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(54) **Ultrasonic transducer with a horn and phased array using such ultrasonic transducers**

(57) This invention relates to an ultrasonic transducer (10;11) comprising an ultrasonic transducer part (10';11') having a height and a width, and at least one horn part (10'';11'') having one outside end and the other end attached to the ultrasonic transducer part (10';11'), at least the height or the width of the outside end of the horn part (10'';11'') being smaller than the height or the width of the ultrasonic transducer part (10';11'). This type of ultrasonic transducers are advantageously used in an ultrasonic transducer phased array for emitting/receiving ultrasonic waves in a scanning zone, in which the centers of adjacent outside ends of the horn parts (10'';11'') are spaced from each other by a distance of about, or inferior to, half the wavelength ($\lambda/2$) of the emitted ultrasonic radiation (Shannon Law).

Such an ultrasonic transducer array permits to solve prior art technical problems in terms of scanning speed, precision, cost and power, and are well adapted for applications as robot or vehicle guidance.

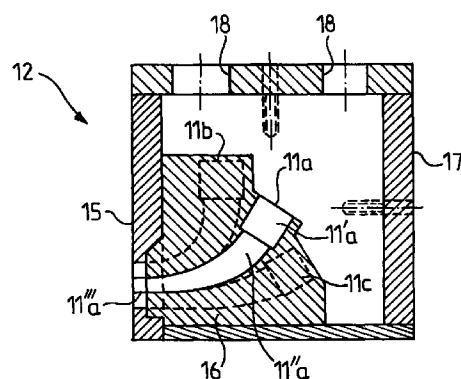


FIG.5b

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Description

[0001] This invention relates to an ultrasonic transducer, comprising an ultrasonic transducer part and at least one horn part, an ultrasonic transducer phased array using a plurality of such ultrasonic transformers, and an ultrasonic detection apparatus implementing such an ultrasonic transducer or such an ultrasonic transducer phased array.

[0002] The use of ultrasonic transducers arranged in array is well-known, particularly for scanning an observation area for controlling robots or vehicles. This type of application requires an acoustic power high enough to scan a large area with a detecting depth of several meters, and an operating speed suitable for controlling the movements of the robots or vehicles. A known solution resides in improving the focus of the acoustic energy (i.e. the directivity) of one ultrasonic transducer by using a flaring horn, i.e. trumpet-shaped horn, so as to focus the emission/reception directivity of an acoustic transducer towards one determined direction. The acoustic waves may be focused in a predetermined direction whereby the reception sensibility of acoustic waves is increased in this predetermined direction.

[0003] As an example of such ultrasonic transducers used in array, US patent n° 5 165 064 discloses a mobile robot using an array of several ultrasonic transducers 1a to 1p, each transducer 1k being provided with a rectilinearly flaring horn 2 so as to monitor its own sector S_k and avoid crosstalk, as illustrated in figures 1a and 1b. This system can detect the presence of an object in one sector, however, as the direction in which the acoustic energy is focused is fixed relative to the robot or the vehicle, it cannot precisely identify the position of the object in the sector, or it needs further ultrasonic transducers so as to proceed the return echo. This type of solution is expensive, not flexible in terms of selection of an emitting/receiving direction in a scanning zone, and not accurate enough for some specific applications.

[0004] British patent n° 1 487 308 discloses an ultrasonic radiation sensor comprising a table array of ultrasonic receivers 1a, 1b, 1c,... as illustrated in figures 2a and 2b, each ultrasonic receiver 1k being provided with an exponential horn 3 focusing the ultrasonic energy of its own sector onto each ultrasonic receiver 1k located at the bottom end of each horn 3, so as to reduce the threshold level for incident ultrasonic energy at which a perceptible output can be obtained. However, this is done to the detriment of the resolution level. The main drawbacks of these types of transducer arrays are the same as the above mentioned ones (complicated structure, inaccurate and slow).

[0005] In order to avoid these problems, phased arrays using ultrasonic transducers have been developed in recent years. The ultrasonic transducers are arranged in one or two dimensional arrays (e.g. linear, table, star or honeycomb array) and electronically controlled by varying the phase of the excitation signal supplied to each ultrasonic transducer controlled as an ultrasonic emitter, so as to form strengthened beams in a desired direction of the observation area by the summation of the acoustic pulses from the individual ultrasonic transducers. This way of focusing the acoustic energy obviates the use of flaring horns which were necessary hitherto in order to focus acoustic power in one direction, as described above, which direction was, moreover, fixed.

[0006] Contrary to the previous solutions, the direction of the focused acoustic energy may be variable when controlled by varying the phases of each transducer. By using successive shots in which successive phase variations between the excitation signals supplied to the transducers are introduced, a scanning of the observation area is achieved. By identifying the return echo from each shot, in at least one ultrasonic transducer controlled as a receiver, the location, configuration and distribution of objects in the scanned area are recognized. An example of a one-dimensional ultrasonic transducer phased array is disclosed in Japanese patent JP 052357. Such phased arrays are much more flexible than the above mentioned known scanning systems, as any desired emitting/receiving direction may be selected in a wide angular sector.

[0007] The use of such ultrasonic transducer phased array for robot or vehicle guidance requires high acoustic power (i.e. large transducers) to scan a large area (about five to ten meters, in a range of ± 60 to ± 90 degrees), as well as operating speed for quickly recognizing the dimension and position of objects in the scanned area. Figure 3a shows a linear array 4 of seven ultrasonic transducers 1a to 1g. The seven ultrasonic transducers may be used as emitters and at least one of them may be controlled as a receiver after each shot. Particularly, due to the high acoustic impedance of the air, a good power/cost compromise can be achieved in the air with a phased array using circular ultrasonic transducers 1a to 1g of the MA40S™ type commercialized by MURATA MFG. CO., LTD, under a nominal frequency of 40 Hz, i.e. $\lambda = 8,5$ mm. An emitting wavelength of 8,5 mm is considered as being suitable for a sufficient power (a scanning depth of about 10 meters) for this type of ultrasonic transducer phased array in the air. Each ultrasonic transducer 1a to 1g has a directivity (i.e. angular range) of 100° , a detection range (scanning depth) of 0,2 to 4 m, and a diameter of $9,9 \pm 0,3$ mm. As a result, the distance d ($d = 10$ mm) between the centers of two adjacent transducers 1a and 1b is at least substantially on the same order as the wavelength λ ($\lambda = 8,5$ mm) of the emitting radiation.

