côtés et un transducteur (31, 32, 33, 34) qui lui est couplé, la structure de panneau (11) ayant une répartition de modes résonnants d'action d'ondes de flexion déterminant des performances acoustiques conjointement au transducteur (31, 32, 33, 34), **caractérisé en ce que** le transducteur (31, 32, 33, 34) est placé à une première position marginale de la structure de panneau (11) qui n'est pas en elle-même sélectionnée pour la meilleure interaction fonctionnelle avec la structure de panneau, et dans lequel un moyen de blocage de bord (83) est couplé au bord du panneau à au moins une position discrète supplémentaire distincte de la première position et choisie pour améliorer le fonctionnement acoustique du dispositif en association avec le transducteur (31, 32, 33, 34).

3. Dispositif acoustique actif selon l'une quelconque des revendications précédentes, comprenant en outre une structure d'écran acoustique autour et au-delà de ladite structure de panneau.

4. Dispositif acoustique actif selon l'une quelconque des revendications précédentes, dans lequel la structure de panneau (11) est au moins partiellement transparente ou translucide.

5. Dispositif acoustique actif selon l'une quelconque des revendications précédentes, dans lequel le moyen transducteur (31, 32, 33, 34) est du type électromécanique.

6. Dispositif acoustique actif selon l'une quelconque des revendications précédentes, dans lequel le moyen transducteur (31, 32, 33, 34) fonctionne de façon à lancer des ondes de compression dans un bord de la structure de panneau (11) et/ou à dévier latéralement un bord de la structure de panneau (11) pour lancer des ondes de flexion transversales le long de la structure de panneau (11) et/ou à appliquer une torsion à un point de la structure de panneau et/ou à produire une déflexion linéaire d'une région de bord locale de la structure de panneau (11).

7. Dispositif acoustique actif selon la revendication 2 ou l'une quelconque des revendications 3 à 6 lorsqu'elle est rattachée à la revendication 2, dans lequel la structure de panneau a une forme rectangulaire ayant des côtés adjacents dont les longueurs sont dans le rapport 1 : 1,13; dans lequel le transducteur est placé à une position marginale sur un des côtés les plus longs; et dans lequel des moyens de blocage de bord (X) sont couplés au bord du panneau à l'ensemble des quatre coins du panneau et à des points médians de l'ensemble des trois côtés du panneau autres que ledit côté parmi les côtés les plus longs.

8. Dispositif acoustique actif selon la revendication 7, dans lequel le transducteur est placé à une position marginale approximativement à un quart de la distance le long d'un des côtés les plus longs du panneau.

9. Dispositif acoustique actif selon la revendication 7, dans lequel des moyens de blocage de bord supplémentaires sont couplés audit côté parmi les côtés les plus longs.

10. Dispositif acoustique actif selon la revendication 9, dans lequel les moyens de blocage de bord supplémentaires sont couplés audit côté parmi les côtés les plus longs à un point situé approximativement au quart dudit côté à partir du coin du panneau qui est le plus éloigné de l'excitateur.

11. Dispositif acoustique actif selon la revendication 7, dans lequel des moyens de blocage de bord (O) sont en outre couplés au bord du panneau à des points situés approximativement au quart et aux trois-quarts le long de chacun de l'ensemble des trois côtés du panneau autres que ledit côté parmi les côtés les plus longs.

12. Dispositif acoustique actif selon la revendication 11, dans lequel le transducteur est placé à une position marginale approximativement à 0,42 de la distance le long d'un des côtés les plus longs du panneau.

13. Procédé pour améliorer le fonctionnement acoustique d'un dispositif acoustique actif à modes répartis comprenant une structure de panneau à plusieurs côtés (11) et un transducteur (31, 32, 33, 34) qui lui est couplé, la structure de panneau ayant une répartition de modes résonnants d'action d'ondes de flexion déterminant des performances acoustiques conjointement au transducteur (31, 32, 33, 34), **caractérisé en ce que** le transducteur (31, 32, 33, 34) est placé à une première position marginale de la structure de panneau (11) qui n'est pas en elle-même sélectionnée pour la meilleure interaction fonctionnelle avec la structure de panneau; et **en ce que** le procédé comprend l'étape consistant à :

coupler une masse (93) au bord du panneau à une position discrète supplémentaire distincte de la première position et choisie pour améliorer le fonctionnement acoustique du dispositif en association avec le transducteur (31, 32, 33, 34).

