(51) International Patent Classification 6 : B06B 1/02	A1	(11) International Publication Number: WO 95/02464
		(43) International Publication Date: 26 January 1995 (26.01.95)

(21) International Application Number: PCT/CA94/00379

(22) International Filing Date: 12 July 1994 (12.07.94)

(30) Priority Data:
091,009   14 July 1993 (14.07.93)   US

(60) Parent Application or Grant
(63) Related by Continuation
US   08/091,009 (CIP)
Filed on   14 July 1993 (14.07.93)

(71) Applicant (for all designated States except US): THE UNI-
VERSITY OF BRITISH COLUMBIA [CA/CA]; Room 331
- IRC Building, 2194 Health Sciences Mall, Vancouver,
British Columbia V6T 1Z3 (CA).

(72) Inventor; and
(75) Inventor/Applicant (for US only): WHITEHEAD, Lorne, A.
[CA/CA]; 3015 West 12th Avenue, Vancouver, British
Columbia V6K 2R4 (CA).

(74) Agent: WIGGS, Blake, R.; Oyen Wiggs Green & Mutala, 480
- 601 West Cordova Street, Vancouver, British Columbia
V6B 1G1 (CA).

(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH,
CN, CZ, DE, DK, ES, FI, GB, GE, HU, JP, KE, KG, KP,
KR, KZ, LK, LT, LU, LV, MD, MG, MN, MW, NL, NO,
NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, US,
UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR,
GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF,
BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG),
ARIPO patent (KE, MW, SD).

Published
With international search report.
Before the expiration of the time limit for amending the
claims and to be republished in the event of the receipt of
amendments.

(54) Title: HIGH PRESSURE LOW IMPEDANCE ELECTROSTATIC TRANSDUCER
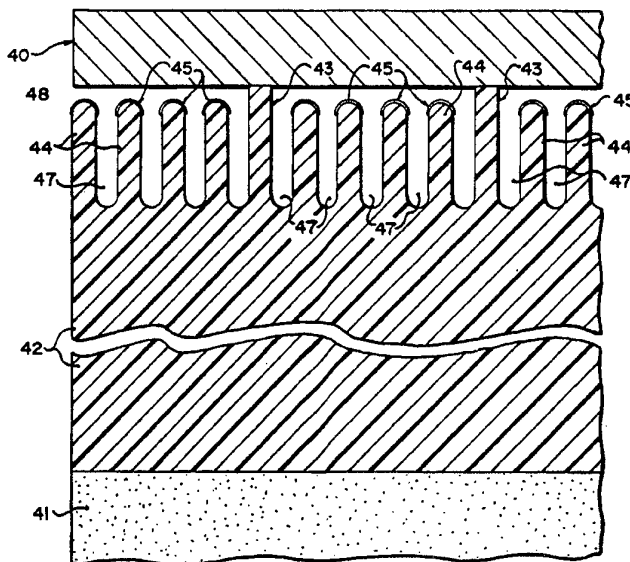
(57) Abstract

    An electrostatic transducer in which two sheets (40, 42) are separated by a gas-filled gap. The sheets have conductive surfaces for imposing electric fields within the gap when an electrical potential is applied across the sheets. A flexible positioning mechanism (43) maintains the gap at a desired time-averaged thickness. The gap is made up of a plurality of thick regions (47) and a plurality of thin regions (48). Both regions have a total projected area which is a substantial portion of the total area of one of the sheets. The average thickness of the gap in the thick regions greatly exceeds (by at least ten times) the gap's average thickness in the thin regions. The electrostatic field energy of the electric fields is concentrated in the thin regions.

HIGH PRESSURE LOW IMPEDANCE ELECTROSTATIC TRANSDUCER

Field of the Invention

This application pertains to an electrical-to-mechan-
ical transducer in which displacement is caused by a force
of attraction between approximately parallel conductive
surfaces, with the surfaces being structured to yield low
mechanical impedance and allow high electrostatic pres-
sures.

Background of the Invention

Conventional electrostatic transducers, such as those
used in certain loudspeakers, employ air gaps between
conductive plates. The gap size in such transducers is
reasonably large: typically in the range of 0.3 to 3 mm.
Such transducers can be made using very thin film conduc-
tive sheets, for example a vacuum-deposited layer of
aluminium on a very thin polymeric substrate such as
polyester film. It is a fairly straightforward matter to
design such transducers to provide a good impedance match
to air. That is, the mechanical impedance associated with
oscillations of the mass of the conductive sheets, and the
mechanical impedance associated with the restorative force
holding the sheets in place, is low compared to the mechan-
ical impedance of air, so that most of the mechanical power
of the transducer is conducted away as sound. Further-
more, such transducers can lend themselves to reasonably
efficient conversion of electrical power to mechanical
power, provided that the magnitude of the oscillation of
the conductive sheets is a reasonable fraction of the size
of the gap, which is often the case.

