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Other: **EPODOC, WPI**

(54) Title of the Invention: **Product with integrally formed vibrating panel loudspeaker**
Abstract Title: **Product with integrally formed vibrating panel loudspeaker**

(57) A product having a vibrating panel loudspeaker integrally formed within a shell component of the product comprises a sheet-like shell component 2 providing a part of a casing defining an externally facing outer boundary surface of the product. An exciter is coupled to an inner actuatable portion 10 of the shell component.. The shell component has an unmoveable outer deadened portion 3 surrounding a generally planar circular inner actuatable portion 10 bounded by and integrally formed to the outer deadened portion to provide a continuity on the externally facing outer boundary surface of the shell component from the outer deadened portion across the inner actuatable portion (see figs 3A-3E) .
Masses (50-54, figs 6 & 7) may be used to tune the frequency response of the loudspeaker.

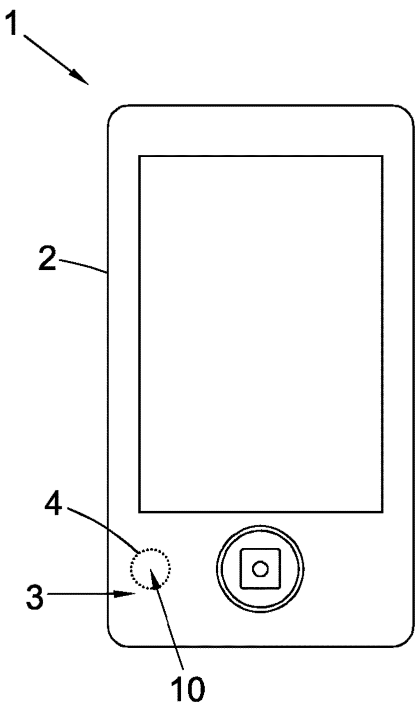

Fig. 1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

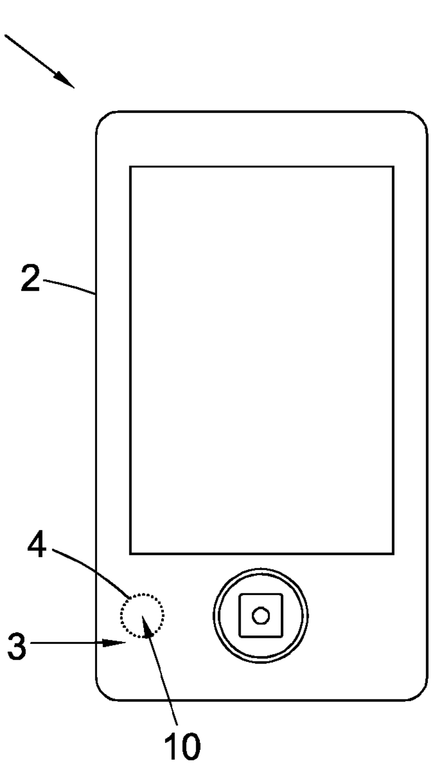

Fig. 1

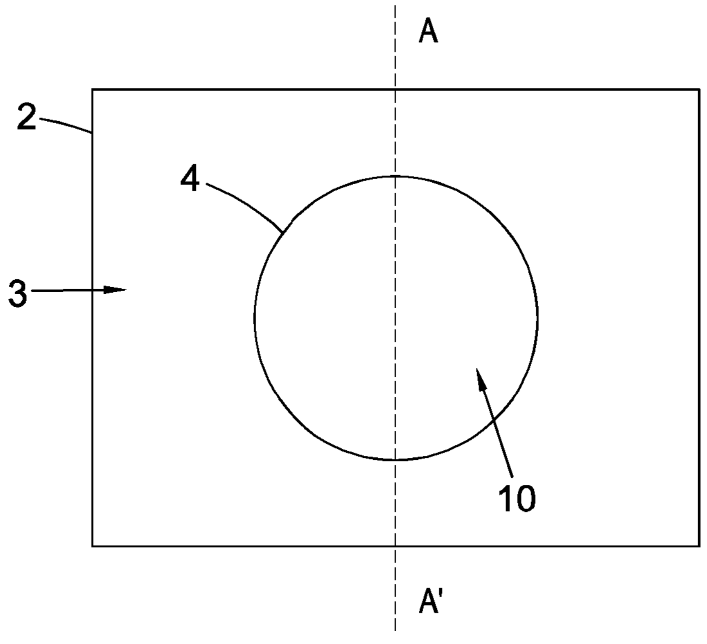

Fig. 2

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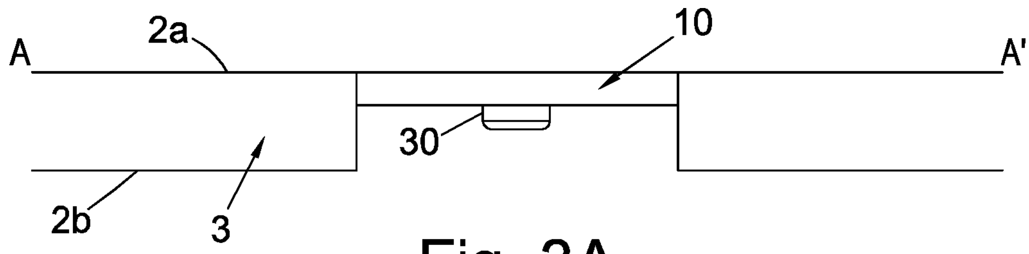