14. Procédé pour améliorer le fonctionnement acoustique d'un dispositif acoustique actif à modes répartis comprenant une structure de panneau à plusieurs côtés (11) et un transducteur (31, 32, 33, 34) qui lui est couplé, la structure de panneau (11) ayant une répartition de modes résonnants d'action d'ondes de flexion déterminant des performances acoustiques conjointement au transducteur (31, 32, 33, 34), **caractérisé en ce que** le transducteur (31, 32, 33, 34) est placé à une première position marginale de la structure de panneau (11) qui n'est pas en elle-même sélectionnée pour la meilleure interaction fonctionnelle avec la structure de panneau (11); et **en ce que** le procédé comprend l'étape consistant à :

bloquer le bord du panneau à une position discrète (83) supplémentaire distincte de la première position et choisie pour améliorer le fonctionnement acoustique du dispositif en association avec le transducteur (31, 32, 33, 34).

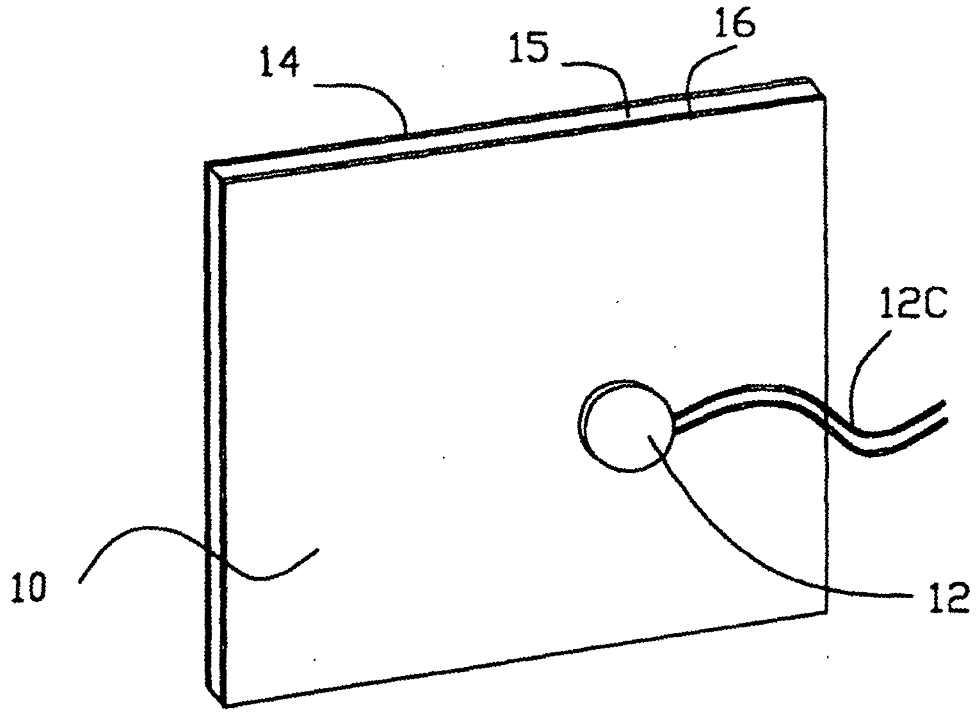

FIG.1

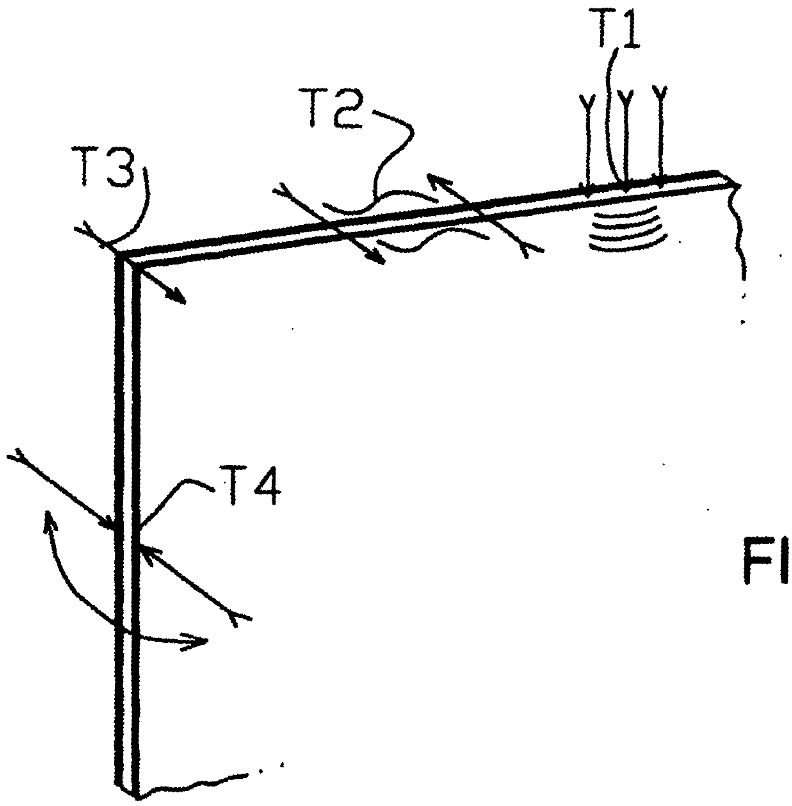

FIG.2

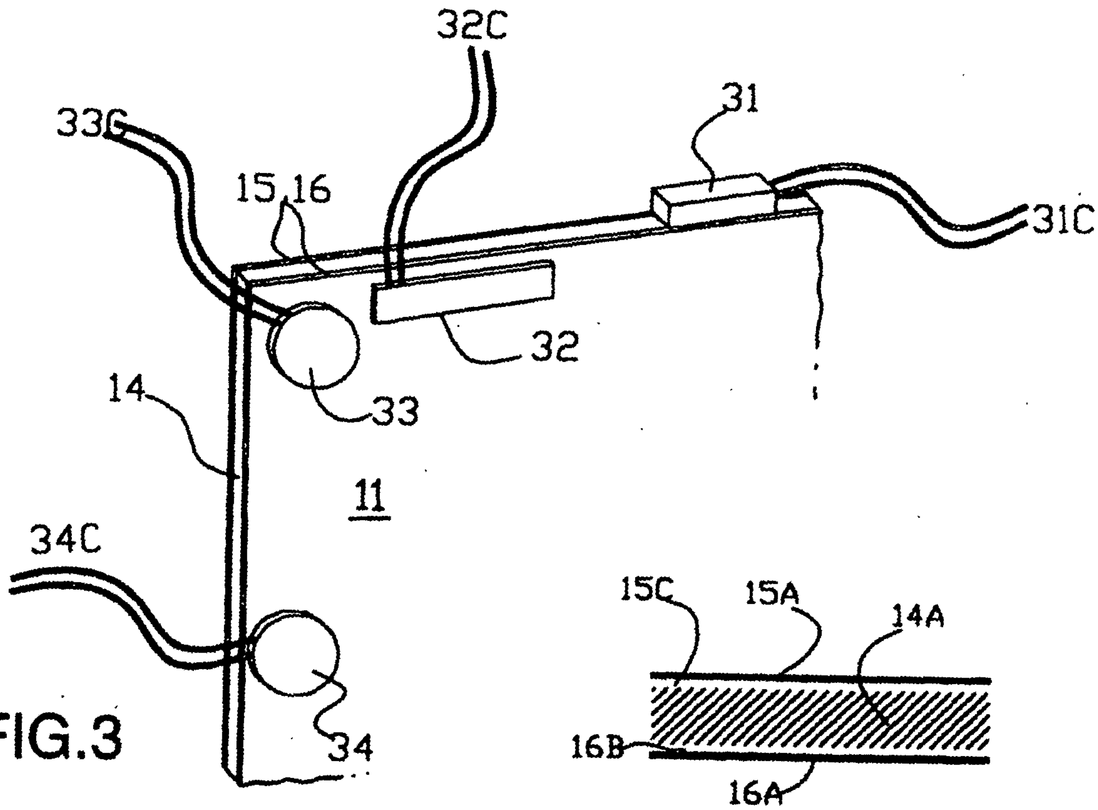

FIG.3

FIG.3A

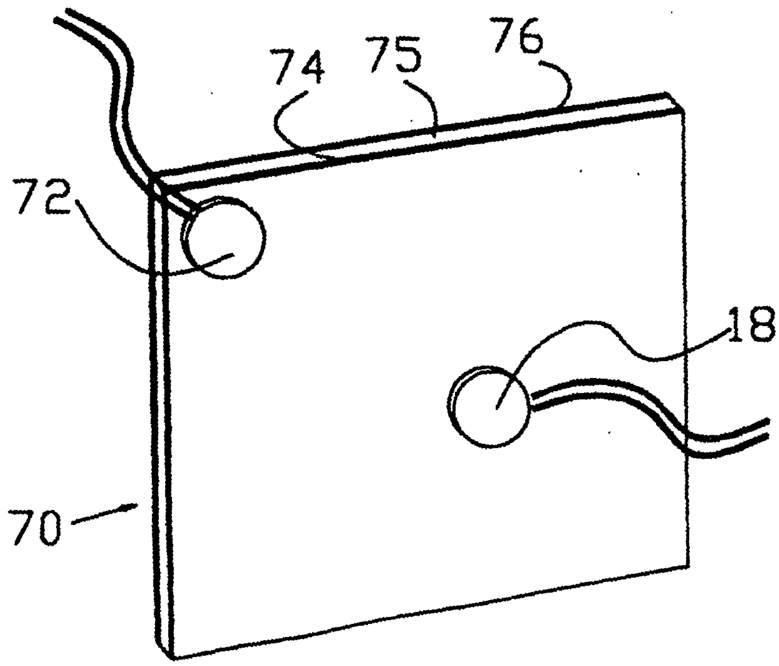

FIG.4

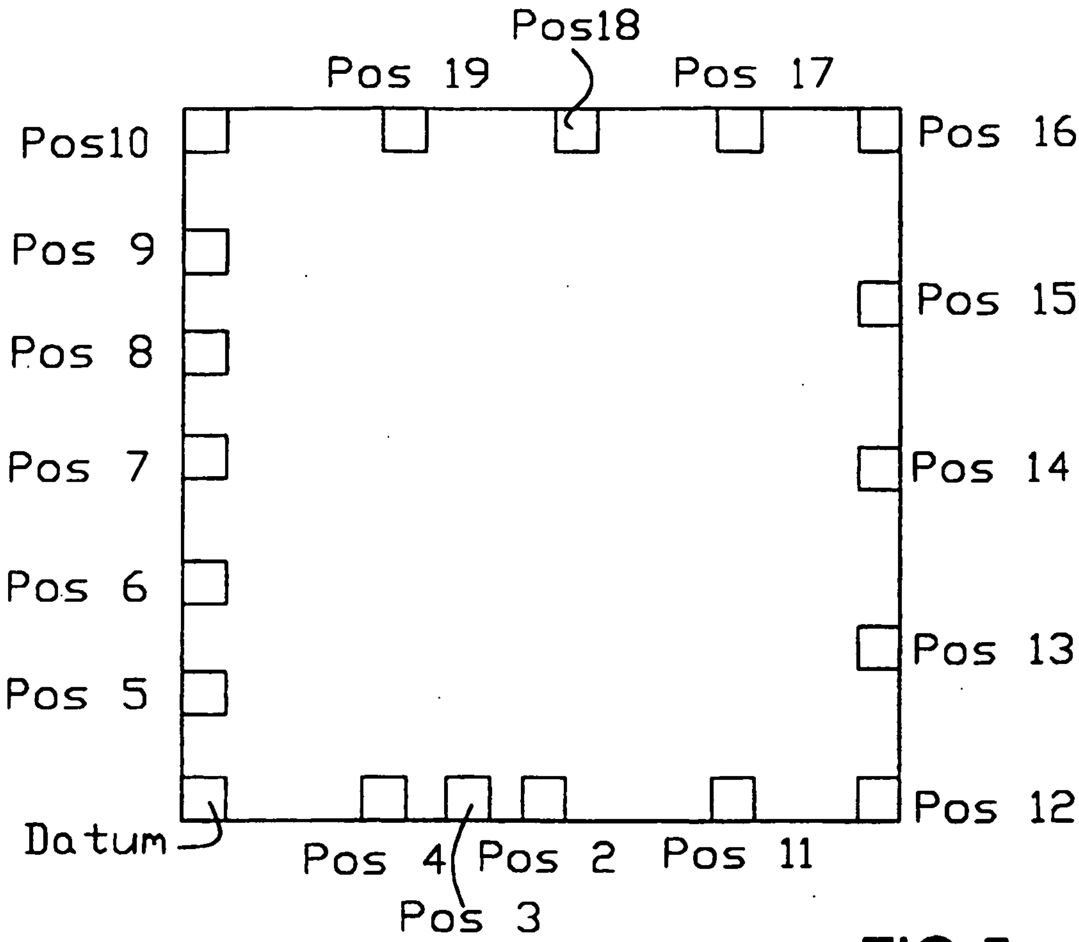
Pos18
Pos 19
Pos 17
Pos10
Pos 16
Pos 9
Pos 15
Pos 8
Pos 7
Pos 14
Pos 6
Pos 13
Pos 5
Pos 12
Datum
Pos 4
Pos 2
Pos 11
Pos 3

