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# (54) Waterproof transducer for half-wavelength array

(57) The ultrasonic transducer device (10) for a λ/2 ultrasonic sensor phased array comprises a rectangular housing having thin sidewalls (13), having a height h, and having a rectangular or elliptical membrane (12) attached to the upper extremities of the sidewalls, and having a longer side A and a shorter side $a_1$, and a vibrator (11) attached to said membrane (12) for causing said membrane to vibrate.

According to the present invention, the thickness e of the sidewalls fulfils the following equation

$$e/a_1 = \frac{d_1 - a_1}{2a_1} \leq \frac{1}{8} \text{ with } d_1 \leq \lambda/2,$$

the height h fulfils the following equation

$$0.1 \times d_1 \leq h < 0.6 \times d_1, \text{ with } d_1 = \lambda/2$$

so as to avoid generation of parasitic flexural vibration of said sidewalls, and
the longer side A has the following relation with the shorter side $a_1$:

$$1.5 \times a_1 \leq A \leq 3 \times a_1.$$

The device is sensitive and robust and may be used for indoor and outdoor applications such as parking-aid systems for vehicles.

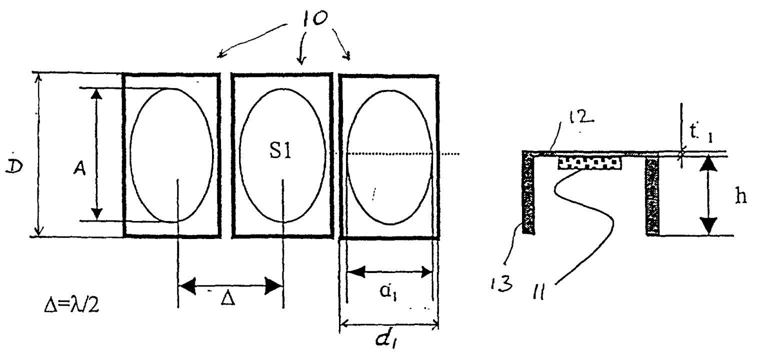


Figure 2

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## Description

**[0001]** The present invention concerns electronic scanning arrays using an ultrasonic transducer for measuring positions, by determination of distances and angles to objects in indoor and outdoor applications and may be used, for example, in parking-aid systems in vehicles.

**[0002]** The transducers are used as emitters and receivers and arranged such that at least two ultrasonic beams are generated in the observation area when they are excited by an appropriate electronic scanning signal.

**[0003]** In order to make an electronic scanning acoustic array without grating lobes, it is necessary to have a distance between two adjacent transducer centres of the array of half wavelength (λ/2) order. As explained in e.g. the document EP-A-0 898 175 in the name of the present applicant, in an array configuration, the acoustic field of the transmitter array is given by a superposition of the vibrations from the emitters electronically excited with different phases. The resulting generated wave consists of a main lobe and of secondary lobes, or side lobes. In a linear transducer array, the directivity of the different lobes depends on the number of transducers and the frequency (wavelength), and the radius of the transducers (angular width) and appodisation (weighting) of the excitation signals supplied to the transducers. The angular distance between the lobes depends on the distance between the transducers. As is known to a skilled person, in order to avoid any interference echoes of the secondary lobes, it is necessary to increase the main lobe power and to decrease, or even eliminate, the secondary lobes.

**[0004]** Thus, in the best configuration, in order to avoid the side lobe problem, it is necessary to have a distance between two adjacent element centres of less than or equal to λ/2. For example, at 40 kHz in air medium at room temperature (~15°C to 25°C), this means a distance between two adjacent elements of less than or equal to approximately 4.25 mm in the scanning plane. The frequency is generally chosen to be around 40 kHz, but in any case more than 32 kHz (below this frequency ultrasounds would disturb dogs), but less than 100 kHz due to increased air attenuation of the emitted and reflected signal.

**[0005]** Furthermore, the application of such a transducer array in outdoor application requires a robust device with a high sensitivity. The device should not only be waterproof, but it should also be capable of surviving a certain impact, such as when a vehicle hits an obstacle during a parking manoeuvre.