Fig. 3A

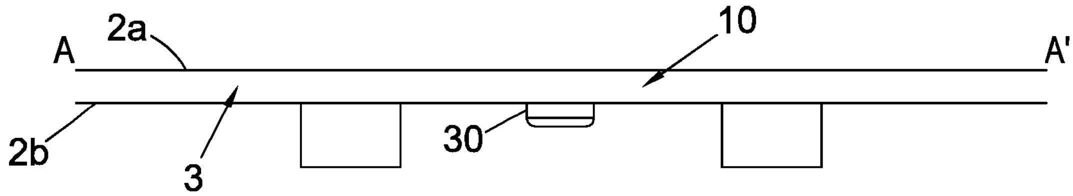

Fig. 3B

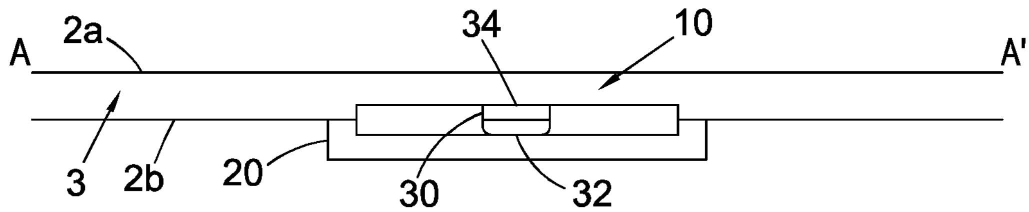

Fig. 3C

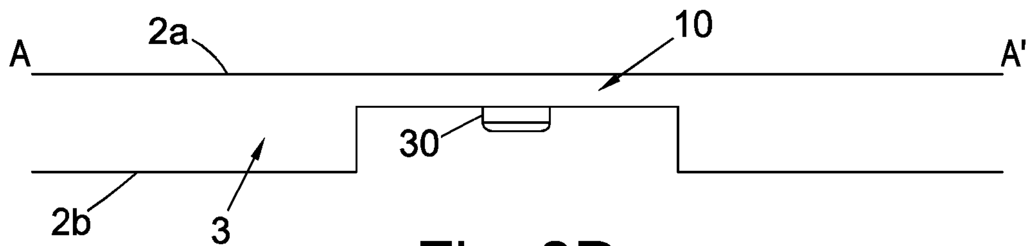

Fig. 3D

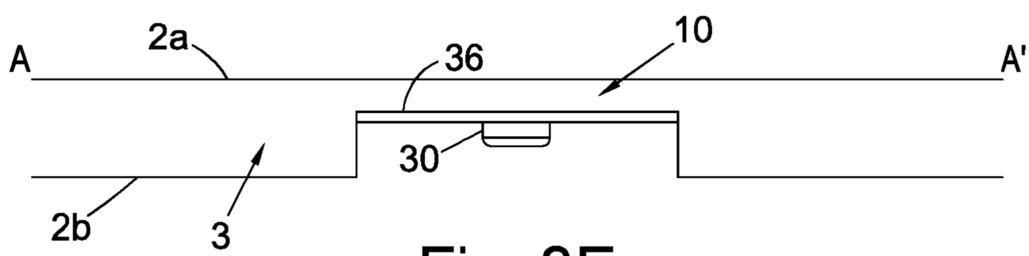

Fig. 3E

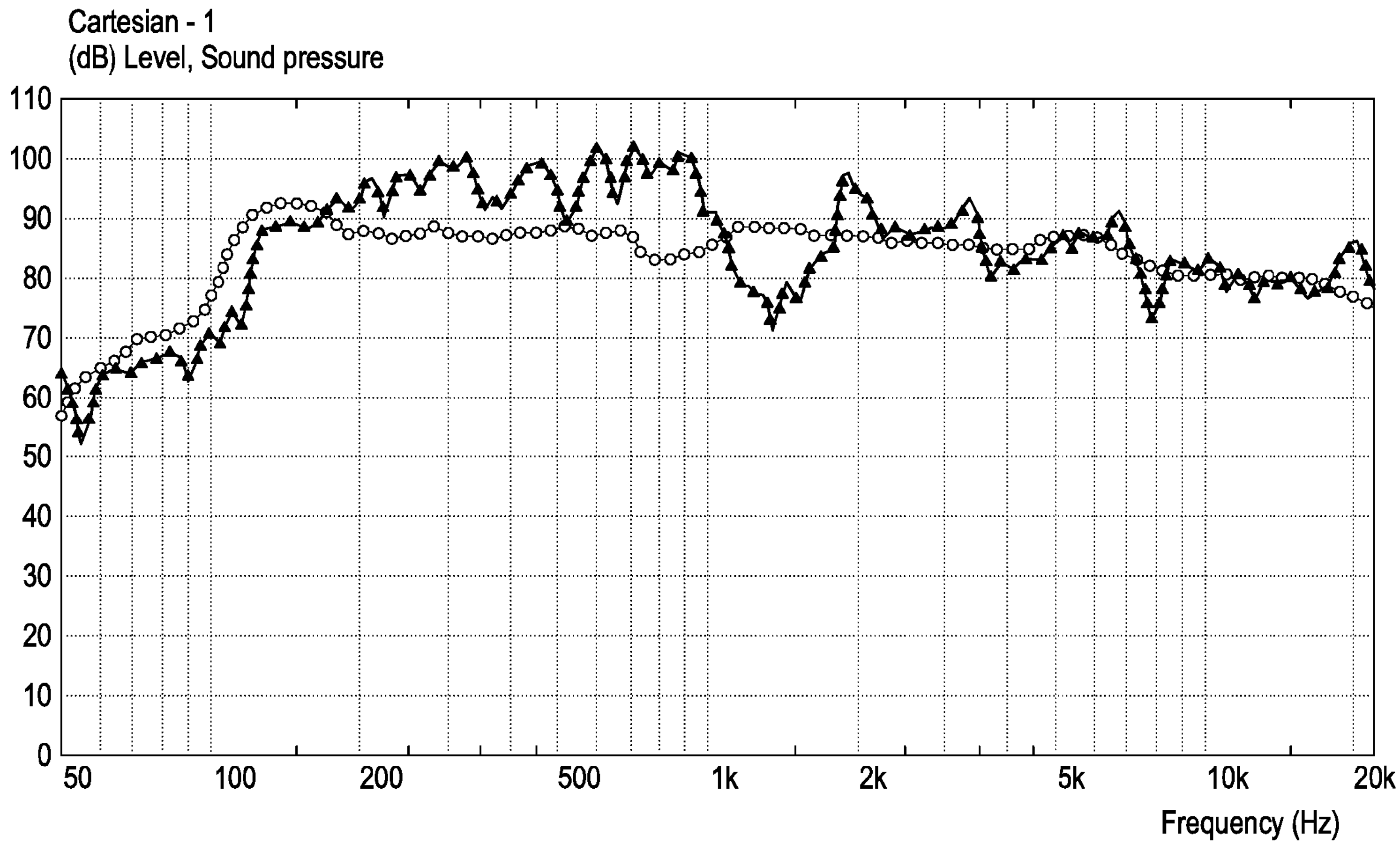
Cartesian - 1
(dB) Level, Sound pressure
110
100
90
80
70
60
50
40
30
20
10
0
50
100
200
500
1k
2k
5k
10k
20k
Frequency (Hz)