FIG.5

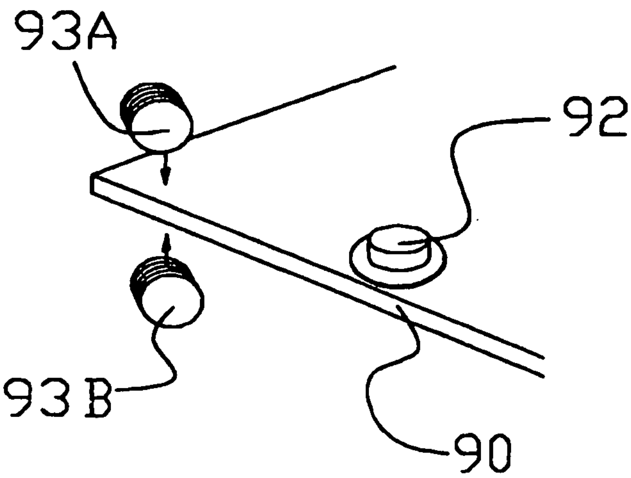
93A
92
93 B
90

FIG. 5A

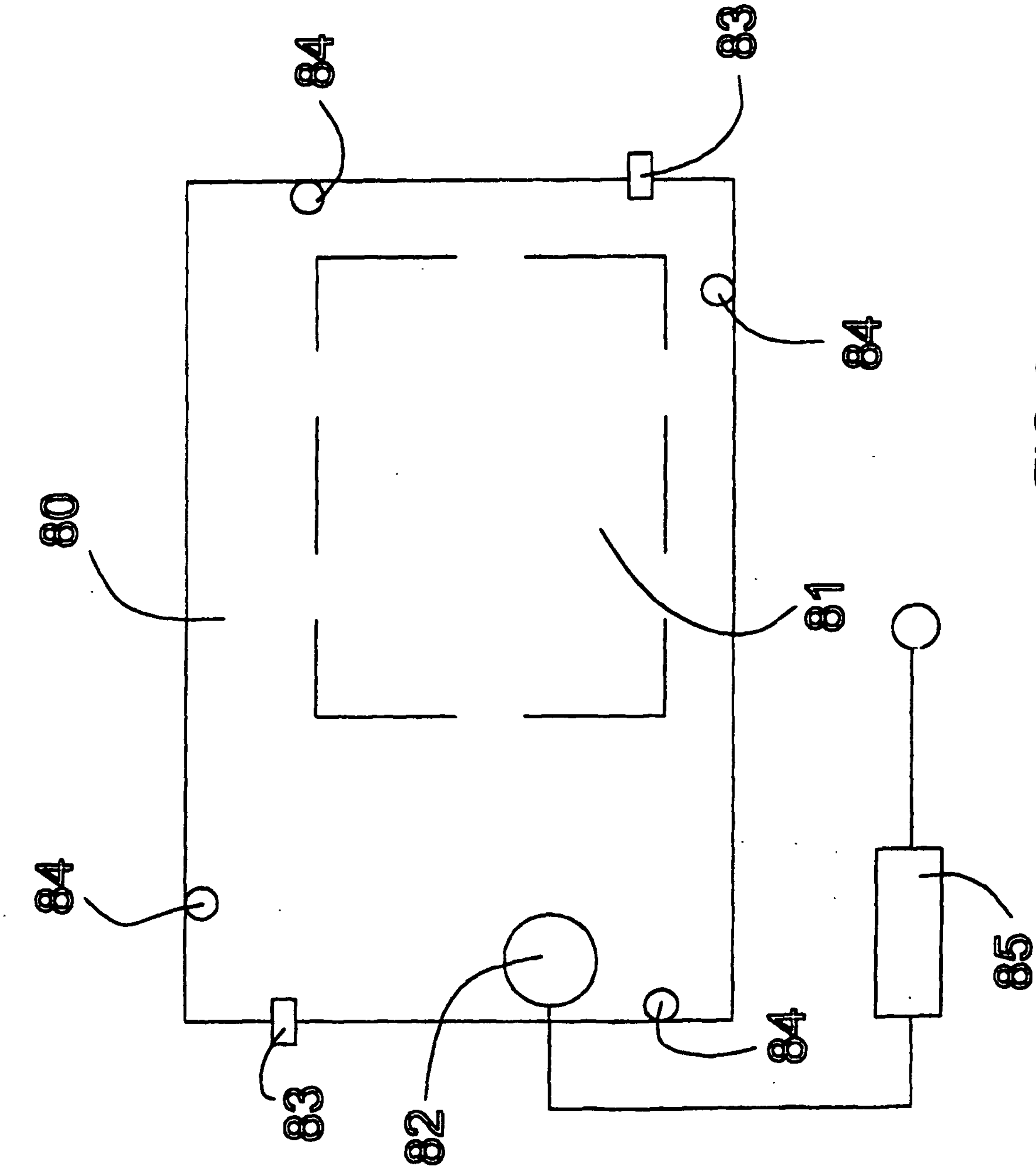

FIG.6

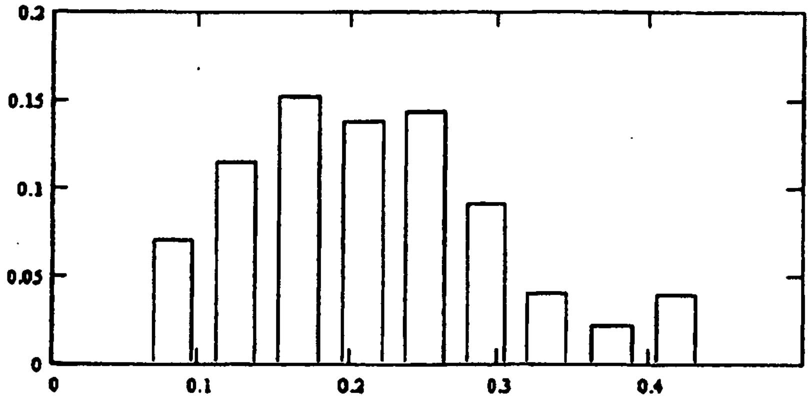