**[0006]** Several transducer technologies are already known which allow to realise λ/2 arrays, for example the publication "ultrasonic vehicle guidance transducer" - Ultrasonics - 1990 Vol. 28 November shows an example of an electrostatic ultrasonic array, and the publication "ultrasonic transducers and transducer arrays for application in Air" shows an example of PVDF array. However, these technologies are expensive and the transducer surface is too fragile for use in outdoor applications. For instance, the membrane thickness of electrostatic foil transducers is in the order of a few μm.

**[0007]** Generally, the structure used for mounting the transducer element consists of a bilaminar vibrating structure composed of a piezoelectric plate coupled to an elastic diaphragm, see e.g. the documents US-A-5 987 992, US-A4 705 981 or US-A3 736 632. This structure uses the flexural vibration of a thin membrane, in general less than 1 mm, to generate or to receive acoustic waves. During emission, the piezoelectric plate transforms the electrical signal into a mechanical vibration of the membrane, and during reception, the piezoelectric plate transforms the mechanical vibration into an electrical signal.

**[0008]** In general, such a transducer has a resonant behaviour, i.e. the resonance frequency of the membrane vibration corresponds to the acoustic wave propagation frequency. In such prior art devices, the membrane is attached to a rigid and large part that is called the housing.

**[0009]** Figure 1 shows an example of a typical prior art transducer structure. As can be seen, piezoelectric element 1 is attached to membrane 2, which is supported by housing 3. The membrane has a diameter of a0, called the membrane size. The transducer size is the membrane size plus the sidewall thickness and thus is $d_0$. The centre of the transducer is referenced as S0. The membrane thickness is indicated as $t_0$. In order to avoid flexion of the housing walls, the housing is preferably thick. However, this way of mounting the transducer leads to a large transducer size so that a distance of λ/2 between the centres of the transducers in the arrayed sensor becomes very difficult. Indeed, if this distance is respected, the device will suffer from sensitivity and weakness problems of the active surface as will be explained in detail hereafter.

**[0010]** To make a half-wavelength array means that the distance between two adjacent transducer centres is

$$\Delta=\frac{\lambda}{2}=d \text{ so } d=\frac{c}{2f_a} \quad (1)$$

**[0011]** (For simplification we suppose that the transducers are tangent so the gap between transducers is supposed to be zero), wherein

d = the size of the transducer in the scanning plane,
λ = the wavelength of the acoustic wave,
c = the velocity of sound,
$f_a$= the frequency of the acoustic wave, and
Δ = the distance between two transducers centres.

**[0012]** The relation (1) means that the transducer size is fixed by the acoustic wavelength, i.e. by the frequency

$f_a$.

**[0013]** According to the reference "Formula for natural frequency and mode shapes", BELVINS KREIGER 1995, the vibration resonance frequency of a plate is given by the relation

$$f_{ij} = \frac{\lambda_{ij}^{\ 2}}{2\pi a^2}\left(\frac{E \bullet t^3}{12\gamma(1-\nu)^2}\right)^{\frac{1}{2}}$$

For a given vibration mode and given material this relation could be simply written as

$$f_V \propto \sqrt{\frac{t^3}{a^2}} \qquad (2),$$

wherein

$f_V$ is the membrane vibration mode frequency,
a is the width or radius of the membrane, and
t is its thickness.

**[0014]** The relation (2) means that to get $f_V$=$f_a$= operating frequency, the membrane size "a" and the membrane thickness "t" must be set to a value determined by this relation and by the membrane material.

**[0015]** In particular for a given frequency and given material of the membrane, if the membrane size "a" decreases, the thickness "t" must also decrease to keep constant the frequency.

**[0016]** Hence a skilled person understands well that if the size "d" of the transducer is set to match the λ/2 (half-wavelength) requirement, with a large housing (wall part) as described in the cited prior art, the membrane size "a" will be small and consequently the membrane thickness must be reduced to match the resonance frequency, thus leading to a very thin, and fragile, membrane.