Fig. 4

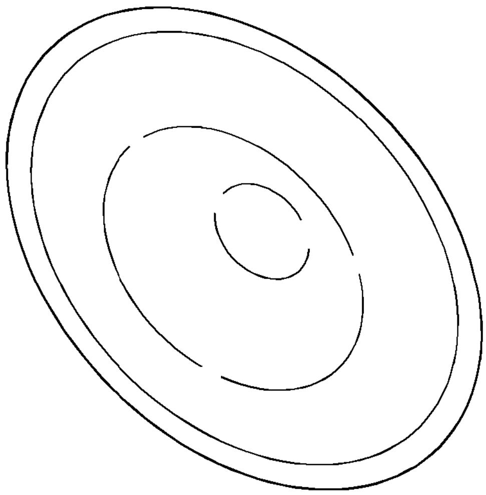

Fig. 5A

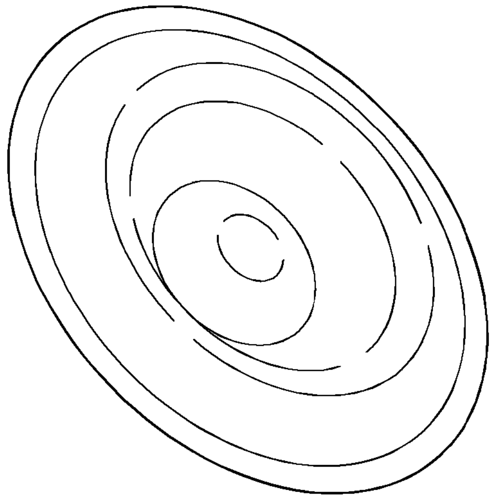

Fig. 5B

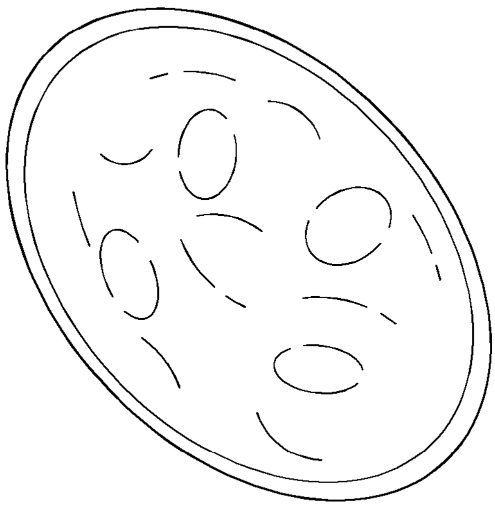

Fig. 5C

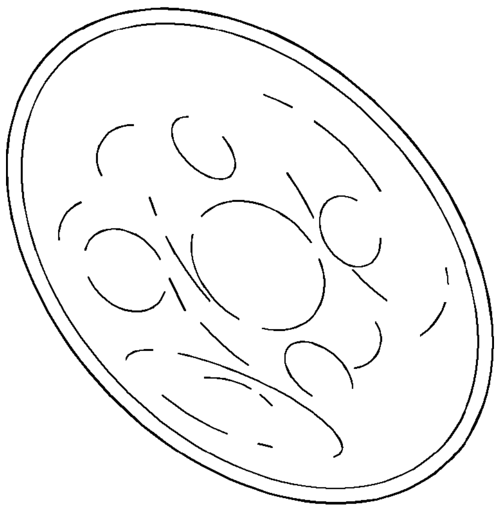

Fig. 5D

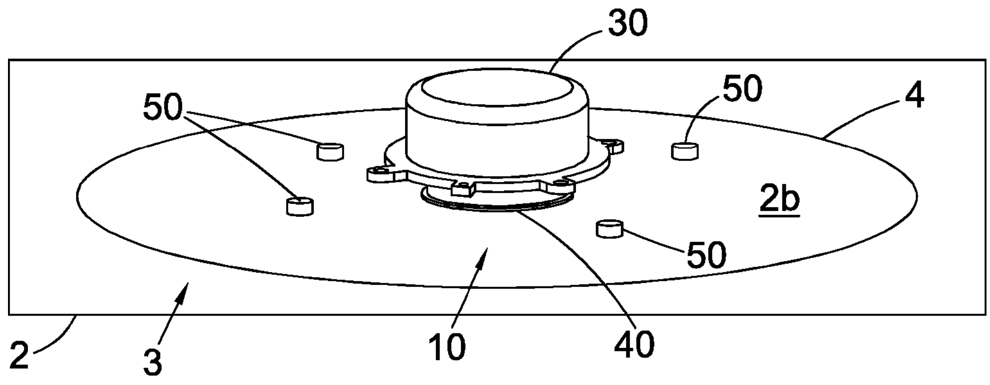

Fig. 6

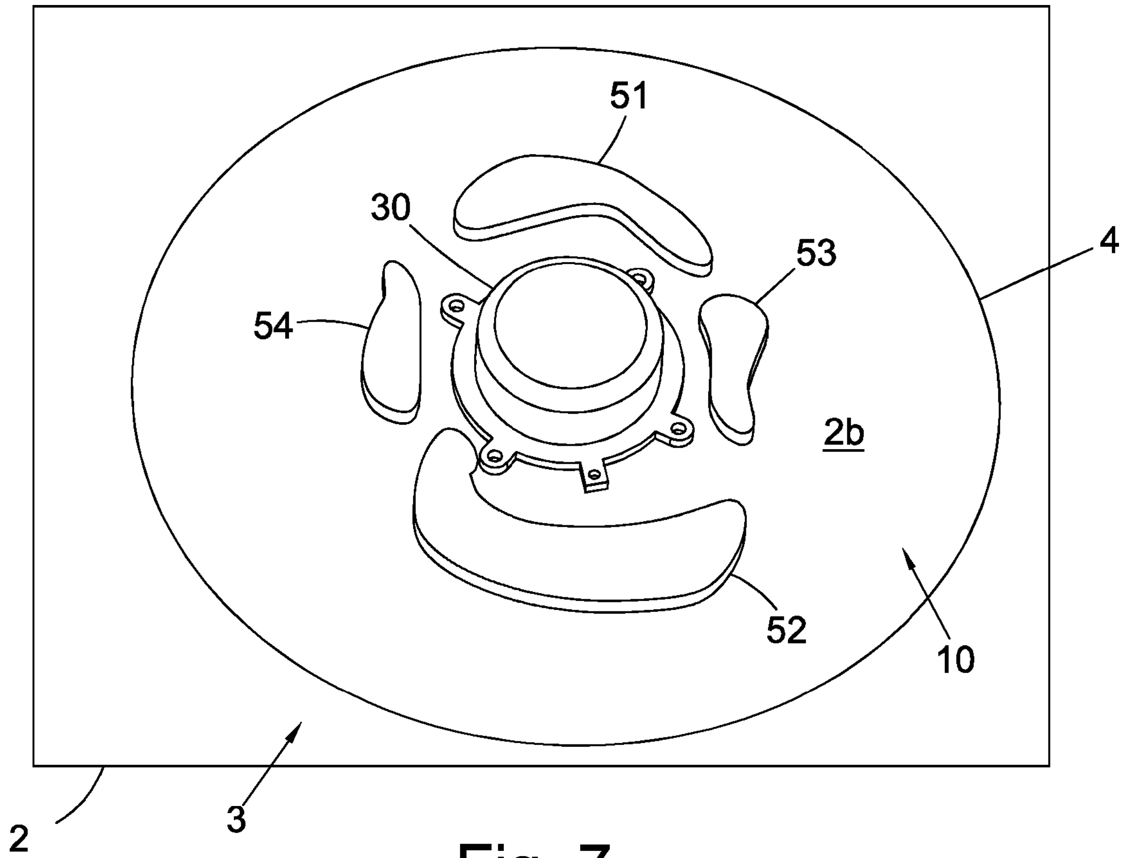

Fig. 7

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PRODUCT WITH INTEGRALLY FORMED VIBRATING PANEL LOUDSPEAKER

[0001] This invention relates to a vibrating panel loudspeaker integrally formed within a shell component of a product, in particular to the shell component of the product having a circular inner actuatable portion.

BACKGROUND

[0002] Many products have a speaker inside to enable the product to emit sound. For example, all mobile phones have a speaker integrated within. The speaker is placed behind the casing of the product and the casing directly over the speaker is formed into a speaker grille to protect the speaker from foreign objects while still allowing the air, and hence sound, to clearly pass from the speaker to the outside of the product. Due to the grille holes within the casing, the product may be damaged if dust and/or liquid such as water passes through the holes into the product. The small grille holes also make the product difficult to clean. Even if the holes can be cleaned, the cleaning fluid may pass into the product and damage the product. Moreover, the grilles are indiscreet and may change the overall appearance and perception of the product from the exterior. For example, if the product was a painting on a wall and a speaker was integrated in the painting such that the painting exterior had grilles, this may ruin the appearance of the painting. Further, the design of many consumer electronics products is constrained by the speakers and grilles being unavoidably present in the product design, and also by the positioning of the speakers and grilles in discreet and unobtrusive locations. This limits the freedom of the designer and impairs the provision of what may be an otherwise desirable design.

[0003] As products reduce in size and the number of speakers in products increases, the grilles become more difficult to manufacture and the likelihood of speaker and product damage from substances entering through the grilles increases. This can both decrease the aesthetic quality and the lifetime of the product and is detrimental to both consumers and product manufacturers. Further, it can add significant limitations to design freedom, leading to complicated and suboptimal product design.

[0004] It is in this context that the presently disclosed vibrating panel loudspeaker integrally formed within a shell component of a product and associated disclosures have been devised.

BRIEF SUMMARY OF THE DISCLOSURE

[0005] In consideration of the context of the above background, the present inventors have realised that integrating a vibrating panel loudspeaker into a shell component of a product would provide an advantageous means of providing a product with audio output addressing the needs of current design ideals and also acoustic limitations and requirements of current audio-visual technology.

[0006] Thus, viewed from one aspect, the present disclosure provides a product having a vibrating panel loudspeaker integrally formed within a shell component of the product. The product comprises a sheet-like shell component providing a part of a casing defining an externally facing outer boundary surface of a product; and an exciter coupled to an internally facing surface of the shell component ,the shell component having an outer deadened portion surrounding a generally planar circular inner actuatable portion bounded by and integrally formed to the outer deadened portion to provide a continuity on the externally facing outer boundary surface of the shell component from the outer deadened portion across the inner actuatable portion, the exciter being coupled to the inner actuatable portion of the shell component, the product being configured such that the outer deadened portion of the shell component is substantially unmoveable by the exciter, and such that the inner actuatable portion is movable in response to actuation by the exciter, wherein the substantially unmovable bounding edge of the outer deadened portion acts to deaden the outer boundary edge of the inner actuatable portion such that the inner actuatable portion forms an elastic membrane that is caused to vibrate, on operation of the exciter, to generate sound.

[0007] The term “externally facing outer boundary surface” will be understood to mean a surface in fluid communication with the outer atmosphere, which includes an external surface of a product that is easily visible when a user observes the product and an external surface inside a product that is not visible when a user observes the product but that is in fluid contact with external surroundings and with the user.

[0008] The vibrating panel loudspeaker is discreetly formed within the shell component of the product such that the presence of the loudspeaker is not readily perceptible. This removes the need for grille holes and ensures the product appearance is aesthetically pleasing. In addition, the inner actuatable portion, which generates the sound, is bounded by and integrally formed to the outer deadened portion of the shell component, ensuring the product is sealed around the speaker such that no foreign substances can enter the shell component in the area close to the speaker. Moreover, the integrally formed speaker can be manufactured together with the product to ensure manufacturing ease.

[0009] In the integrated vibrational panel loudspeaker of the present design, the inner actuatable portion is bounded by and integrally formed to the outer deadened portion which is substantially unmoveable by the exciter. The inner actuatable portion is movable in response to actuation by the exciter, wherein the substantially unmovable bounding edge of the outer deadened portion acts to deaden the outer boundary edge of the inner actuatable portion such that the inner actuatable portion forms an elastic membrane that is caused to vibrate, on operation of the exciter, to generate sound. As a result, even when the inner actuatable portion is caused to vibrate by the exciter, there are no discontinuities between the inner actuatable portion and the outer deadened portion and the outer deadened portion is substantially unmoveable. This means that the vibrating panel loudspeaker can be integrated within the shell component of the product such that the vibrating loudspeaker can remain unseen within the product if desired, the shell component is a barrier to foreign objects and the rest of the shell component of the product is substantially unmovable when the inner actuatable portion vibrates, in use. This also ensures that the entire product does not substantially vibrate when the vibrating panel loudspeaker is in use.

[0010] As a result of the inner actuatable portion being bounded by the outer deadened portion and the substantially unmovable bounding edge of the outer deadened portion acting to deaden the outer boundary edge of the inner actuatable portion, acoustic wave generation by the inner actuatable portion is achieved not through pistonic motion of the inner actuatable portion as a whole (as in the case of a diaphragm or cone of a traditional dynamic loudspeaker). Rather, acoustic waves are created by the exciter (which may be a moving coil exciter or another appropriate electrical signal-motion transducer) exciting the inner actuatable portion material to be deflected away from its at-rest position to vibrate in vibrational modes along its length between its substantially unmovable bounding edge. In this regime, the vibrational modes in which the inner actuatable portion more naturally resonates – the resonant modes – and in which the electrical signal driving the exciter can more easily transfer a greater amount of energy, are dependent on the distance from the excitation point to the constrained edge of the speaker. Further, the resonant modes are also dependent on other factors that act against the deformation of the inner actuatable portion material (such as a relatively rigid circular foot coupling the exciter voice coil to the inner actuatable portion) into an acoustic signal. The amount of energy transferable into the different vibrational modes of the speaker governs the transfer function of the vibrating panel loudspeaker – i.e. its frequency response.

[0011] Although circular cones are used in conventional pistonic cone loudspeakers to generate sound via pistonic motion of the cone, this is a completely different speaker technology. This is because the edge of the cone in a pistonic cone loudspeaker is arranged to move pistonically. In contrast, the outer boundary edge of the inner actuatable portion in the presently disclosed integrated vibrating panel loudspeaker is physically constrained such that it is substantially unmovable by the exciter. One effect of this constrained edge is that there exists a restoring force which acts to restore the inner actuatable portion to a flat equilibrium whenever the exciter causes a displacement of the central region of the inner actuatable portion. The presence of the restoring force helps to ensure that any slight unbalancing of the inner actuatable portion does not affect the ability of the inner actuatable portion to generate sound. This is unlike in a pistonic cone loudspeaker in which a distortion of the pistonic motion of the speaker cone would be detrimental to the sound generated and could also damage the speaker.

[0012] In order to transfer sufficient vibrational energy into a range of frequencies spread across the low-range frequencies (LF), mid-range frequencies (MF) and high frequencies (HF) to produce a good quality audio response, it is possible for the inner actuatable portion of the shell component to be rectangular, with one or more exciters being located at specific positions to produce an acoustically-designed response. The rectangular inner actuatable portion ensures that the distance from the exciter to the fixed bounding edge of the inner actuatable portion is not the same all the way around the inner actuatable portion so that the inner actuatable portion has a range of paths along the surface into which the inner actuatable portion can be excited to produce different resonant frequencies. A variation in the distance from the exciter to the bounding edge helps to ensure that the frequency response for the vibrating panel loudspeaker is substantially smoothed. In other words, the frequency response for the vibrating panel loudspeaker does not exhibit as many or as pronounced disadvantageous notches or peaks or dips in the frequency response, particularly in the low frequency region and the mid frequency region.