[0008] Figure 3b shows the acoustic lobe pattern 5 obtained by controlling the above ultrasonic transducer phased array 4 along axis AA' in a -15° shot. The arrow V is the propagation direction of the acoustic waves provided by each ultrasonic transducer 1a to 1g of the phased array 4. Such an arrangement raises a further problem. Since this physical limitation does not fulfill Shannon rule (distance between centers of two adjacent transducers to be inferior to $\lambda/2$), the spatial acoustic energy distribution results in a main focused energy beam (main lobe 6) and side lobes due to the spectrum aliasing (aliasing lobe 7) and diffraction at the array aperture (diffraction lobes 8). The side lobes 7 and 8 may have

high amplitudes and create interference echoes. For these reasons, the known methods and apparatuses are focusing on increasing main lobe 6 which is used for scanning, and on decreasing or eliminating side lobes 7 and 8.

[0009] In an ultrasonic transducer phased array, the directivity (power and angle relative to the main lobe) of the side lobes depends on the number of transducers, the excitation frequency (wavelength λ), the diameters of the transducers (angular width of lobes) and ponderation (weighting) of the excitation signals supplied to the transducers.

[0010] As stated above, λ should be about 8 to 9 mm so as to avoid signal attenuation in air. Due to transducer/air acoustical impedance matching, the diameters of the transducers are set to a value which ensures a sufficient power level. On the other hand, the interference echoes may be lowered by decreasing the distance between the transducers (i.e. increasing the angular distances between main lobe and side lobes).

[0011] The problem of interference echoes due to side lobes may also be partially electronically solved by confirmation shots or combination of two different lobe patterns in one direction.

[0012] However, all known solutions lead to lower power level and/or the operating speed and consequently to a lower scanning depth and a slower guidance control.

[0013] Therefore there is an important need to develop new solutions which can solve the above mentioned problems (speed, precision, cost) of the different solutions without lowering the acoustic power (i.e. the scanning distance) required for applications as robot or vehicle guidance.

[0014] The object of this invention is to overcome the above problems by using an ultrasonic transducer of the type described above, in which at least the height or the width of the outside end of the horn part is smaller than the height or the width of the ultrasonic transducer part.

[0015] Advantageously, at least the height or the width of the outside end of the horn part may be inferior to, or about, half height or half width of the ultrasonic transducer part.

[0016] The section of the outside end of the horn part may be circular or elliptic and/or may be equal to the section surface of the ultrasonic transducer part.

[0017] The longitudinal symmetry axis of the horn part may be rectilinear, bent or exponential.

[0018] The above ultrasonic transducer may comprise a bent acoustical mirror towards which the outside end of the horn part is pointed.

[0019] Such acoustical mirror may advantageously be made of a polymer or metal material, and may be parabolic or cylindrical.

[0020] The inner wall of the horn part may be smooth and the material used for the horn part may be a polymer.

[0021] The outside end of the horn part may be provided with a protection grid.

[0022] The present invention also relates to an ultrasonic transducer phased array which comprises a plurality of such ultrasonic transducers.

[0023] Advantageously, the centers of adjacent outside ends may be spaced from each other by a distance of about, or inferior to, half the wavelength ($\lambda/2$) of the emitted ultrasonic radiation.

[0024] The horn parts of the ultrasonic transducers of the above ultrasonic transducer phased array may be configured so as to form a single acoustic transformer element.

[0025] The outside ends of the horn parts of the ultrasonic transducers may be arranged in a one-dimensional or two-dimensional array.

[0026] The surface defined by the outside end array may be curved.

[0027] The ultrasonic transducers may be controlled as ultrasonic emitters and at least two other ultrasonic transducers may be provided and controlled as ultrasonic receivers.

[0028] Other ultrasonic transducers may be provided and controlled as receivers, which comprise an ultrasonic transducer part and a horn part flaring towards the outside.

[0029] The present invention also relates to an ultrasonic detection apparatus comprising at least one ultrasonic transducer of the above mentioned type, or at least one ultrasonic transducer phased array of the above mentioned type, controlled with an electronic control system.

[0030] Additional features and advantages of the invention will appear from the following description in which the preferred embodiments are set forth in detail in connection with the accompanying drawings.

Figure 1a and 1b (already described) show a conventional ultrasonic transducer provided with a flaring horn and an array using such ultrasonic transducer, respectively.

Figures 2a and 2b (already described) show another conventional ultrasonic receiver provided with a flaring horn and an array using such conventional ultrasonic receivers, respectively.

Figures 3a and 3b (already described) show a known ultrasonic transducer phased array and a corresponding acoustic lobe pattern emission in horizontal plan, respectively.

Figures 4a to 4d show four exemplary embodiments of ultrasonic transducers according to the present invention.

Figures 5a and 5b show two different views of the same phased array using ultrasonic transducers of the type of figure 4b, according to a first embodiment of the present invention.

Figures 6a and 6b show two different views of the same phased array using ultrasonic transducers of the type of figure 4b, according to a second embodiment of the present invention.

Figures 7a and 7b show the ultrasonic transducer phased array of Fig.3a, and its corresponding outside end phased array according to the present invention, as well as the acoustic lobe pattern in horizontal plan obtained by using ultrasonic transducers according to the present invention.

[0031] In all the above mentioned figures, the same elements keep the same references.

[0032] In Fig.4a, one exemplary embodiment of an ultrasonic transducer 10 according to the invention comprises an ultrasonic transducer part 10' and a horn part 10". Contrary to the natural tendency of the ultrasonic transducer field, and according to an important feature of the present invention, the end of the horn part 10" which is open to the observation area, i.e. the outside, (the so-called outside end) is narrower than the end to which the ultrasonic transducer part 10' is attached. More generally, according to the present invention, at least one dimension of the outside end surface of the horn part 10" is smaller than one dimension of the ultrasonic transducer part 10', i.e. of the ultrasonic diaphragm dimension. The ultrasonic transducer part 10' may be constituted with a circular ultrasonic transducer of the above mentioned type, emitting acoustical waves through the horn part 10" in its longitudinal direction towards the outside end.