**[0017]** As may be understood, as a countermeasure it is possible to make the housing (or the wall) as thin as possible in order to have a transducer size and membrane size almost the same.

**[0018]** However, this will lead to a parasitic vibration appearing on the wall. This will affect the transducer performances, in particular its frequency and directivity pattern. Furthermore, the occurrence of such wall vibration will create an acoustic coupling between the different elements.

**[0019]** The object of the present invention is to propose a new transducer design in which the geometry is determined in such manner to allow the realisation of a λ/2 array, compatible with industrial constraint in term of reliability, performances and cost.

**[0020]** Thus, the present invention concerns an ultrasonic transducer device as defined in the appended claims.

**[0021]** The present invention also concerns an ultrasonic half-wavelength sensor array comprising at least two of such transducers, as also defined in the claims.

**[0022]** Thanks to the transducer device of the present invention, it is possible to provide a sensitive transducer array with λ/2 arrangement between the transducer elements, the transducers being robust and suitable for outdoor applications.

**[0023]** Other features and advantages of the device according to the present invention will become clear from reading the following description, which is given solely by way of a non-limitative example thereby referring to the attached drawings in which:

FIGURE 1 is a schematic view of a previously cited prior art transducer structure,
FIGURE 2 shows a schematic view of a preferred embodiment of the transducer device according to the present invention,
FIGURE 3 shows a schematic view of an embodiment of a λ/2 sensor array comprising several transducer devices according to the present invention, and
FIGURE 4 shows a schematic view of another embodiment of a λ/2 sensor array comprising several transducer devices according to the present invention.

**[0024]** In figure 2, several transducer devices 10 according to the present invention are shown. Each device 10 has a structure such that it may be used in a λ/2 ultrasonic sensor phased array in indoor or outdoor application. This means that within the array, the centre of each transducer device is separated a distance λ/2 from the next device's centre. Such a sensor array may be used, for example, as a vehicle parking-aid sensor. In this case, the sensor array can be positioned, e.g. in the bumper of the vehicle so as to measure the position (distance and angle) to an obstacle. Of course, such a sensor may also be used, e.g., for the detection of presence and localisation of objects and/or in combination with robotics.

**[0025]** The transducer device 10 according to the present invention comprises a housing having thin sidewalls 13. These sidewalls are thinner than the sidewalls of the prior art device. Thus, the total diameter of the device may be reduced, and therefore also the size of the sensor array can be reduced compared to prior art arrays.

**[0026]** As can be seen in figure 2, the housing is rectangular and has a longer side D and a shorter side $d_1$. The sidewalls 13 have a height referenced "h". The housing further comprises a membrane 12 attached to the upper extremities of the sidewalls 13 to close of the housing at its top surface. A vibrating element 11, such as a piezoelectric plate, is attached to the bottom surface of membrane 12 so as to be situated within the housing. Vibrating element 11 is arranged to cause membrane 12 to vibrate in a bending mode.

**[0027]** Membrane 12 is of rectangular or elliptical shape and has a longer side A and a shorter side $a_1$. Due to the usual placing of the sensor array in a bumper of a vehicle, the longer side is referred to as the vertical size of the membrane, whereas the shorter side is referred to as the horizontal size of the membrane. Thus, the longer side A is arranged in a direction perpendicular to the scanning plane, whereas the shorter side $a_1$ is arranged in a direction parallel to the scanning plane.

**[0028]** As mentioned above, the sidewalls are thinner than those of prior art devices are. In order to avoid flexural vibration of such thin sidewalls, the present inventors have realised that by using a rectangular design and by using a specific height of the sidewalls, a greater sensitivity of the device may be obtained thereby ensuring sufficient reliability of the device allowing for outdoor applications. Indeed, the rectangular or elliptical design of the membrane and housing results in a larger radiating surface than is the case for prior art devices.

**[0029]** The performances are optimal provided the membrane is mounted in a correct manner, and the array is placed as mentioned such that the shorter side of the membrane is in the scanning plane. Thus, the membrane may then also have a thickness that is sufficient to ensure a correct and reliable operation even in outdoor applications such as vehicle parking-aid assistance, even when using a resonance frequency in the order of about 40 kHz.