[0013] Corners of rectangular loudspeakers are stiffer in nature than the rest of the loudspeaker and are ineffective at producing sound. Therefore, only part of the loudspeaker of rectangular loudspeakers is effective at producing sound. For circular loudspeakers, the whole loudspeaker is effective at producing sound. Thus, for loudspeakers of the same surface area, the regions that are effective at producing sound would be smaller for a rectangular loudspeaker than a circular loudspeaker due to the presence of corners. Consequently, a circular loudspeaker would provide better sound power output per surface area than a rectangular loudspeaker, which is advantageous for small products or products with a small surface area. Although the quality of the output audio spectrum may be less balanced, the integrated circular vibrating panel loudspeaker has been found to provide output sound of sufficient overall quality and loudness for small consumer electronics products. This is the case in particular when mode balancing means are used (see below).

[0014] Thus, there is provided a vibrating panel loudspeaker with good acoustic performance and which is simple to form within a shell component of a product. The disclosed vibrating panel loudspeaker is easy to manufacture and easy to maintain whilst also providing good sound quality, even for a limited surface area. It has the additional advantage that the design allows for the speaker to be discreet if desired.

[0015] Generally, circularly formed components, such as the inner actuatable portion of the presently disclosed design, are relatively difficult and expensive to manufacture, compared to rectangular or square components, particularly where small batches are concerned, as expensive tooling needs to be designed, made and used to manufacture the parts. As the vibrational panel loudspeaker is now integrally formed within a shell component of a product, the circular inner actuatable section can be manufactured as part of the product manufacturing, often at a mass scale. As such, the previous undesirability of the circular components can be overcome.

[0016] The shape of the externally facing outer boundary surface of the product may be such that the presence of the speaker is not readily perceptible from the exterior of the casing.

[0017] The externally facing outer boundary surface of the shell component may be a continuous generally planar surface.

[0018] The exciter may be located substantially at an axial centre of the circular inner actuatable portion. This enables the vibrating panel loudspeaker to produce loud audio. The exciter is mounted substantially centrally on the inner actuatable portion so that the exciter is spaced as far as possible from the fixed boundary of the inner actuatable portion on all sides, allowing for the maximum vibration of the inner actuatable portion, causing efficient sound production. This ensures that, as products reduce in size, the circular vibrating panel loudspeaker integrally formed within a shell component of the product can still produce sufficiently loud sound of sufficient quality. Ease of assembly and efficient acoustic operation of the vibrating panel loudspeaker is achieved by coupling the exciter axially centrally to an internally facing surface of the inner actuatable portion. In this way, the distance from the exciter to the outer boundary edge of the inner actuatable portion is substantially the same all the way around the exciter. Further, when the exciter is mounted axially centrally on the internally facing surface of the inner actuatable portion, an axial angle of the exciter relative to the rear surface of the inner actuatable portion remains substantially unchanged during operation of the exciter (which would not be true were the exciter to be mounted away from the centre of the inner actuatable portion).

[0019] The inner actuatable portion may be formed to have a substantially constant density per unit area across the externally facing outer boundary surface of the shell component. In some embodiments, the inner actuatable portion may be formed to have a density per unit volume which is different in different regions of the inner actuatable portion.

[0020] The inner actuatable portion and outer deadened portion of the shell component may be composed of the same material.

[0021] The inner actuatable portion and outer deadened portion of the shell component may be the same thickness.

[0022] The inner actuatable portion may be thinner than the outer deadened portion of the shell component.

[0023] The inner actuatable portion and outer deadened portion may together provide a continuous form to the external surface of the shell component.

[0024] A transition from the inner actuatable portion to the outer deadened portion may be a sloping edge.

[0025] The material of the inner actuatable portion may be more flexible material than the material of the outer deadened portion of the shell component.

[0026] The boundary between the inner actuatable portion and outer deadened portion may be sealed.

[0027] The shell component may provide a sealed surface of the external casing of the product.

[0028] A deadening component may be mounted to the shell component around the boundary between the inner actuatable portion and outer deadened portion to act to deaden the outer deadened portion of the shell component.

[0029] The exciter may be inertially mounted to the shell component.

[0030] The product may comprise a frame fixed to the internally facing surface of the outer deadened portion, and the exciter may be mounted to and supported by the frame such that the exciter is coupled to the internally facing surface of the shell component. Thus, operation of the exciter may directly move the inner actuatable portion of the shell component relative to the frame.

[0031] The frame may be formed from a plastics material.

[0032] The inner actuatable portion may have an outer diameter of less than 30 centimetres, optionally less than 25cm, optionally less than 20cm, optionally less than 15cm, optionally less than 10 cm, optionally less than 8cm, optionally less than 6cm, optionally less than 4cm, optionally less than 3cm.

[0033] The product may comprise mode distribution means configured to induce, in use, non-circularly symmetric distortion of natural modes of oscillation of the inner actuatable portion in response to operation of the exciter in an assembly of the shell component and the exciter absent the mode distribution means.

[0034] The mode distribution means may be configured to induce, in use, non-rotationally symmetric distortion of natural modes of oscillation of the shell component in response to operation of the exciter in the assembly of the shell component and the exciter absent the mode distribution means. The term “non-rotationally symmetric” will be understood to mean that there is no rotational symmetry in the distortion of the natural modes of oscillation of the inner actuatable portion. In other words, the distortion in the natural modes of oscillation of the inner actuatable portion on the plane of the externally facing outer boundary surface of the inner actuatable portion is not repeated at any other rotational angle of the inner actuatable portion. Thus, the acoustic energy in the frequency response of the inner actuatable portion can be particularly effectively distributed to the notches in the frequency response (and away from the peaks in the frequency response).

[0035] The mode distribution means may comprise one or more components coupled to the inner actuatable portion to add weight thereto to induce the distortion in the natural modes of resonant oscillation of the inner actuatable portion in the assembly of the shell component and the exciter in response to operation of the exciter.

[0036] The one or more components may be formed from non-toxic metal.

[0037] The one or more components may be formed from a non-ferrous material, for example a substantially non-ferrous metal such as stainless steel. Thus, when the exciter is a magnet-based exciter, such as a moving coil exciter, then the proximity of the one or more components to the exciter will not interfere in the operation of the exciter.

[0038] The one or more components may be coupled to the inner actuatable portion substantially just outside the exciter. Advantageously, this maximises the effect of the mass of the one or more components. In other words, greater masses would need to be used to achieve a similar affect if the masses needed to be positioned further from the centre of the inner actuatable portion, increasing at least the overall weight and material cost of the vibrating panel loudspeaker.

[0039] The one or more components may be coupled to the inner actuatable portion away from the centre of the inner actuatable portion in a direction along the internally facing surface of the shell component.

[0040] The one or more components may be at least two components and each component may be differently spaced from the centre of the inner actuatable portion. Thus, the combination of the inner actuatable portion and the at least two components does not have a line of symmetry dividing a first region comprising one of the at least two components and a second region comprising another of the at least two components.

[0041] The at least two components may each have a different mass. The at least two components may each be formed to have a different shape.

[0042] The at least two components may be spaced apart over a region of at least 60 degrees relative to the centre of the inner actuatable portion.

[0043] The at least two components may be at least four components. A maximum angular spacing between any two components, relative to the centre of the inner actuatable portion, may be less than 180 degrees. Thus, the components may be spaced around substantially the whole of the inner actuatable portion.

[0044] A maximum angular spacing between any two components, relative to the centre of the inner actuatable portion, may be less than 150 degrees. A maximum angular spacing between any two components, relative to the centre of the inner actuatable portion, may be less than 130 degrees. A maximum angular spacing between any two components, relative to the centre of the inner actuatable portion, may be less than 110 degrees. A maximum angular spacing between any two components, relative to the centre of the inner actuatable portion, may be less than 100 degrees.

[0045] The one or more components may be coupled to the internally facing surface of the inner actuatable portion of the shell component. Thus, in use, the one or more components may not be visible by a user, who may see the externally facing outer boundary surface of the shell component.

[0046] The mode distribution means may be provided in the form of depressions defined in the externally facing outer surface of the shell component and configured to be selectively filled in to induce the distortion in the natural modes of resonant oscillation of the inner actuatable portion in an assembly of the shell component and the exciter, in the absence of the mode distribution means, in response to operation of the exciter.

[0047] A centre of mass of an assembly of the inner actuatable portion and the mode distribution means may be away from a centre of the inner actuatable portion in a direction along the externally facing outer boundary surface of the shell component.

[0048] The exciter may be coupled to the internally facing surface of the shell component via a foot and the mode distribution means may be provided at one or more regions of the inner actuatable portion of the shell component outside the foot. The use of the foot ensures that energy from the exciter will be transferred efficiently to the inner actuatable portion of the shell component.

[0049] The mode distribution means may be arranged, in use, to be asymmetric relative to any line of symmetry through the centre of the inner actuatable portion of the shell component.

[0050] The inner actuatable portion and outer deadened portion may be formed to have a substantially constant density per unit area across the externally facing outer boundary surface of the shell component.

[0051] A maximum thickness of the inner actuatable portion may be less than 3 millimetres. In some examples, the maximum thickness of the inner actuatable portion may be approximately 2 millimetres.

[0052] A minimum thickness of the outer deadened portion may be more than or equal to 3 millimetres.

[0053] The inner actuatable portion of the shell component bounded by the outer deadened portion may provide an elastic membrane adapted to achieve a given quality of sound reproduction when transducing an electrical signal used to drive the exciter.

[0054] The product may be configured such that the elasticity of the inner actuatable portion of the shell component is sufficient to cause sound having a high frequency over 4kHz to be emitted from the inner actuatable portion when the exciter is driven at substantially the high frequency. Thus, the inner actuatable portion is formed such that it is suitable for use to reproduce high frequency sounds.