[0033] Accordingly, the ultrasonic transducer according to the present invention ensures the power of the large ultrasonic transducer part, whatever its dimensions are. As its end which is emitting and/or receiving acoustical waves, can be of any desired dimensions smaller than the one of the ultrasonic transducer part, the angular aperture (directivity of the ultrasonic transducer part) can be varied in accordance to the requirements of applications.

[0034] The ultrasonic transducer according to the invention has further advantages as, for instance, the protection of the ultrasonic transducer part against outside damages, or, the use of such type of ultrasonic transducer in phased arrays. In the latter case, the phased arrays can meet the requirements of Shannon rule, i.e. distance between centers of adjacent ultrasonic transducers inferior to or about half the wavelength, while having an acoustic power which can be chosen without limitation. This is made possible as the array is formed by the assembly of the smaller outside ends of the horns and not by the transducers themselves. Examples of such embodiments of the present invention are shown in Figures 5a, 5b, 6a and 6b and will be further described.

[0035] Fig.4b shows another exemplary embodiment of an ultrasonic transducer according to the present invention. The ultrasonic transducer 11 of Fig.4b comprises a first ultrasonic transducer part 11' which may be made of any type of ultrasonic transducer as, for instance, the above mentioned one. In this particular embodiment, the horn part 11" is a exponentially-bent cone. This particular shape makes a better protection from damages coming from the outside (water, dust, ...). The horn may have any desired curvature, in particular it may have a U-shaped curvature as depicted in Fig.4c.

[0036] Fig.4d shows an ultrasonic transducer according to a particular embodiment of the invention, in which an ultrasonic transducer 10, e.g. of the type of Fig.4a, is combined with an acoustical mirror M reflecting the emitting/receiving waves. Preferably, this acoustical mirror is made of a smooth material, i.e. without any surface roughness or edges, as polymer or metal, and bent in a parabolic or cylindrical way.

[0037] The inner walls of the ultrasonic transducers according to the invention are also preferably smooth. Further, the above types of horns may be opened to a tube-shaped part referenced as 10''' in Fig.4a, so as to ensure the directivity of the ultrasonic transducer, e.g. by emitting the acoustical waves perpendicularly to the surface of the outside end.

[0038] Thanks to its acoustic characteristics, the inventive ultrasonic transducer is particularly well adapted for phased arrays to be used in robot or vehicle guidance. Indeed, the spacing of half a wavelength can be respected while keeping the power level of ultrasonic transducers used in previous solutions and available in the market, or by using even more powerful ultrasonic transducers, as the dimensions of the transducers become independent from the Shannon rule. Consequently, the side lobes are eliminated or at least significantly reduced or spread away from the main lobe, depending on the dimensions of the outside ends of the horn parts, i.e. the distance between the centers of two adjacent outside ends and the wavelength which is chosen.

[0039] Fig.5a shows a front view of an ultrasonic detection device 12 using a two dimensional phased array 13 comprising thirteen ultrasonic transducers 11a, 11b,.. of the type of Fig.4b in which the outside ends 11'''a, 11'''b,.. of the ultrasonic transducers 11a, 11b,.. are arranged in staggered rows (quincunx or honeycomb). In this particular embodiment, these ultrasonic transducers are controlled as ultrasonic emitters and the detection device is provided with two other transducers 14a and 14b controlled as receivers. Receivers 14a and 14b may be fixed directly onto the emission/reception surface 15 of the detection device 12, and they can be provided with a conventional flaring horn as illustrated in Fig.5a.

[0040] Fig.5b is a section view of the detection device of Fig.5a along the axis BB'. Transducer 11a is located at the center of the phased array 13, and transducers 11b and 11c in dotted lines are adjacent to the center transducer 11a. Each transducer 11a, 11b,.. comprises an ultrasonic transducer part 11a', 11b',... housing an ultrasonic transducer of any known type, and a horn part 11a'', 11b'',... guiding the emitted ultrasonic waves towards the outside at surface 15. Transducers 11a, 11b,.. comprise a third emitting part 11a''', 11b''',... which is tube-shaped, so that all the transducers

are emitting in the same direction. In a different embodiment, the propagation direction of the acoustic waves generated by the transducers may be different, i.e. the surface of the outside ends are not in the same plan, or in a curved plane. Further, some ultrasonic transducers may be arranged so that their longitudinal axes are inclined relative to the surface plane of the outside ends.

[0041] Advantageously, as illustrated in Fig.5b, the horns parts of the ultrasonic transducers 11a, 11b,.. and/or 14a and 14b are formed in one piece 16, the so-called acoustic transformer element. This element may advantageously be molded in one element or assembled from several pieces of a polymer material. This decreases the cost of the whole detection system (ultrasonic transducers, acoustic transformer element and electronic control system). Further, the horn parts 11a", 11b"... of the ultrasonic transducers 11a, 11b,.. may have different lengths. In this case the ultrasonic transducers have to be electronically controlled so as to compensate the differences in acoustic path lengths. Accordingly, the ultrasonic transducers may be fixed to the acoustical transformer element 16 in a compact way so as to lower the size of the whole device.

[0042] Instead of using a complete ultrasonic transducer available in the market, mounted onto the element 16, the ultrasonic diaphragm and its two contacts may be directly fixed on the polymer element so as to further lower the manufacturing costs. The rear part of the polymer element 16 comprising the ultrasonic transducers mounted herein, is accommodated in a housing 17 having openings 18 to connect the ultrasonic transducers to the electronic control system (not shown in the figures). This type of ultrasonic detection device can be used on a vehicle, the particular shape of the horns, e.g. bent conical horns, preventing the ultrasonic parts to be damaged from the outside. Further, the outside ends of the horns may advantageously be provided with protective parts as grids.

[0043] Fig.6a shows a front view of a ultrasonic detection device 19 according to another embodiment of the present invention, in which the outside ends of the nineteen ultrasonic transducers 11a, 11b,.. are arranged in a two-dimensional array 20 of a six branch star configuration, and in which the ultrasonic transducers 11a, 11b,.. are controlled as emitters. In this particular example, six other ultrasonic transducers 14a, 14b,.. are controlled as receivers. In this example, the horn parts of the ultrasonic transducers 14a, 14b,.. have a conventional tube shape 14' enlarged at their outside ends at the surface 22 of the detection apparatus 19 so as to focus the return echoes onto their transducer parts 14a, 14b,...