A fundamental difficulty with prior art electrostatic
transducers like those described above is that they are
incapable of providing large electrostatic pressures. That
is, the quantity of force per unit area cannot be very
large. This is because the electrostatic force per unit
area in such transducers is given by the formula:

$$F/A = P = \frac{1}{2}\epsilon_0 E^2 \qquad\qquad (1)$$

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where ϵ_0 is 8.85 x 10^{-12} farads per metre and E is the
magnitude of the electric field in the gap between the two
conductive surfaces. For macroscopic gaps of the type
described above, there is a maximum value of E, essentially

5   independent of gap size, which is approximately 10^6 volts
per metre for room pressure air. This corresponds to a
maximum electrostatic pressure of approximately 4.4 N/m^2, or
.00066 PSI. There are many applications where such forces
are too low.

10   Recently, as described in U.S. Patent No. 4,885,783
(Whitehead et al), practical methods have been devised for
constructing electrostatic transducers employing very small
air gaps (i.e. less than 10 micrometres) in which the
breakdown field of air is substantially higher, due to the

15   inhibition of avalanche breakdown from free ions, which is
in turn due to the proximity of solid surfaces relative to
the mean free path of a free ion in the gas. In such
transducers a uniformly structured surface of elastomeric
material creates air pockets of the desired size against a

20   metal plate. Because the material is elastomeric it allows
a reasonable amount of flexibility in the separation of the
transducer's plates.

          Such transducers are able to achieve pressures in the
range of 100 to 1,000 times greater than conventional

25   electrostatic transducers, and they are practical for
certain applications where it is desirable to couple
vibrational energy into media having an intermediate level
of mechanical impedance, such as water, sand, soil, etc.
However, the mechanical impedance of such transducers is

30   too high to efficiently produce mechanical vibration in
air. That is, most of the mechanical power of the trans-
ducer is associated with overcoming internal impedance,
rather than in radiating mechanical energy into air. The
transducer's higher impedance is partially due to the

35   stiffness of the surface of the elastomeric material, but
is predominately due to the difficulty of compressing the
very shallow air pockets in the structure. Although air is

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compressible, the stiffness of an air gap is inversely proportional to the gap's thickness. For the small gap thicknesses characterizing transducers exemplified by U.S. Patent No. 4,885,783 the resultant high stiffness becomes a significant problem. A further disadvantage of such devices is that it is often difficult to concentrate most of the electrostatic field energy in the active air gap, since generally speaking the elastomeric material is substantially thicker than the air gaps (pockets) in the surface of the material.

The present invention provides a transducer which can concentrate most of its electrostatic field energy in the active region of air gaps. The air gaps are small enough to achieve very high breakdown fields, and the structure is designed to reduce the high mechanical stiffness encountered in compressing narrow air gaps.

One specific requirement for producing acoustic excitation in air is in the field of aerodynamic flow. There is evidence that the characteristics of air flow over a rigid surface such as an airplane wing can be substantially modified by acoustic excitation. It would be highly desirable to employ a thin sheet transducer which could be easily applied to the surface of a structure such as a wing, to efficiently cause acoustic excitation of the air flowing over the surface. The prior art discloses no transducers capable of producing displacements of order several microns at frequencies of order 10 kilohertz, with efficiencies of order 1%. Such characteristics are highly desirable. It is a further object of this invention to fulfil this gap in the prior art.

Summary of the Invention

In accordance with the preferred embodiment, the invention provides an electrostatic transducer in which two sheets are separated by a gas-filled gap. The sheets have conductive surfaces for imposing electric fields within the gap when an electrical potential is applied across the

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sheets. A flexible positioning means maintains the gap at
a desired time-averaged thickness. The gap is made up of
a plurality of thick regions and a plurality of thin
regions. The thin regions have a total projected area
5 which is a substantial portion of the total area of one of
the sheets. The thick regions also have a total projected
area which is a substantial portion of the total area of
one of the sheets. The average thickness of the gap in the
thick regions greatly exceeds (by at least ten times) the
10 gap's average thickness in the thin regions. A means is
provided to concentrate the electrostatic field energy of
the electric fields in the thin regions.