[0055] The product may be configured such that the elasticity of the inner actuatable portion of the shell component is sufficiently low to cause sound having a low frequency below 200 Hz to be emitted from the inner actuatable portion when the exciter is operated at substantially the low frequency. Thus, the inner actuatable portion is formed such that it is suitable for use to reproduce low frequency sounds.

[0056] The inner actuatable portion may be substantially stiff enough to be deflected on operation of the exciter to produce audio output across the whole of the region of the inner actuatable portion within the boundary of the outer deadened portion.

[0057] The product may be a consumer electronics product, such as a toy, a video display, a smart phone, a tablet, a loudspeaker, or a gaming device, optionally a portable or handheld device.

[0058] The product may not be only a loudspeaker.

[0059] The casing of the consumer electronics product may be substantially sealed, optionally watertight.

[0060] The product may be plasterboard.

[0061] The material of the shell component may be continuous through the inner actuatable portion and outer deadened portion.

[0062] The inner actuatable portion of the shell component may further comprise a membrane between the continuous material and the exciter, the exciter being inertially mounted to the membrane, wherein the material of the membrane is different to the continuous material.

[0063] The vibrating panel loudspeaker may be as described hereinbefore.

BRIEF DESCRIPTION OF THE DRAWINGS

[0064] Embodiments of the invention are further described hereinafter with reference to the accompanying drawings, in which:

Figure 1 provides an example of a vibrating panel loudspeaker integrally formed within a shell component of a product;

Figure 2 provides another example of a vibrating panel loudspeaker integrally formed within a shell component of a product;

Figures 3A to 3E provide an illustration of a cross-section through the vibrating panel loudspeaker of Figures 1 and 2 according to an example;

Figure 4 shows an example simulated frequency response for an inner actuatable portion of a circular vibrating panel loudspeaker, with and without a mode distribution means;

Figures 5A to 5D are example schematic representations illustrating the displacement at two different resonant modes for each of two different inner actuatable portions.

Figure 6 is an illustration of an underside of an inner actuatable portion of a vibrating panel loudspeaker according to an example;

Figure 7 is an illustration of an underside of an inner actuatable portion of a vibrating panel loudspeaker according to another example;

DETAILED DESCRIPTION

[0065] The present disclosure describes a product having a vibrating panel loudspeaker integrally formed within a shell component of the product, the vibrating panel loudspeaker producing high quality sound per surface area of the shell component of the product and providing a barrier such that foreign objects cannot enter the product through the vibrating panel loudspeaker.

[0066] Figures 1 and 2 are illustrations of a vibrating panel loudspeaker integrally formed within a shell component 2 of a product 1. The vibrating panel loudspeaker may be a flat panel loudspeaker. The product 1 of figure 1 is a mobile phone. In this example, the product 1 is not only a loudspeaker. The product 1 has a shell component 2 which forms part of the protective casing of the product 1. A vibrating panel loudspeaker is integrally formed within the shell component 2 of the product 1. The shell component 2 has an outer deadened portion 3 surrounding a generally planar inner actuatable portion 10. The outer deadened portion 3 has a substantially unmovable bounding edge 4. As illustrated in figures 1 and 2, the inner actuatable portion 10 and the bounding edge 4 are substantially circular to form a circular vibrating panel loudspeaker. For small products or products with a small available outer boundary surface, the circular loudspeaker would still be able to be integrated into the shell component 2 of the product 1 due to its shape and because the inner actuatable portion 10 can be produced to be small. For example, the inner actuatable portion 10 may have an outer diameter of less than 30 centimetres. In the embodiment shown, the inner actuatable portion 10 has an outer diameter of around 5cm. The outer deadened portion 3 may not be completely deadened and may be defined as the area that is not the principle active area.

[0067] The inner actuatable portion 10 is bounded by and integrally formed to the outer deadened portion 3 to provide a continuity on the externally facing outer boundary surface of the shell component 2 from the outer deadened portion 3 across the inner actuatable portion 10. In this sense, there is at least one unbroken path along the surface of the shell component 2 across the span of the inner actuatable portion 10. Indeed, the entire externally facing outer boundary surface of the shell component 2 may be continuous, or seamless, from the outer deadened portion 3 across the inner actuatable portion 10. The shape of the externally facing outer boundary surface of the product 1 may be such that the presence of the speaker is not readily perceptible from the exterior of the casing. For example, the inner actuatable portion 10 and the outer deadened portion 3 together may provide a continuous form to the external surface of the shell component 2. Thus, as shown by dotted lines in figure 1, the boundary 4 may not be visible from the outside of the product 1. In fact, the user may not be able to tell where the vibrating panel loudspeaker is when looking at the product 1, particularly when the loudspeaker is not in use. Alternatively, the transition of the externally facing outer boundary from the inner actuatable portion 10 to the outer deadened portion 3 may be a sloping edge.

[0068] The product 1 may be any product that could require an integrally formed vibrating panel loudspeaker. For example, the product 1 may be plasterboard. In another example, the product 1 may be a painting. In another example, the product 1 may be a consumer electronics product. For example, the product 1 may be a toy, a video display, a smart phone, a tablet, a loudspeaker, or a gaming device, optionally a portable or handheld device. The shell component 2 may define an externally facing outer boundary surface of the product 1. The shell component 2 may surround the product 1. The shell component 2 may be formed from substantially rigid material, for example, metal or plastic such as polyurethane. The shell component 2 may be a thin layer of material and may be formed from a sheet of material. The inner actuatable portion 10 of the shell component 2 may have maximum thickness of less than 3 millimetres. The outer deadened portion 3 may have a minimum thickness of more than or equal to 3 millimetres. In an example, the shell component 2 is plasterboard. The outer deadened portion 3 of the plasterboard may be approximately 12.5mm and the inner actuatable portion 10 of the plasterboard may be approximately 2mm.

[0069] For example, for a painting, the material on which the painting is formed or the frame of the painting may be the shell component 2 with a vibrating panel loudspeaker formed within. It may therefore be preferred that the loudspeaker be invisible within the painting. The integrally formed loudspeaker described allows for such discreetness as described above. It can be formed such that even through the loudspeaker the externally facing outer boundary surface of the shell component 2 is a continuous generally planar surface with no grilles. In another example, if the product 1 is a consumer electronics product, the shell component 2 may provide a barrier to anything inside the product 1 such that no fluid can enter the product 1 and interferes with the electronics within the product 1.

[0070] Figures 3A to 3E provide an illustration of a cross-section through the vibrating panel loudspeaker of Figures 1 and 2 according to an example. It should be noted that these images are not shown to scale, in particular in the thickness direction, nor are they representative or limiting of the shape or form, for example, of the shell component 2 or exciter 30. In detail, figures 3A to 3E illustrate example side views of cross section A-A’ of figure 2. As shown, the shell component 2 of figures 3A to 3E has an outer deadened portion 3 surrounding a generally planar circular inner actuatable portion 10. These figures also show the externally facing outer boundary surface 2a arranged to face outwardly at an outer boundary of the product 1 and an internally facing surface 2b opposite the externally facing outer boundary surface 2a. An exciter 30 is coupled to the internally facing surface 2b of the inner actuatable portion 10 of the shell component 2. The product 1 may be configured such that the outer deadened portion 3 of the shell component 2 is substantially unmoveable by the exciter 30, and such that the inner actuatable portion 10 is movable in response to actuation by the exciter 30, wherein the substantially unmovable bounding edge 4 of the outer deadened portion 3 acts to deaden the outer boundary edge of the inner actuatable portion 10 such that the inner actuatable portion 10 forms an elastic membrane that is caused to vibrate, on operation of the exciter 30, to generate sound.

[0071] In an example, the inner actuatable portion 10 may be formed to have a substantially constant density per unit area across the externally facing outer boundary surface of the shell component 2. In another example, both the inner actuatable portion 10 and outer deadened portion 3 are formed to have a substantially constant density per unit area across the externally facing outer boundary surface of the shell component 2. For example, the inner actuatable portion 10 and outer deadened portion 3 of the shell component 2 may be composed of the same material. Alternatively, the material of the inner actuatable portion 10 may be more flexible material than the material of the outer deadened portion 3 of the shell component 2. The inner actuatable portion 10 and outer deadened portion 3 of the shell component 2 may be formed at the same time during manufacturing of the vibrating panel loudspeaker within the product 1 such that the vibrating panel loudspeaker is easy and quick to manufacture.

[0072] In an example, the exciter 30 may be coupled to the internally facing surface 2b of the shell component 2 via a foot 40 (see Figure 6). The foot 40 provides an interface between the exciter 30 and the internally facing surface 2b of the shell component 2. In an example, the foot 40 is substantially cylindrical and provides a circular interface between the exciter 30 and the internally facing surface 2b of the shell component 2.

[0073] When the inner actuatable portion 10 is caused by the exciter 30 to vibrate on operation of the exciter 30, the outer deadened portion 3 of the shell component 2 is substantially unmoveable and substantially only the inner actuatable portion 10 vibrates relative to the frame 20. In other words, the outer deadened portion 3 is fixed relative to the product 1. This ensures that the internal elements of the product 1 are not damaged by operation of the vibrating panel loudspeaker.

[0074] In figures 3A to 3E, the exciter 30 is located substantially at an axial centre of the circular inner actuatable portion 10 such that a shortest distance from the second part 34 of the exciter 30 to the outer boundary of the inner actuatable portion 10 is substantially the same anywhere around the exciter 30 or the foot 40. Thus, the vibrating panel loudspeaker is centre driven.