[0044] Fig.6b shows a section view of the ultrasonic detection device 19 of Fig.6a along axis CC'. The ultrasonic transducers 11a to 11c according to the invention are advantageously formed in a single acoustic transformer element 21 as in the previous embodiment.

[0045] The ultrasonic transducers of the phased arrays according to the invention may be controlled as receivers of echoes generated by one or several ultrasonic transducers used as emitters. Then, by applying a "beam forming" method to the memorized echo signal received by each receiver, an acoustic image of the shot may be obtained. The principle of the beam forming method is to apply to the echo reception, the same phase correlation made for emitting purposes. That is, the return echo of one shot from a single ultrasonic transducer is received by the ultrasonic transducer array, and a dephased summation of the memorized return echo signals is made so as to obtain the value of the return echo for each angle. For each shot, angular openings θ_i which are corresponding each to a time delay Δ_i , are electronically created for different virtual angles, creating a reception directivity, and, in the particular case of a one-dimensional configuration of k receivers $R_{j(1 \leq j \leq k)}$ (e.g. of the type of Fig.7a in which $k=7$), the scanning is achieved by calculation of the amplitude A for each angle θ_i , i.e. the summation of the dephased echo signal amplitudes S_{Rj} :

$$A(\theta_i) = S_{R1}(t) + S_{R2}(t+\Delta_i) + S_{R3}(t+2.\Delta_i) + \dots + S_{Rk}(t+(k-1).\Delta_i),$$

by checking the maximum of the amplitude $A(\theta_i)$ for different angles θ_i , the target angle is identified. Each target angle corresponds to one time delay. The addition of these individual time delays produces an unambiguous indication of the absolute angle under which the reflecting obstacle is seen from the receivers. The beam forming method may be applied to any two or three dimensional transducer arrays.

[0046] Advantageously, an electronic calibration of the array in terms of phase and power may be made before each use of the ultrasonic phased array, so as to compensate the geometrical defects in the design and dimensions of the horns.

[0047] Further, due to the geometrical flexibility of the horns, a geometrical ponderation (weighting) of the secondary lobes may be easily achieved in parallel to the electronic ponderation of the excitation signals as mentioned above, by controlling the shapes and diameters of the outside ends of the horns, and the spacing between them.

[0048] In a modified implementation of the invention, the horn part of the transducer may be designed so that the section of the outside ends is oval, or elongated, at least the small diameter being inferior to, or about, half wavelength.

Advantageously, the section surface may be equal to the surface of the ultrasonic diaphragm of the ultrasonic transducer. A detection device of the above described type may use such ultrasonic transducers so as to get a focused directivity in one plane and a larger one in the plane perpendicular to the first one.

[0049] Another modified ultrasonic detection apparatus may use one transducer supplying several horn parts so as

to decrease the number of ultrasonic transducers, in accordance with the requirements of the application.

[0050] Several ultrasonic detection devices according to the invention controlled by a unique electronic control system may be implemented in a vehicle for obstacle detection or a robot for guidance purposes, or in an interior space for the purpose of detecting the presence of an intruder.

[0051] Fig. 7a shows the conventional ultrasonic transducer phased array of Fig. 3a (left) and its corresponding outside ends 25 (right) by using ultrasonic transducers according to the invention. In this particular case taken as an example, the acoustic transformer is designed so that the distance d' between two outside ends 25a and 25b is half the distance d between two adjacent transducers 1a and 1b. By using the ultrasonic transducers as described above, the distance d' may be about 4,5 mm which is in the order of half wave length, $\lambda/2 = 4,25$ mm.

[0052] Fig. 7b shows the acoustic lobe pattern obtainable by the phased array of Fig. 3a using ultrasonic transducers according to the invention. This acoustic lobe pattern has to be compared with the acoustic lobe pattern of Fig. 3b obtained with prior art ultrasonic transducers. As shown in Fig. 7b, the side lobes 24 has been lowered and the directivity of main lobe 23 is increased.

[0053] For instance, the implementation of the present invention can perform indoor robot navigation in autonomous way. By using prior art ultrasonic transducers of the MA40S3 type in the ultrasonic transducer elements according to the invention, a main lobe with a thickness of 20° to 30° (at -3db) may be obtained, the accuracy as for the distance is about 1cm, the accuracy as for the angle is about 2° , the operation range is from 0,5 m to 10 m, the response time is from 50 to 500 ms, and electronic scanning is $\pm 90^\circ$ of the observation area.

[0054] The ultrasonic transducers and ultrasonic detection devices according to the invention may also be employed in a solid medium (e.g. for non-destructive testing) and in a liquid medium, e.g. water, but the invention is particularly well-adapted to be used in a gaseous medium as, for instance, air.

[0055] In case of using such ultrasonic transducers in a solid or liquid medium, the horn parts may be full (i.e. solid) and independent from each others.

[0056] Only a few ultrasonic transducers, easily available in the market, are necessary and the acoustical transformer for ultrasonic transducer phased array may be simply manufactured and compacted with inexpensive materials. Consequently the whole improved ultrasonic detection system has a compact size, low cost and provides a protection against the dirt and rain. Further, a system according to the invention is not sensitive to parasitic light sources and can operate in the dark.

[0057] The present invention has a large range of applications. For instance, it can be used for vehicles (back sonar system, automatic car parking, collision protection, passenger detection), in industry (automatic parts distribution, automatic packaging, remote control of objects on assembly lines, cleaning robots, etc.), at home (automatic floor cleaning) and for public health (sonar for blind persons, movement detection for elderly person).

Claims

1. Ultrasonic transducer (11) comprising an ultrasonic transducer part (11') having a height and a width, and at least one horn part (11'') having one outside end and the other end attached to the ultrasonic transducer part (11'), characterized in that at least the height or the width of the outside end of the horn part (11'') is smaller than the height or the width of the ultrasonic transducer part (11').
2. Ultrasonic transducer according to claim 1, characterized in that at least the height or the width of the outside end of the horn part (11'') is inferior to or about half height or half width of the ultrasonic transducer part (11').
3. Ultrasonic transducer according to claim 1 or 2, characterized in that the section of the outside end of the horn part (11'') is circular or elliptic.
4. Ultrasonic transducer according to one of the previous claims, characterized in that the section surface of the outside end of the horn part (11'') is equal to the section surface of the ultrasonic transducer part (11').
5. Ultrasonic transducer according to one of the previous claims, characterized in that the longitudinal symmetry axis of the horn part (11'') is rectilinear.
6. Ultrasonic transducer according to one of claims 1 to 4, characterized in that the longitudinal symmetry axis of the horn part (11'') is bent.
7. Ultrasonic transducer according to claim 6, characterized in that the longitudinal symmetry axis is exponential.
8. Ultrasonic transducer according to claim 5, characterized in that it further comprises a bent acoustical mirror (M)

towards which the outside end of the horn part (10'') is pointed.