The flexible positioning means is preferably an
elastomeric material. Advantageously, one of the sheets
15 may be formed of an elastomeric material bearing a conduc-
tive coating, the coating having a thickness less than that
which would significantly impede the sheet's flexibility.

A means may be provided to equalize the gas pressure
in the gap with the gas pressure external to the trans-
20 ducer, at frequencies substantially below the transducer's
intended operating frequency range.

The conductive surface on at least one of the sheets
may be coated with a thin ceramic to electrically isolate
the surface from the gap.

25 The gap thickness in the thin regions is preferably
less than or equal to the Paschen minimum distance for the
gas and the gas pressure in the gap.

The sheets have a component z_{gas} of net mechanical impe-
dance per unit area due to pressure changes required to
30 compress and rarefy the gas within the gap; and, a compo-
nent z_{mass} of net mechanical impedance per unit area due to
the sheets' mass. The gap thickness in the thick regions
is sufficiently large that the magnitude of z_{gas} is of the
same order as, or less than the magnitude of z_{mass} at
35 frequencies within the transducer's intended operating fre-
quency range.

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The width of the individual thin regions is less than the width at which the viscosity or inertia of gas flow into or out of the thin regions would substantially in-crease the transducer's net mechanical impedance per unit
5 area at frequencies within the transducer's intended operating frequency range.

The positioning means has a net mechanical impedance per unit area z_{pos}, the magnitude of which is of the same order as, or less than the magnitude of z_{mass} for fre-
10 quencies within the transducer's intended operating fre-quency range.

Brief Description of the Drawings

Figure 1 is a simplified cross-sectional illustration
15 of a prior art electrostatic transducer.

Figure 2 is a graph which illustrates the relationship between breakdown voltage "V", plate separation distance "d" and pressure "P" of a gas maintained between the opposed plates of an electrostatic transducer like that
20 shown in Figure 1.

Figure 3 is a greatly enlarged cross-sectional side elevation view of a portion of a transducer constructed in accordance with the preferred embodiment of the invention.

Figures 4A, 4B and 4C illustrate alternative tech-
25 niques for applying a conductive surface to one of the opposed sheets comprising the Figure 3 structure.

Figure 5 is a schematic illustration showing how the separation distance between the opposed sheets comprising the Figure 3 structure can be maintained reasonably con-
30 sistently at a desired dimension.

Figures 6A and 6B are respectively cross-sectional side and end elevation views, on a greatly enlarged scale, of a transducer constructed in accordance with the pre-ferred embodiment of the invention. Figure 6C is a further
35 enlarged view of the encircled portion of the Figure 6B structure.

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Figure 7 shows how the invention can be applied to modify the characteristics of air flow over a rigid surface such as an airplane wing.

5 Detailed Description of the Preferred Embodiment

Figure 1 is a simplified cross-sectional view of a conventional electrostatic transducer consisting of a pair of opposed metal plates 10, 12 which are separated a distance "d" by an air gap. If an A.C. voltage source 16

10 is connected across plates 10, 12 to establish an electrical potential difference across the plates an electrostatic force is generated which causes the plates to oscillate in the direction indicated by double-headed arrow 18. The magnitude of such oscillation varies in proportion to the

15 magnitude of the square of the applied voltage. There is a maximum breakdown voltage of about 10^6 volts per meter beyond which any further increase in voltage across plates 10, 12 results in arcing between the plates, in which case the transducer fails due to a large increase in the flow of

20 electrical current.

Figure 2 is a graph which illustrates the relationship between breakdown voltage "V", plate separation distance "d" and pressure "P" of a gas maintained between the opposed plates of an electrostatic transducer like that

25 shown in Figure 1. The graph shows that for a given cathode material (the "cathode" being the plate having the lower voltage) such as commercial aluminium, the breakdown voltage V decreases as the product Pd decreases, until a minimum voltage "V_{min}" is reached; and, that the breakdown

30 voltage V then increases dramatically as the product Pd continues to decrease. It may thus be seen that if the gas pressure P is held constant, the breakdown voltage V decreases as the plate separation distance d decreases until the aforementioned minimum voltage V_{min} (known as the

35 "Paschen minimum") is reached, but the breakdown voltage V then increases dramatically as the plate separation distance d is further decreased. As Figure 2 indicates, the

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Paschen minimum voltage for air, with a commercial alumin-
ium cathode, is about 254 volts, and occurs when the
product Pd is about 1.2 Torr cm. If the gas pressure P is
1 atmosphere (i.e. 760 Torr) this corresponds to a plate
5   separation distance d of about 1.2 Torr cm./760 Torr = 1.6
x 10^{-3} cm. or about 16 microns.