**[0030]** In view of the above, the inventors have created a simulation model to determine the optimum configuration for the transducer according to the present invention.

**[0031]** The following results were obtained. These results were used to build a transducer having a steel membrane and sidewalls. However, the simulations further confirmed the same results when using other materials, such as other metals, e.g. aluminium, or polymers, such as loaded epoxy resin based polymers, i.e. the same conditions should be fulfilled.

**[0032]** In the preferred design, the height "h" of the sidewalls is chosen to be

$$0.1 \times d_1 \leq h \leq 0.6 \times d_1 \qquad (3),$$

**[0033]** with $d_1 = \lambda/2$, due to the requirement of mounting the transducer device in a $\lambda/2$ electronic scanning sensor array. Thus, the distance $\Delta$ between each transducer centre must be less than or equal to $\lambda/2$ in the scanning plane. Preferably, $\Delta = d_1 + \alpha$ ($\alpha \leq d_1/10$) for a compact design.

**[0034]** Furthermore, the vertical size A of the membrane 12 is chosen larger than the horizontal size a1, and preferably fulfils the following relation

$$1.5 \times a_1 \leq A \leq 3 \times a_1 \qquad (4).$$

**[0035]** Indeed, if A is set to be smaller than 1.5 x $a_1$, this will lead to an increase of the first vibration mode, whereas if "a" is chosen larger than 3 x $a_1$, this will generate a higher vibration mode which disturbs the vertical directivity.

**[0036]** This can be justified by the fact that according to the reference "Formula for natural frequency and mode shapes", already cited above, the factor $\lambda_{ij}$ is dependent on the ratio $A/a_1$. In particular, the frequency of the vibration mode (1,1) increases when the ratio $A/a_1$ increases. Furthermore, a complete FEM simulation showed that the quality factor of the mode (1,1) decreases when the ratio $A/a_1$ increases, while the quality factor of higher mode becomes predominant.

**[0037]** It should thus be understood that it is important to optimise the ratio $A/a_1$ in such a manner to have an as large as possible radiating surface to allow for high sensitivity ($A/a_1 \geq 1.5$) and to keep high the quality factor of the first mode named (1,1) mode (typically $A/a_1 \leq 3$).

**[0038]** The thickness of the sidewalls is referenced "e" and fulfils the following relation:

$$e = (d_1 - a_1)/2$$

**[0039]** By respecting the relations (3) and (4) for the sensor design, the inventors thus have realised a transducer whose ratio of sidewalls thickness, referenced "e", compared to the shorter side $a_1$ of the membrane fulfils the following relation

$$e/a1 = \frac{d_1 - a_1}{2a_1} \leq \frac{1}{8} \qquad (5).$$

**[0040]** In fact, A should be set as large as possible in accordance with the resonance frequency and the vibration mode.

**[0041]** As mentioned above, the sensitivity of the transducer is proportional to the membrane surface. As the transducer device according to the present invention has thinner sidewalls, the membrane horizontal size $a_1$ can be larger than the diameter $a_0$ of a conventional circular membrane as shown in Figure 1. Indeed, if the distance between the transducer centre's is maintained at $\lambda/2$, then $a_1 > a_0$. Furthermore, as the horizontal size A is chosen larger than $a_1$, the entire membrane surface will be much larger as compared to the prior art membrane.

**[0042]** Furthermore, as the thickness of the membrane increases with the membrane size, according to formula (2) above, the thickness $t_1$ of the membrane of the transducer device according to the present invention will be greater than the thickness $t_0$ (see Figure 1) of the prior art transducer.

**[0043]** Consequently, the transducer device according to the present invention has a higher sensitivity and is less fragile as compared to the prior art transducer.

**[0044]** Preferably, the material of the housing and of membrane 12 is metallic or a polymer material. In particular, aluminium or steel is suitable from a manufacturing cost point of view and advantageously also improves shielding characteristics of the device. However, a loaded epoxy based-polymer can also be used.