9. Ultrasonic transducer according to claim 8, characterized in that said acoustical mirror (M) is made of a polymer or metal material, and is parabolic or cylindrical.

10. Ultrasonic transducer according to one of the previous claims, characterized in that the inner wall of the horn part (11'') is smooth.

11. Ultrasonic transducer according to claim 10, characterized in that the material used for the horn part (11'') is a polymer.

12. Ultrasonic transducer according to one of the previous claims, characterized in that the outside end of the horn part is provided with a protection grid.

13. Ultrasonic transducer phased array (12;19) characterized in that it comprises ultrasonic transducers (10,11) according to one of the previous claims.

14. Ultrasonic transducer phased array according to claim 13, characterized in that the centers of adjacent outside ends are spaced from each other by a distance of about, or inferior to, half the wavelength ($\lambda/2$) of the emitted ultrasonic radiation (11).

15. Ultrasonic transducer phased array according to claim 13 or 14, characterized in that all the horn parts (11'') of the ultrasonic transducers (11) are configured so as to form one acoustic transformer element (16;21).

16. Ultrasonic transducer phased array according to one of claims 13 to 15, characterized in that the outside ends of the horn parts (11a''-11s'') of the ultrasonic transducers (11a-11s) are arranged in a one-dimensional or two-dimensional array.

17. Ultrasonic transducer phased array according to claim 16, characterized in that the surface defined by the outside end array is curved.

18. Ultrasonic transducer phased array according to one of claims 13 to 17, characterized in that they are controlled as ultrasonic emitters and at least two other ultrasonic emitters are provided and are controlled as ultrasonic receivers.

19. Ultrasonic transducer phased array according to claim 18, characterized in that other ultrasonic transducers are provided and controlled as receivers, which comprise an ultrasonic transducer part and a horn part flaring towards the outside.

20. Ultrasonic detection apparatus comprising at least one ultrasonic transducer according to one of claims 1 to 12 controlled with an electronic control system.

21. Ultrasonic detection apparatus comprising at least one ultrasonic transducer phased array according to one of claims 13 to 19 controlled with an electronic control system.