FIG.7A

300Hz-3kHz

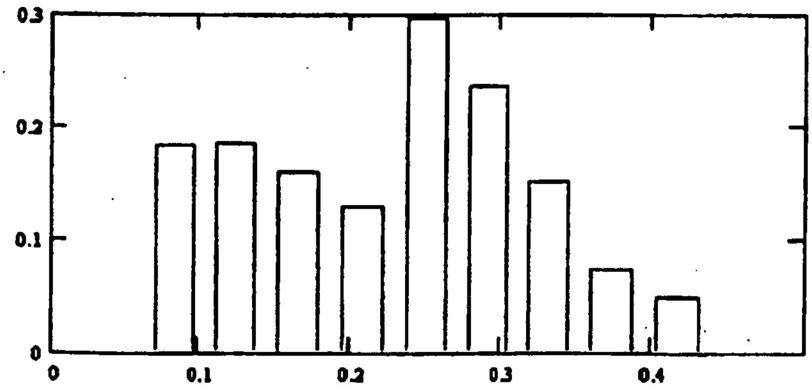

FIG.7B

300Hz-3kHz

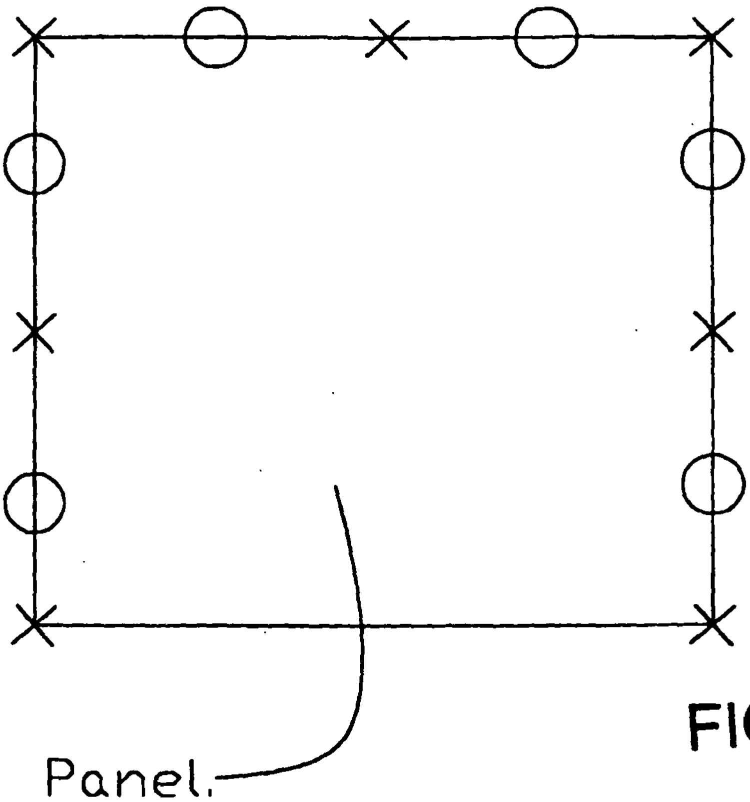

FIG.8