[0075] In figure 3A, the continuity on the externally facing outer boundary surface of the shell component 2 from the outer deadened portion 3 across the inner actuatable portion 10 is clearly illustrated. The inner actuatable portion 10 is thinner than the outer deadened portion 3. The inner actuatable portion 10 may be formed by reducing the thickness of the shell component 2. In this figure, there is a line between the inner actuatable portion 10 and outer deadened portion 3 to illustrate that there may be a material discontinuity. The inner actuatable portion 10 and outer deadened portion 3 may be bonded together after production or may be co-moulded. This may enable the materials of the inner actuatable portion 10 and outer deadened portion 3 to differ. However the inner actuatable portion 10 is formed, the boundary between the inner actuatable portion 10 and outer deadened portion 3 is sealed such that no external fluids can pass through the boundary. In some examples, the shell component 2 may provide a substantially sealed surface of the external casing of the product 1 and the inner actuatable portion 10 may not contain any holes such that no external fluids can pass through the shell component 2 into the inside of the product 1. Thus, the casing of the product 1 may be watertight. In an example, the material of the shell component 2 is plasterboard. The plasterboard forming the inner actuatable portion 10 may be manufactured separately from the plasterboard forming the outer deadened portion 3 and the inner actuatable portion 10 and outer deadened portion 3 may be bonded together after production.

[0076] As figure 3A illustrates, the transition of the internally facing surface 2b from the outer deadened section to the inner actuatable section may be perpendicular to the internally facing and externally facing planes of the shell component 2. Alternatively, the transition of the internally facing surface 2b from the inner actuatable portion 10 to the outer deadened portion 3 may be a sloping edge.

[0077] Figure 3A also illustrates an exciter 30 that is inertially mounted to only the internally facing surface 2b of the shell component 2. Thus, the exciter 30 may be free to move when activated to enable sound generation. The first part 32 of the exciter 30 may have sufficient inertial mass such that operation of the exciter 30 causes movement of the inner actuatable portion 10 even when the first part 32 of the exciter 30 is not mounted to any frame 30.

[0078] In Figure 3B, a shell component 2 is provided with a deadening component mounted to the shell component 2 around the boundary between the inner actuatable portion 10 and outer deadened portion 3. In this example, the inner actuatable portion 10 and outer deadened portion 3 of the shell component 2 are the same thickness. The deadening component acts to deaden the outer deadened portion 3 of the shell component 2 and the outer boundary edge of the inner actuatable portion 10. The inner actuatable portion 10 of the shell component 2 bounded by the outer deadened portion 3 provides an elastic membrane adapted to achieve a given quality of sound reproduction when transducing an electrical signal used to drive the exciter 30. For example, the elasticity of the inner actuatable portion 10 of the shell component 2 may be sufficient to cause sound having a high frequency, for example over 4kHz, to be emitted from the inner actuatable portion 10 when the exciter 30 is driven at substantially the high frequency. The elasticity of the inner actuatable portion 10 of the shell component 2 may be sufficiently low to cause sound having a low frequency, for example below 200 Hz, to be emitted from the inner actuatable portion 10 when the exciter 30 is operated at substantially the low frequency.

[0079] Figure 3C provides another example side view of cross section A-A' of figure 2. In this example, the vibrating panel loudspeaker further comprises a frame 20 fixed to the internally facing surface 2b of the outer deadened portion 3 of the shell component 2. The frame shape is an open cylinder, comprising a flat circular component and sides to extend the edge of the circle. The sides of the frame are secured to the internally facing surface 2b of the shell component 2 at the bounding edge 4. The frame may be mounted to the internally facing surface 2b of the shell component 2 at the bounding edge 4 of the outer deadened portion 3. A first part 32 of the exciter 30 is mounted to the flat circular component of the frame 20 and a second part 34 of the exciter 30 is mounted to the internally facing surface 2b of the shell component 2 such that the exciter 30 is between the internally facing surface 2b of the shell component 2 and the flat circular component of the frame. The second part 34 of the exciter 30 may be supported by the frame.

[0080] It will be understood that the frame can be secured to the internally facing surface 2b of the shell component 2 in a variety of ways. For example, holes and/or an adhesive fastening means can be used to secure the frame. In examples, the adhesive may extend substantially around the whole of the bounding edge 4 of the shell component 2. In other examples, the adhesive may be provided in a plurality of distributed locations around the bounding edge 4.

[0081] Figure 3D illustrates another example of a cross-section through the vibrating panel loudspeaker of Figures 1 and 2. In this example, the material of the shell component 2 is continuous through the inner actuatable portion 10 and outer deadened portion 3. Thus, the vibrating panel loudspeaker may have been formed with the shell component 2 of the product 1 to enable use of a continuous material. The inner actuatable portion 10 is thinner than the outer deadened portion 3. In an example, the sheet like shell component 2 which forms the outer deadened portion 3 may have been shaped to produce an inner actuatable portion 10. For example, the inner actuatable portion 10 may have been formed by reducing the thickness of a section of the sheet-like shell component 2. Figure 3D also illustrates an exciter 30 that is inertially mounted to the internally facing surface 2b of the shell component 2.

[0082] In an example, the material of the shell component 2 of Figure 3D is plasterboard. The exciter 30 may be inertially mounted directly to the internally facing surface of the plasterboard. The plasterboard may be continuous through the inner actuatable portion 10 and outer deadened portion 3. The plasterboard may be manipulated such that the inner actuatable portion 10 is thinner than the outer deadened portion 3. For example, the plasterboard may be thinned, compressed or cut in a machining process after formation of the plasterboard such that the inner actuatable portion 10 is thinner than the outer deadened portion 3. Alternatively, the inner actuatable portion 10 and outer deadened portion 3 may be formed during manufacture of the plasterboard, such as by moulding. The formation of the plasterboard in this way ensures that the manufacturing process to form the vibrating panel loudspeaker is fast and simple such that it is possible to manufacture the vibrating panel loudspeakers in bulk.

[0083] Figure 3E illustrates another example of a cross-section through the vibrating panel loudspeaker of Figures 1 and 2. Similarly to Figure 3D, in this example, material of the shell component 2 is continuous through the inner actuatable portion 10 and outer deadened portion 3. The inner actuatable portion 10 is thinner than the outer deadened portion 3. In Figure 3E, the shell component 2 of the vibrating panel loudspeaker further comprises a membrane 36 between the exciter 30 and the continuous material of the shell component 2. This figure also illustrates the exciter 30 inertially mounted to the membrane 36. The exciter 30 may be mounted to the centre of the membrane 36. In an example, the membrane 36 forms at least part of the inner actuatable portion 10 of the shell component 2 of the product, such that the membrane 36 is the elastic membrane that is caused to vibrate, on operation of the exciter, to generate sound.

[0084] The membrane 36 of Figure 3E may be of a different material to the continuous material of the shell component 2 and may be fixed to the continuous material. For example, the membrane 36 may be attached to the continuous material of the shell component 2 at the boundary between the inner actuatable portion 10 and outer deadened portion 3. In an example, the membrane 36 is more elastic than the continuous material of the shell component 2. In another example, the membrane 36 is less porous and more watertight than the continuous material of the shell component 2. The membrane 36 may have a circular opening in the middle such that the exciter 30 is in fluid contact with the continuous material of the shell component 2. In an example, the continuous material of the shell component 2 is plasterboard. The membrane 36 may be between the plasterboard and the exciter 30.

[0085] Where the product is a plasterboard, a sheet of plasterboard may be provided having a loudspeaker formed as part thereof in which a portion of the plasterboard itself is actuated as an elastic membrane with a deadened edge in order to produce sound. The loudspeaker being not visible from the externally facing surface of the plasterboard in use as the a continuous surface is provided across the inner actuatable portion 10 and outer deadened portion 3 of the loudspeaker.

[0086] In an example, the first part 32 of the exciter 30 comprises an electromagnet which can be activated and de-activated by an input electronic signal. The second part 34 of the exciter 30 comprises a metal component, such as a coil, which can be attracted and/or repelled by the electromagnet of the first part 32 when the electromagnet is activated. Thus, the inner actuatable portion 10 can be caused to vibrate and produce sound in response to operation of the electromagnet of the first part 32 of the exciter 30 by the input electronic signal. The exciter 30 as described may be termed a moving coil exciter having, for example, a neodymium or other rare earth magnet. It will be understood that the skilled person is aware of other exciters which can be used in vibrating panel loudspeakers, including methods for their construction and operation. Other examples of exciters include moving magnet exciters, magneto drivers, and piezo-electric exciters.

[0087] For a centrally mounted exciter 30 in a circular inner actuatable portion 10 with a substantially unmovable bounding edge 4, there is no natural variation in the distances from the exciter 30 location to the fixed bounding edge 4 of the outer deadened portion 3 around the inner actuatable portion 10, and as a result, the natural frequency response of the inner actuatable portion 10 features resonant peaks and dips, particularly in the LF range, and generally significantly more energy is transferred into the mid-range frequencies than low range frequencies This may result in the production of a sound response that some users may perceive to be ‘tinny’.

[0088] A discreet and easily mountable speaker can be provided having a desirably good audio response by a circular vibrating panel speaker in which the inner actuatable portion 10 is bounded by an outer deadened portion 3 around its outer boundary, in which the inner actuatable portion 10 is excited by a substantially centrally-positioned exciter 30, in which mode distribution means are provided, configured to induce, in use, non-circularly symmetric distortion of natural modes of oscillation of the inner actuatable portion 10 in response to operation of the exciter 30 in an assembly of the inner actuatable portion 10 and the exciter 30 absent the mode distribution means.