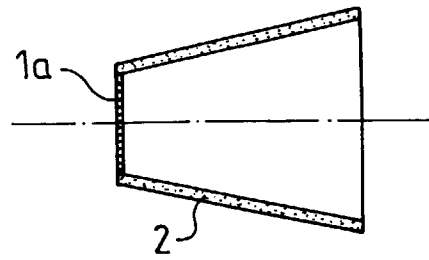


FIG. 1a

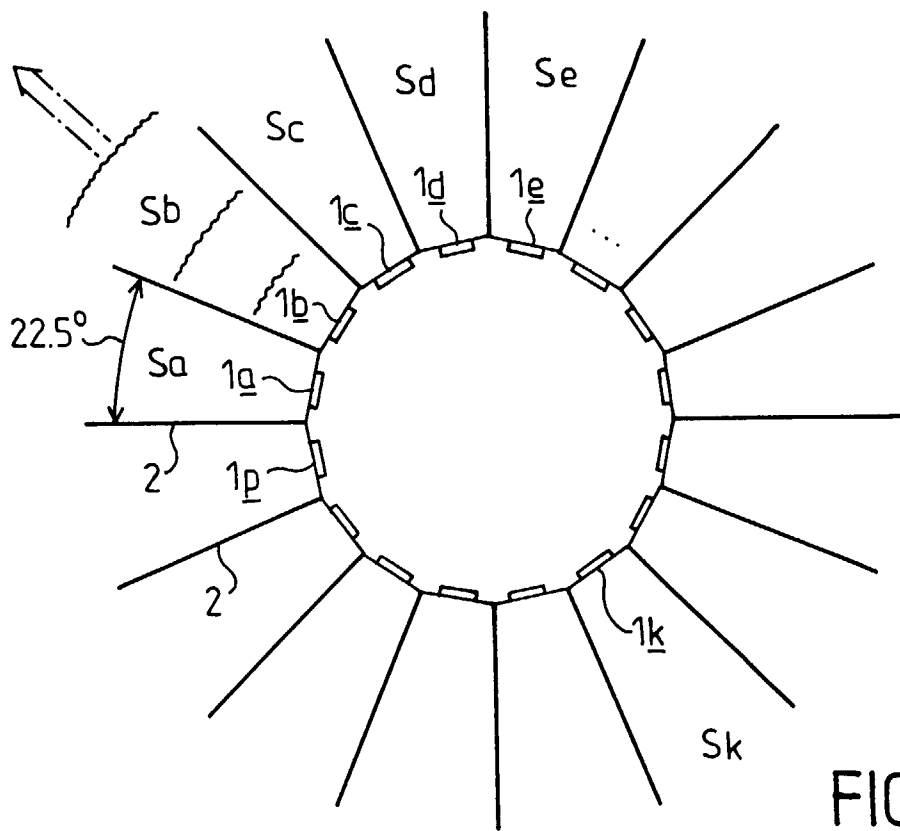


FIG. 1b

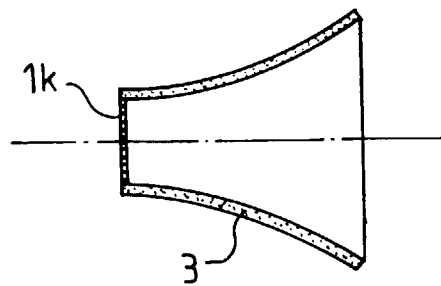


FIG. 2a

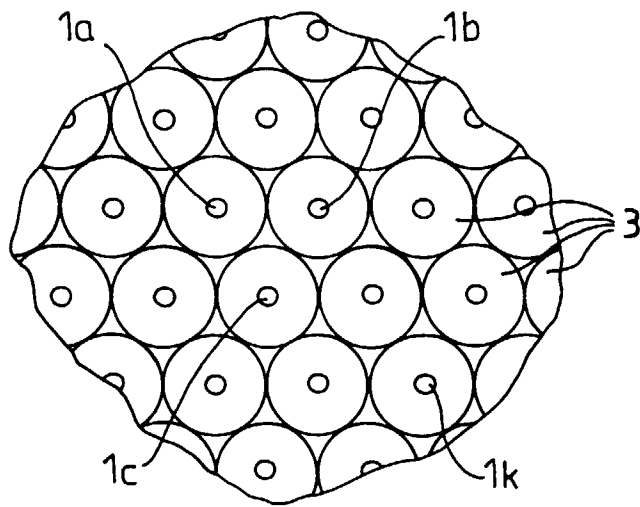


FIG. 2b

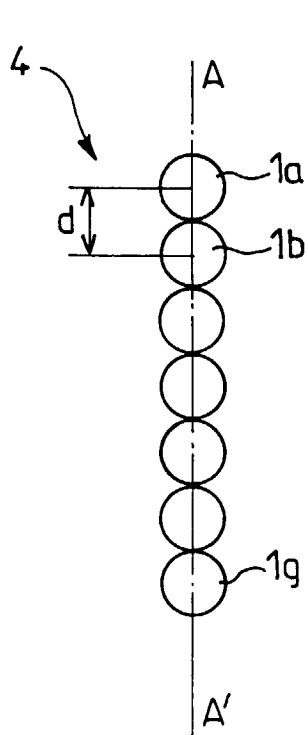


FIG. 3a

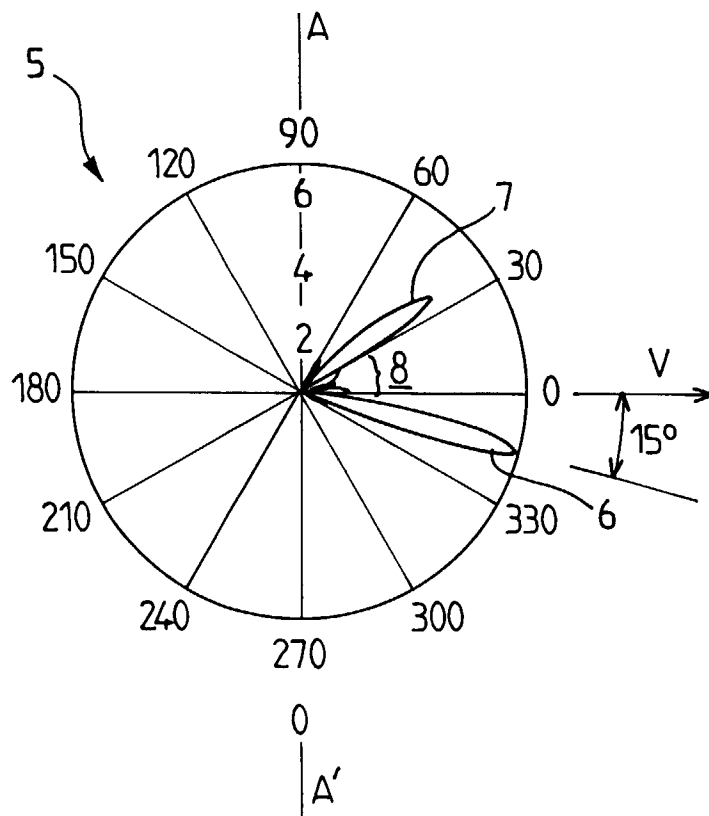


FIG. 3b

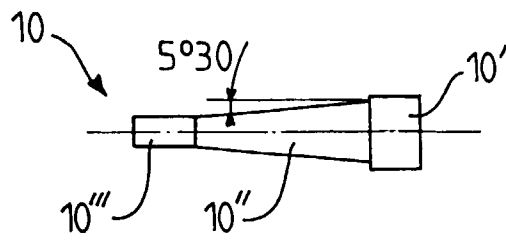


FIG. 4a

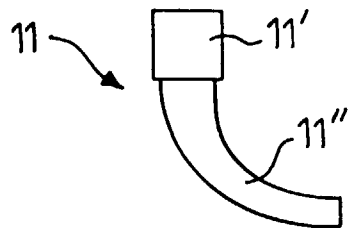


FIG. 4b

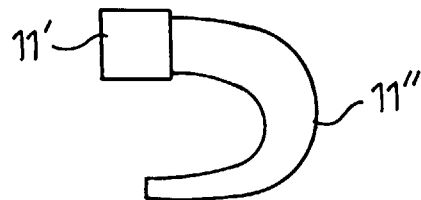


FIG. 4c

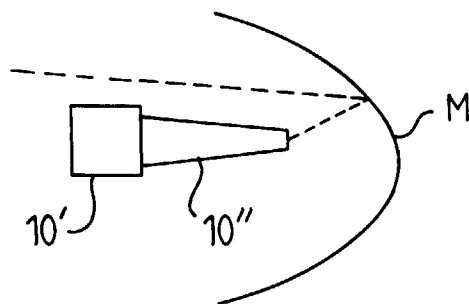


FIG. 4d

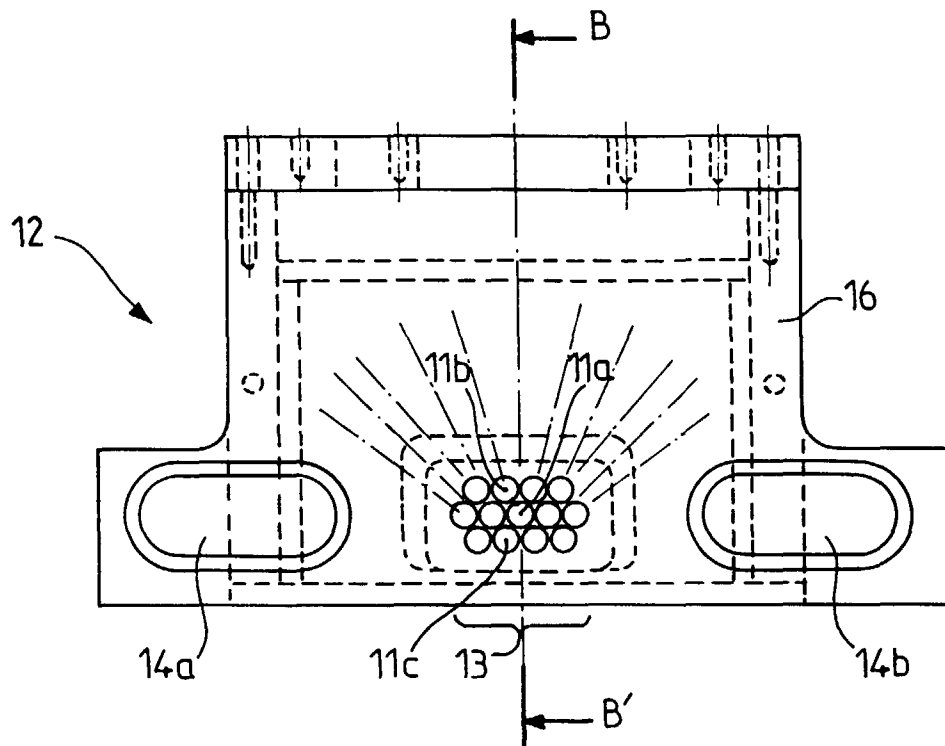


FIG. 5a

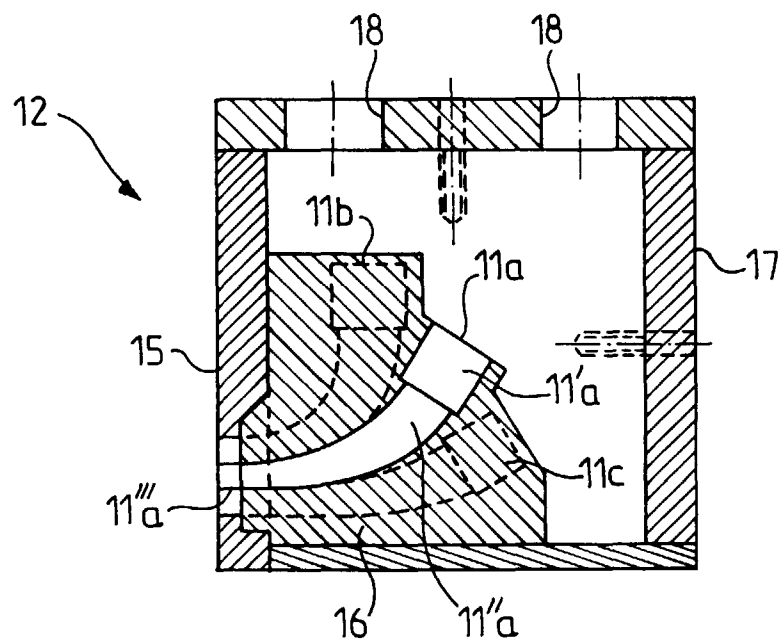


FIG. 5b

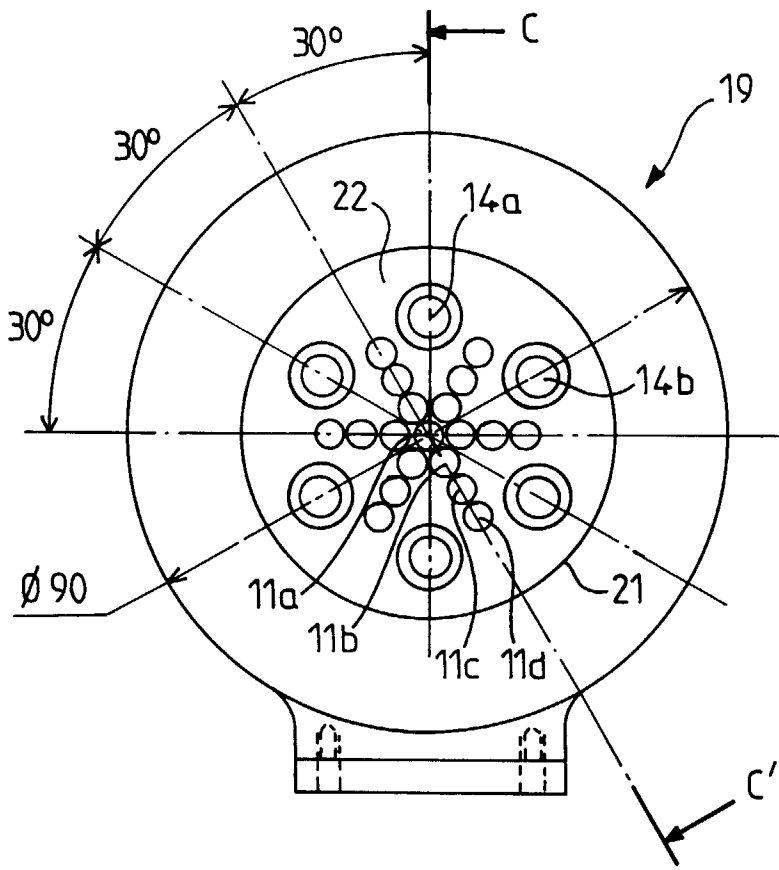


FIG. 6a

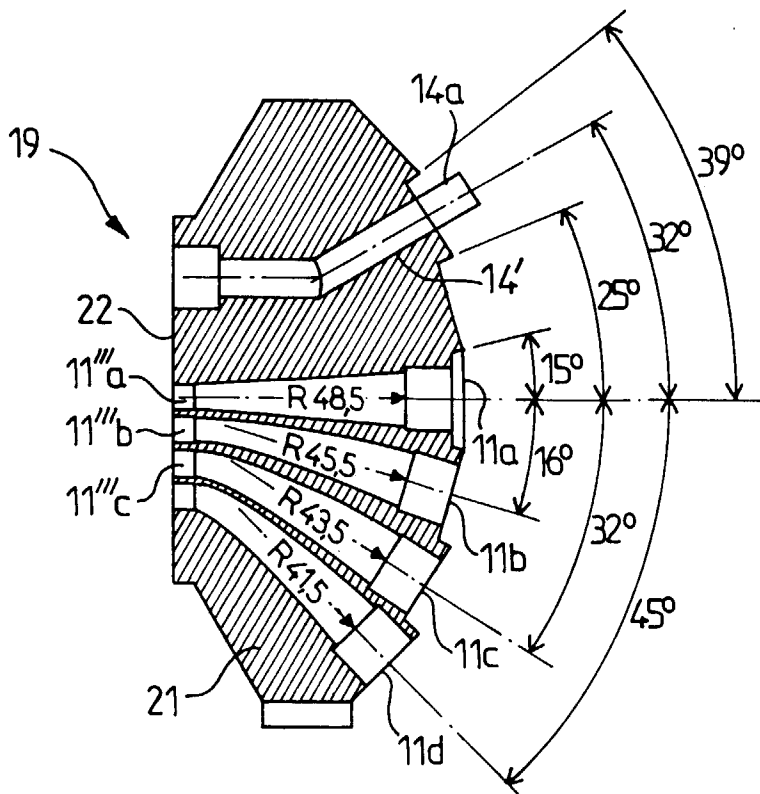


FIG. 6b

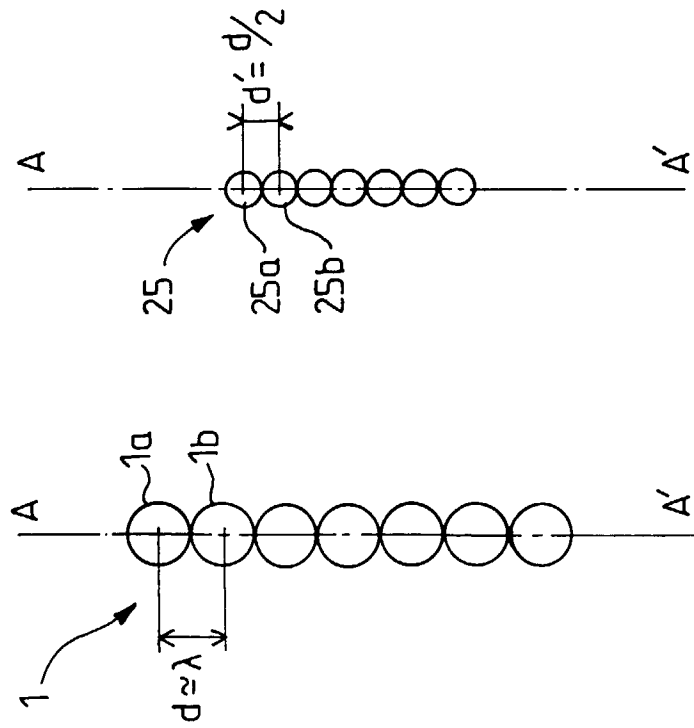


FIG. 7a

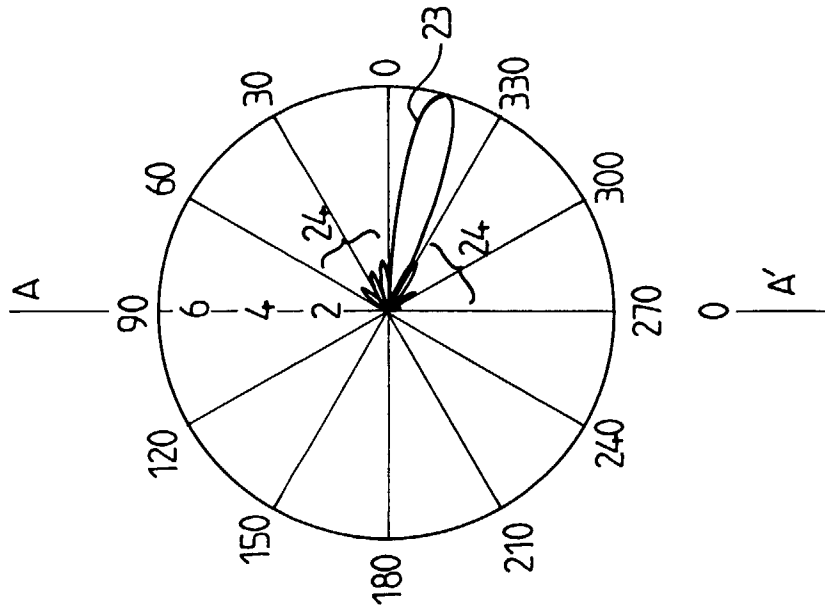


FIG. 7b



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Application Number