**[0045]** By assembling several of such transducer devices according to the present invention together, an ultrasonic half-wavelength sensor phased array is obtained which thus is compact in size, but has a high sensitivity and is robust.

**[0046]** Figure 3 shows a first embodiment of such a λ/2 sensor phased array. Array 20 comprises in this example seven transducer devices 10 according to the present invention, which are arranged so that their centres S1 are spaced apart a distance λ/2. Transducer devices 10 are mounted on a rigid support 21.

**[0047]** Support 21 is preferably made of resin or resin glass fibre, or resin metallic powder material to ensure sensor protection. In this embodiment, the transducer devices 10 are manufactured and mounted individually and then assembled in the support. Preferably, a silicone rubber 22 is used for positioning the devices in the support. This seal 22 also provides an acoustic separation between the transducers. In this manner, the transducers can thus be sorted and selected before mounting to obtain optimal array performance.

**[0048]** Figure 4 shows another embodiment of a λ/2 sensor array. Here array 30 is manufactured as one part, i.e. support 31 and transducers 10 are an integral part of the array.

**[0049]** The manner in which the array is connected and the vibrator is activated is considered well known to a skilled person so that it does not seem necessary to further explain such.

**[0050]** Having described a preferred embodiment of this invention, it will now be apparent to one of skill in the art that other embodiments incorporating its concept may be used. It is felt, therefore, that this invention should not be limited to the disclosed embodiment, but rather should be limited only by the scope of the appended claims.

## Claims

1. Ultrasonic transducer device (10) for a λ/2 ultrasonic sensor phased array in which each device's centre is separated by a distance λ/2, said sensor phased array scanning in a scanning plane so as to measure the distance and angular position of objects, comprising:

   - a rectangular or elliptical housing having thin sidewalls (13) of thickness e, with $e=[d_1-a_1]/2$, having a height h, and having a rectangular or elliptical membrane (12) attached to the upper extremities of the sidewalls so as to close the housing on its top surface, the membrane having a longer side A in the direction perpendicular to the scanning plane and a shorter side $a_1$ in the same direction as the scanning plane, and
   - a vibrator (11) attached to said membrane (12) for causing said membrane to vibrate in a bending mode,

   **characterised in that**

   the sidewalls thickness e fulfils the following relation

   $$e/a_1 = \frac{d_1 - a_1}{2a_1} \leq \frac{1}{8} \text{ with } d_1 \leq \lambda/2$$

   so as to permit a λ/2 spacing phased array configuration with a high sensitivity property,

   the height h of said sidewalls (13) is optimised to suppress parasitic vibration and fulfils the following equation

   $$0.1 \times d_1 \leq h \leq 0.6 \times d_1, \text{ with } d_1 \leq \lambda/2$$

   so as to avoid generation of parasitic flexural vibration of said sidewalls, and **in that**

   the longer side A of said membrane has the following relation with the shorter side $a_1$:

   $$1.5 \times a_1 \leq A \leq 3 \times a_1.$$

2. Ultrasonic transducer device (10) according to claim 1, wherein said housing and said membrane are made of a metal or of a polymer material.

3. Ultrasonic transducer device (10) according to claim 1, wherein said housing and said membrane are made of steel or aluminium.

4. Ultrasonic transducer device (10) according to claim 1, wherein said housing and said membrane are made of a loaded epoxy resin-based polymer.

5. Ultrasonic half-wavelength sensor phased array (20, 30) comprising a rigid support (21, 31) containing at least two ultrasonic transducer devices (10) according to anyone of claims 1 to 4.

6. Ultrasonic half-wavelength sensor phased array (20, 30) according to claim 5, wherein said rigid support (21, 31) is made of resin, resin glass fibre, or

resin metallic powder.

**7.** Ultrasonic half-wavelength sensor phased array (20, 30) according to claim 5 or 6, wherein said support (21, 31) further comprises a silicone rubber seal (22) for positioning the transducer devices (10) in the support (21, 31) thus constituting an acoustic separation between said transducer devices.