[0089] It has been found that without the mode distribution means, the substantially uniform distance from the exciter 30 to the boundary of the circular inner actuatable portion 10 would lead to poorer sound quality, for example due to acoustic artefacts in the frequency response for the vibrating panel loudspeaker (in particular at low and mid frequencies). Such artefacts are typically due to a restriction in the movement of different regions of the inner actuatable portion 10 imposed by the presence of the exciter 30. In some cases, the disadvantageous artefacts would be in the form of one or more notches and/or peaks in the low and mid frequency regions of the frequency response of the assembly of the inner actuatable portion 10 and the exciter 30 absent the mode distribution means.

[0090] The mode distribution means induce non-circularly symmetric distortion of natural modes of oscillation of the inner actuatable portion 10. By including the mode distribution means, acoustic energy from other areas of the frequency response can be redistributed to the frequency corresponding to the notches and/or peaks. The frequency response at the frequencies corresponding to be notches can be increased and the frequency response at the frequencies corresponding to the peaks can be decreased, resulting in a more uniform frequency response, as seen in Figure 4. Thus, the natural frequency response of the circular vibrating panel speaker is adjusted to smooth out the resonant peaks and troughs, and to balance the frequency spectrum, in particular the LF and mid-range, to produce a desirable and perceptibly ‘good’ audio response.

[0091] The effect of the mode distribution means on the frequency response of the circular vibrating panel speaker can be seen in particular in Figure 4, which shows a simulated frequency response for a circular vibrating panel loudspeaker as described above, both with and without the mode distribution means. The line having data points represented by triangles shows the frequency response of the vibrating panel loudspeaker as described, in the absence of the mode distribution means. As can be seen, the frequency response exhibits several pronounced peaks and notches, in particular at low and mid frequencies (i.e. below 10kHz), though there also continue to be peaks and notches in the high frequency region of the frequency response. Further, the reproducible sound intensity in the mid-range frequencies (generally around 200-2000 Hz) can be seen to be relatively high, whereas the low frequency range (below around 200 Hz) is relatively weakly reproduced. The line having data points represented by circles shows the frequency response of the vibrating panel loudspeaker as described, including the mode distribution means. As can be seen, the frequency response is far smoother when compared with that shown by the solid line. The height of the peaks and the depth of the notches have both been reduced to substantially flatten the frequency response, leading to an increase in the audio quality produced by the vibrating panel loudspeaker, particularly at low and mid frequencies. Further, it can be seen that the low range frequency response has been boosted by shifting some energy from the mid-ranges in particular.

[0092] This redistribution and smoothing of the reproducible frequencies is achieved by the mode distribution means inducing non-circularly symmetric distortion of natural modes of oscillation of the inner actuatable portion 10. As can be seen in Figures 5A and 5B, which are schematic representations illustrating the displacement at resonant modes in the inner actuatable portion 10 in the absence of the mode distribution means. Figure 5A shows the first resonant mode and Figure 5B shows the second resonant mode in which the unmovable bounding edge 4 of the shell component 2 and the fixing of the internally facing surface 2b of the shell component 2 to relatively rigid cylindrical foot 40 of the exciter 30 represent boundary conditions. As can be seen from Figures 5A and 5B, the intensity of displacement in these natural resonant modes from excitation of the inner actuatable portion 10 is significant, meaning that a large amount of energy is coupled into them.

On the other hand, Figures 5C and 5D are schematic representations illustrating the displacement at resonant modes in the inner actuatable portion 10 with the mode distribution means added to the inner actuatable portion 10. Figure 5C shows the first resonant mode and Figure 5D shows the second resonant mode. Thus, it can be seen that the intensity of the displacement in the resonant modes is greatly reduced, meaning that the excess energy is coupled into other modes of vibration, thereby enabling vibrational energy to be coupled into the generation of a broader range of different frequencies. It will also be appreciated that the displacement from the first and second resonant modes of the inner actuatable portion 10 (with the mode distribution means) is achieved by a non-circularly symmetric distortion applied by the mode distribution means to the inner actuatable portion 10. Indeed, the displacement from the modes of resonance of the inner actuatable portion 10 (with the mode distribution means) is not even rotationally symmetric on the inner actuatable portion 10. This mode distribution means enables the smoothing and improvement of the audio response of the circular vibrating panel loudspeaker. Including mode distribution means in the vibrating panel loudspeaker of figures 1 and 2 having a circular inner actuatable portion 10, which results in a further advantage of a perceptibly ‘good’ audio response.

[0093] As previously mentioned, one effect of the constrained edge of the inner actuatable portion 10 is that there exists a restoring force which acts to restore the inner actuatable portion 10 to a flat equilibrium whenever the exciter 30 causes a displacement of the central region of the inner actuatable portion 10. The presence of the restoring force helps to ensure that any slight unbalancing of the inner actuatable portion 10 caused by the mode distribution means does not affect the ability of the inner actuatable portion 10 to generate sound.

[0094] Yet further, good acoustic performance of the vibrating panel loudspeaker is ensured by providing mode distribution means, which counter the otherwise negative effects of mounting the exciter 30 substantially at an axial centre of the circular inner actuatable portion 10.

[0095] Figure 6 is an illustration of an underside of the vibrating panel loudspeaker of Figures 1 and 2. Figure 6 illustrates the shell component 2 of the product 1. As has been described with reference to previous figures, the shell component 2 has an outer deadened portion 3 surrounding a generally planar circular inner actuatable portion 10. The outer deadened portion 3 has a substantially unmovable circular bounding edge 4. The shell component has an externally facing outer boundary surface 2a (see figures 3A to 3D) and an internally facing surface 2b. The exciter 30 may be mounted to the internally facing surface 2b of the inner actuatable portion 10 of the shell component 2 via a foot 40 in contact with the internally facing surface 2b of the shell component 2. Alternatively the exciter 30 may be mounted directly on the internally facing surface 2b of the shell component 2. Owing to the circular geometry of the inner actuatable portion 10 and the central mounting of the foot 40 or the exciter 30 on the inner actuatable portion 10, the inner actuatable portion 10 is provided with mode distribution means in the form of one or more components 50 coupled to the internally facing surface 2b of the inner actuatable portion 10 to add weight thereto. The one or more components 50 are arranged such that the inner actuatable portion 10 in combination with the one or more components 50 is non-circularly symmetric. In other words, the natural modes of oscillation of the inner actuatable portion 10 in response to operation of the exciter 30 in an assembly of the inner actuatable portion 10 and the exciter 30, absent the mode distribution means are distorted. Thus, it has been found that significant notches and/or peaks in the frequency response of the vibrating panel loudspeaker, which would otherwise be present due to the circular shape of the inner actuatable portion 10 and central mounting of the exciter 30, can be lessened in intensity. In some examples, the notches and/or peaks can be substantially eliminated from the frequency response by careful positioning of the mode distribution means. Viewed in another way, audio energy from peaks in the frequency response for the vibrating panel loudspeaker in the absence of the mode distribution means can be redistributed to heavily damped areas of the frequency response.

[0096] In this example, the arrangement of the one or more components 50 is non-rotationally symmetric. In this example, the one or more components 50 are in the form of metal weights. In this example, the metal weights are formed from a non-toxic metal. Suitable non-toxic metals include stainless steel. In this example, the one or more components 50 are mounted on the rear surface 2b of the inner actuatable portion 10.

[0097] Although the presently described example uses four metal weights 50 to provide the mode distribution means, it will be understood that the mode distribution means may be provided in any other suitable way. For example, the inner actuatable portion 10 could be provided with one or more bulges or depressions defined in the internally facing surface

2b thereof. The one or more bulges and depressions could be arranged such that the natural modes of oscillation of the inner actuatable portion 10 in response to operation of the exciter 30 in an assembly of the inner actuatable portion 10 and the exciter 30, absent the mode distribution means are distorted.

[0098] Figure 7 is a further illustration of an underside of the vibrating panel loudspeaker of Figures 1 and 2 showing the internally facing surface 2b of the inner actuatable portion 10 of the shell component 2. The inner actuatable portion 10 is substantially as described hereinbefore, in particular with regard to figure 6, apart from the hereinafter noted differences. In particular, the mode distribution means is provided by a plurality of components 51, 52, 53, 54, at least one of which has a different size and shape to another of the plurality of components 51, 52, 53, 54. In this example, a first component 51 is positioned substantially opposite a second component 52, though the first component 51 has a depth greater than the second component 52 and the first component 51 is a different size and shape to the second component 52. A third component 53 is positioned on the rear surface 2b of the inner actuatable portion 10, rotationally spaced from the first component 51 and the second component 52. A fourth component 54 is positioned substantially opposite the third component 53. The fourth component 54 has a depth less than the third component 53. The fourth component 54 has a size and shape different from the third component 53. Further, the first, second, third and fourth components 51, 52, 53, 54 are specifically positioned to distort the natural modes of oscillation of the inner actuatable portion 10, substantially as described hereinbefore.

[0099] In summary, there is provided a product 1 having a vibrating panel loudspeaker integrally formed within a shell component 2 of the product 1. The product 1 comprises a sheet-like shell component 2 providing a part of a casing defining an externally facing outer boundary surface 2a of a product 1 or part of a casing defining an internal surface of the product 1 that is in fluid communication with the externally facing outer boundary surface 2a; and an exciter 30 coupled to an internally facing surface 2b of the shell component 2 ,the shell component 2 having an outer deadened portion 3 surrounding a generally planar circular inner actuatable portion 10 bounded by and integrally formed to the outer deadened portion 3 to provide a continuity on the externally facing outer boundary surface of the shell component 2 from the outer deadened portion 3 across the inner actuatable portion 10, the product 1 being configured such that the outer deadened portion 3 of the shell component 2 is substantially unmoveable by the exciter 30, and such that the inner actuatable portion 10 is movable in response to actuation by the exciter 30, wherein the substantially unmovable bounding edge 4 of the outer deadened portion 3 acts to deaden the outer boundary edge of the inner actuatable portion 10 such that the inner actuatable portion 10 forms an elastic membrane that is caused to vibrate, on operation of the exciter 30, to generate sound.