EP 98 40 0043

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 002, no. 032 (E-018), 28 February 1978 -& JP 52 153472 A (OKI ELECTRIC IND CO LTD), 20 December 1977, * abstract *	1,6,13,16	B06B3/00
A	---	18,19	
A	US 4 131 505 A (DAVIS JR PAUL H) 26 December 1978 * column 2, line 64 - line 66; figures 1-4, A * * column 4, line 64 - line 67 *	1,3-5	
A	---		
A	US 4 392 410 A (DURRELL ROBERT R) 12 July 1983	6	
A	---		
A	US 3 792 701 A (KLOZ ET AL) 19 February 1974 * figures 1-3 *	6	
A	---		
A	GB 1 300 160 A (COMMISSARIAT A L'ENERGIE ATOMIQUE) 20 December 1972 * page 2, column 1, line 37 - line 42 * * page 3, column 1, line 33 - line 35; figure 1A *	8	TECHNICAL FIELDS SEARCHED (Int.Cl.6) B06B G10K
A	---		
A	US 5 371 483 A (BHARDWAJ MAHESH C) 6 December 1994 * column 3, line 27 - line 30; figure 1 *	11	
A	---		
A	FR 2 412 842 A (KRAUTKRAMER GMBH) 20 July 1979 * page 8, line 22 - line 37; figure 6 *	13,21	
A	---		
A	WO 87 01269 A (MEDICAL INNOVATION COMPANY A/S) 12 March 1987 * page 5, line 10 - page 7, line 34; figures 1,2 *	6,11,13,16,18-21	

	-/--		
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 29 June 1998	Examiner Anderson, A
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 40 0043

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	GB 1 010 112 A (AEROPROJECTS INC.) 17 November 1965 * page 4, column 1, line 42 - column 2, line 101; figures 2,3 *	15	
A,D	US 5 165 064 A (MATTABONI PAUL J) 17 November 1992		
A,D	GB 1 487 308 A (EMI LTD) 28 September 1977		
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
Place of search THE HAGUE		Date of completion of the search 29 June 1998	Examiner Anderson, A
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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