**8.** Ultrasonic half-wavelength sensor phased array (30) according to anyone of claims 5 to 7, wherein said support (31) and said transducer devices (10) are an integral part of the array (30).

*PRIOR ART*

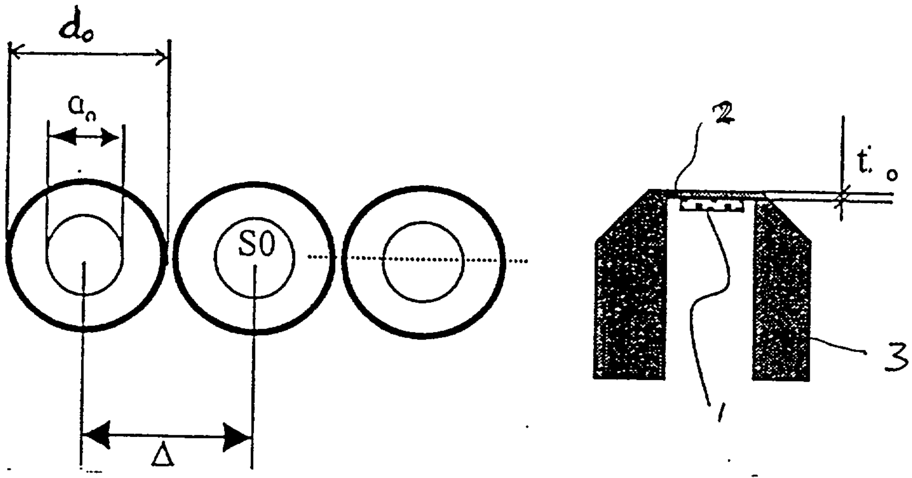


Figure 1

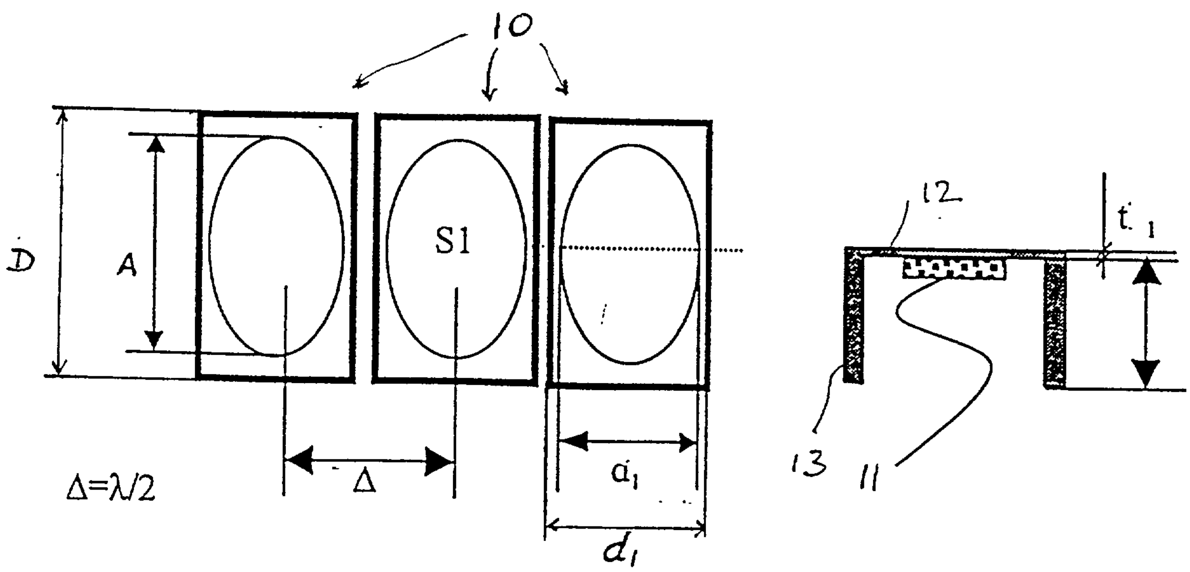


Figure 2

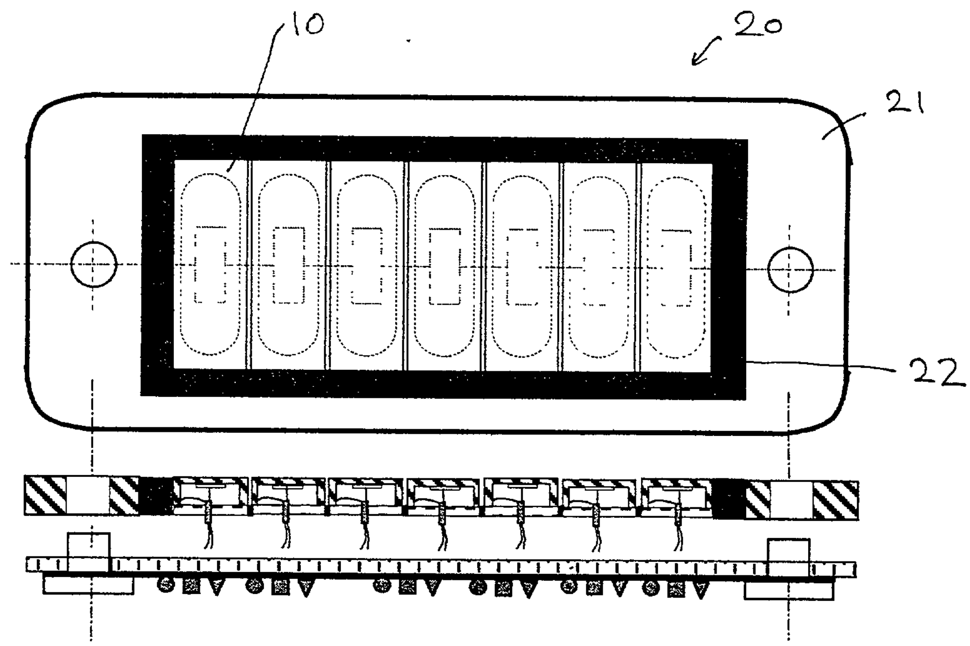


Figure 3

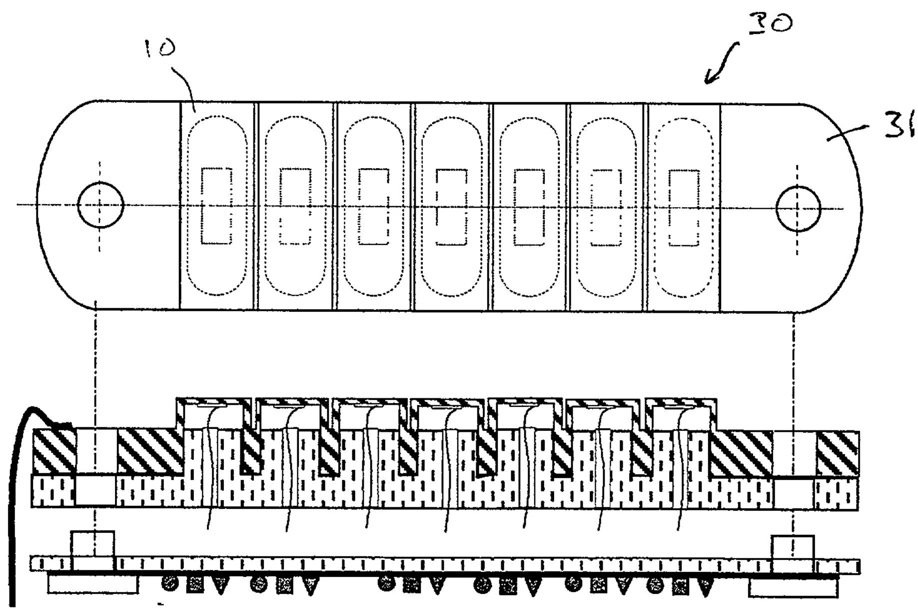


Figure 4

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# EUROPEAN SEARCH REPORT

Application Number
EP 00 40 2981

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| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int.Cl.7) |
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The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 19 April 2001 | Haasbroek, J |

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