[00100] Throughout the description and claims of this specification, the words “comprise” and “contain” and variations of them mean “including but not limited to”, and they are not intended to (and do not) exclude other components, integers or steps. Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

[00101] Features, integers, characteristics or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

CLAIMS

1. A product having a vibrating panel loudspeaker integrally formed within a shell component of the product, the product comprising:

a sheet-like shell component providing a part of a casing defining an externally facing outer boundary surface of a product; and

an exciter coupled to an internally facing surface of the shell component,

the shell component having an outer deadened portion surrounding a generally planar circular inner actuatable portion bounded by and integrally formed to the outer deadened portion to provide a continuity on the externally facing outer boundary surface of the shell component from the outer deadened portion across the inner actuatable portion, the exciter being coupled to the inner actuatable portion of the shell component,

the product being configured such that the outer deadened portion of the shell component is substantially unmoveable by the exciter, and such that the inner actuatable portion is movable in response to actuation by the exciter, wherein the substantially unmovable bounding edge of the outer deadened portion acts to deaden the outer boundary edge of the inner actuatable portion such that the inner actuatable portion forms an elastic membrane that is caused to vibrate, on operation of the exciter, to generate sound.

2. The product of claim 1, wherein the shape of the externally facing outer boundary surface of the product is such that the presence of the speaker is not readily perceptible from the exterior of the casing.

3. The product of claim 1, 2 or 3, wherein the externally facing outer boundary surface of the shell component is a continuous generally planar surface.

4. The product as claimed in any preceding claim, wherein the exciter is located substantially at an axial centre of the circular inner actuatable portion.

5. The product as claimed in any preceding claim, wherein the inner actuatable portion is formed to have a substantially constant density per unit area across the externally facing outer boundary surface of the shell component.

6. The product as claimed in any of the preceding claims, wherein the inner actuatable portion and outer deadened portion of the shell component are composed of the same material.

7. The product as claimed in any of the preceding claims, wherein the inner actuatable portion and outer deadened portion of the shell component are the same thickness.

8. The product of any of claims 1 to 6 wherein the inner actuatable portion is thinner than the outer deadened portion of the shell component.

9. The product of claim 8 wherein the inner actuatable portion and the outer deadened portion together provide a continuous form to the external surface of the shell component.

10. The product of claim 8 wherein a transition from the inner actuatable portion to the outer deadened portion is a sloping edge.

11. The product as claimed in any of the preceding claims, wherein the material of the inner actuatable portion is more flexible material than the material of the outer deadened portion of the shell component.

12. The product as claimed in any of the preceding claims, wherein the boundary between the inner actuatable portion and outer deadened portion is sealed.

13. The product as claimed in any of the preceding claims, wherein the shell component provides a sealed surface of the external casing of the product.

14. The product as claimed in any of the preceding claims, wherein a deadening component is mounted to the shell component around the boundary between the inner actuatable portion and outer deadened portion to act to deaden the outer deadened portion of the shell component.

15. The product as claimed in any of the preceding claims, wherein the exciter is inertially mounted to the shell component.

16. The product as claimed in any of claims 1 to 14, further comprising a frame fixed to the internally facing surface of the outer deadened portion, wherein the exciter is mounted to and supported by the frame such that the exciter is coupled to the internally facing surface of the shell component.

17. The product as claimed in any of the preceding claims, wherein the inner actuatable portion has an outer diameter of less than 30 centimetres.

18. The product as claimed in any of the preceding claims, further comprising mode distribution means configured to induce, in use, non-circularly symmetric distortion of natural modes of oscillation of the inner actuatable portion in response to operation of the exciter in an assembly of the shell component and the exciter absent the mode distribution means.

19. The product as claimed in claim 18, wherein the mode distribution means are configured to induce, in use, non-rotationally symmetric distortion of natural modes of oscillation of the inner actuatable portion in response to operation of the exciter in the assembly of the shell component and the exciter absent the mode distribution means.

20. The product as claimed in claims 18 or 19, wherein the mode distribution means comprise one or more components coupled to the inner actuatable portion to add weight thereto to induce the distortion in the natural modes of resonant oscillation of the inner actuatable portion in the assembly of the shell component and the exciter in response to operation of the exciter.

21. The product as claimed in claim 20, wherein the one or more components are formed from non-toxic metal.

22. The product as claimed in claims 20 or 21, wherein the one or more components are coupled to the inner actuatable portion away from the centre of the inner actuatable portion in a direction along the internally facing surface of the shell component.

23. The product as claimed in any of claims 20 to 22, where the one or more components is at least two components and wherein each component is differently spaced from the centre of the inner actuatable portion.

24. The product as claimed in claim 23, wherein the at least two components are spaced apart over a region of at least 60 degrees relative to the centre of the inner actuatable portion.

25. The product as claimed in claims 23 or 24, wherein the at least two components is at least four components and wherein a maximum angular spacing between any two components, relative to the centre of the inner actuatable portion, is less than 180 degrees.

26. The product as claimed in any of claims 20 to 25, wherein the one or more components are coupled to the internally facing surface of the inner actuatable portion of the shell component.

27. The product as claimed in any preceding claim, wherein a centre of mass of an assembly of the inner actuatable portion and the mode distribution means is away from a centre of the inner actuatable portion in a direction along the externally facing outer boundary surface of the shell component.

28. The product as claimed in any preceding claim, wherein the exciter is coupled to the internally facing surface of the shell component via a foot and wherein the mode

distribution means is provided at one or more regions of the inner actuatable portion of the shell component outside the foot.

29. The product as claimed in any preceding claim, wherein the mode distribution means is arranged, in use, to be asymmetric relative to any line of symmetry through the centre of the inner actuatable portion of the shell component.

30. The product as claimed in any preceding claim, wherein the inner actuatable portion and outer deadened portion are formed to have a substantially constant density per unit area across the externally facing outer boundary surface of the shell component.

31. The product as claimed in any preceding claim, wherein a maximum thickness of the inner actuatable portion is less than 3 millimetres.

32. The product as claimed in any preceding claim, wherein a minimum thickness of the outer deadened portion is more than or equal to 3 millimetres.

33. The product as claimed in any preceding claim, wherein the inner actuatable portion of the shell component bounded by the outer deadened portion provides an elastic membrane adapted to achieve a given quality of sound reproduction when transducing an electrical signal used to drive the exciter.

34. The product as claimed in any preceding claim, wherein the product is configured such that the elasticity of the inner actuatable portion of the shell component is sufficient to cause sound having a high frequency over 4kHz to be emitted from the inner actuatable portion when the exciter is driven at substantially the high frequency.

35. The product as claimed in any preceding claim, wherein the product is configured such that the elasticity of the inner actuatable portion of the shell component is sufficiently low to cause sound having a low frequency below 200 Hz to be emitted from the inner actuatable portion when the exciter is operated at substantially the low frequency.

36. The product as claimed in any preceding claim, wherein the product is a consumer electronics product, such as a toy, a video display, a smart phone, a tablet, a loudspeaker, or a gaming device, optionally a portable or handheld device.

37. The product as claimed in any preceding claim, wherein the product is not only a loudspeaker.

38. The product as claimed in any preceding claim, wherein the casing of the consumer electronics product is substantially sealed, optionally watertight.

39. The product as claimed in any preceding claim, wherein the product is plasterboard.

40. The product as claimed in any of the preceding claims, wherein the material of the shell component is continuous through the inner actuatable portion and outer deadened portion.

41. The product as claimed in claim 40, wherein the inner actuatable portion of the shell component further comprises a membrane between the continuous material and the exciter, the exciter being inertially mounted to the membrane, wherein the material of the membrane is different to the continuous material.

Intellectual Property Office

Application No:	GB1809370.8	**Examiner:**	Peter Easterfield
Claims searched:	1 to 41	**Date of search:**	31 October 2018

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-41	US 2003/059068 A1 (BANK et al) see figs 12a, 12b
X	1-41	US 6580799 B1 (AZIMA et al) see fig 2 and col 2 lines 28-37
X	1-41	US 6266426 B1 (AZIMA et al) see figs 3 & 4
X	1-41	WO 2016/085615 A1 (APPLE) see fig 2A and para [0020]
X	1-41	WO 00/69212 A1 (NEW TRANSDUCERS) see figs 1-4 and page 3 line 24 to page 4 line 9
X	1-41	WO 00/36875 A2 (WHARFEDALE) see figs 3-5
A	-	GB 2360665 A (SLAB) see fig 7 and page 8 lines 35, 36
A	-	WO 2005/101899 A2 (NEW TRANSDUCERS) see figs 1, 2
A	-	WO 02/45460 A2 (NEW TRANSDUCERS) see fig 1
A	-	GB 2504691 A (JAGUAR LAND ROVER) see page 6 lines 15-18
A	-	US 2009/175484 A1 (SAINT VINCENT et al) see para [0059]

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A	-	US 2009/232333 A1 (KONDO et al) see para[0038]

Categories:

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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

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H04R

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
H04R	0007/04	01/01/2006