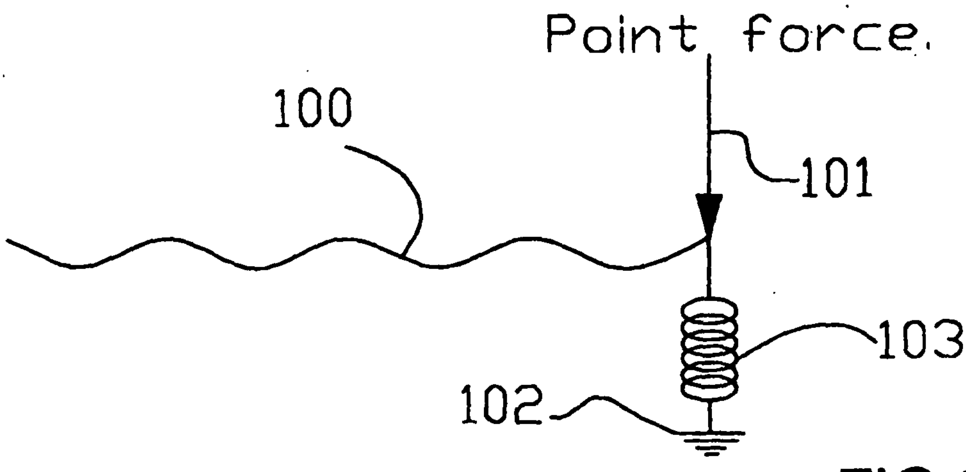

FIG.9

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 9709842 A **[0003] [0004] [0010] [0016] [0026]**
- WO 9203024 A **[0010]**