It has been recognized that an electrostatic trans-
ducer capable of measuring small displacements can be made
by making d as small as possible. [See: W.B. Gauster and
10 M.A. Breazeale: "Detector for Measurement of Ultrasonic
Strain Amplitudes in Solids", Rev. Sci. Instrum. 37, 1544-
1548 (1966); and, J.H. Cantrell and J.S. Heyman: "Broadband
Electrostatic Acoustic Transducer for Ultrasonic Measure-
ments in Liquids", Rev. Sci. Instrum. 50, 31-33 (1979)].
15 Unfortunately however, it is very difficult to construct a
practical electrostatic transducer having a plate separ-
ation gap "d" of only about 16 microns and the difficulty
increases as "d" is further decreased (as it must be if an
electrostatic transducer having higher breakdown voltages
20 is to be produced). Expensive precision machining and
cumbersome mounting techniques are required which preclude
the use of such transducers in most practical situations.

As disclosed in U.S. Patent No. 4,885,783 (Whitehead
et al), a practical electrostatic transducer which exploits
25 the foregoing phenomenon can easily be constructed and
operated at values of Pd which are significantly less than
the value of Pd required to achieve the minimum breakdown
voltage of the particular gas maintained between the
transducer plates. In such devices, an elastomeric dielec-
30 tric material is placed between plates 10, 12 of the Figure
1 electrostatic transducer and is maintained in contact
with both plates. It is of course well known to provide a
dielectric material between a pair of opposed plates across
which a voltage potential difference is maintained (as in
35 a conventional capacitor). However, if the dielectric
material has very slight surface irregularities or pockets,
and is elastomeric (for example, neoprene rubber), then the

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desired increase in gap breakdown voltage can be achieved,
thereby facilitating production of transducers having
substantially greater electrostatic forces per unit area.

Typically, a neoprene rubber dielectric (not shown)
5   having a breakdown field of about 2×10^7 volts per meter is
disposed between plates 10, 12 and in contact therewith.
The rubber surfaces are very slightly irregular such that,
when viewed on the microscopic scale, they exhibit a large
plurality of pockets having an approximate average depth
10 "d" of about 10 microns each.   Accordingly, when such a
dielectric is disposed between the transducer plates a
corresponding large plurality of discrete gaps on the order
of about 10 microns are provided between each plate and the
adjacent surface of the rubber dielectric.

15   The innumerable slight irregularities on the dielec-
tric's surface effectively comprise a gap of about 10
microns between the transducer plates and the adjacent
faces of the dielectric material. As indicated above, such
small gaps are capable of sustaining relatively high volt-
20 ages before breakdown occurs.   Moreover, because the
dielectric material is elastomeric, the transducer plates
are able to oscillate significantly in response to the
large electrostatic forces which correspond to the large
voltages sustainable by the dielectric's slight surface
25 irregularities.   The gap width of about 10 microns is a
"time-averaged" width, in the sense that the gap repeatedly
widens and narrows as the elastomer is deformed during
oscillation of the transducer.

There have been many applications of such textured
30 elastomeric dielectrics in different configurations, but
all suffer from the problem that as the plate separation
distance decreases, air must be compressed within the many
small irregularities on the dielectric's surface.   To
understand the significance of this problem, it is necess-
35 ary to discuss the approximate magnitudes of a variety of
mechanical impedances.   In this regard, because we are
dealing with roughly planar surfaces, it is appropriate to

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speak in terms of mechanical impedances per unit area; that is, the ratio of force per unit area (i.e. pressure) to velocity. As is well known, for reasonably small oscillations, most systems behave approximately linearly, such that the mechanical impedance of both planar surfaces and acoustic media are well defined concepts which depend on frequency, and certain physical constants.

For air, for example, the mechanical impedance per unit area, z, is given by:

$$z_{air} = \rho c \tag{2}$$

where ρ is the density of air (approximately 1.20 kg/m^3) and c is the speed of sound in air (approximately 342 metres per second at 20°C and 760 mmHg). Thus, Equation 2 yields a value of z_{air} of 410 (N/m^2)/(m/sec).

The mechanical impedance per unit area of an air gap is given by:

$$z_{gas} = P_{atm}/2\pi f d_{gap} \tag{3}$$

where P_{atm} is atmospheric pressure (1.013 x 10^5 N/m^2), d_{gap} is the thickness of the air gap, and f is the frequency of the oscillation. At a typical frequency of 10 kHz and for a typical desirable time-averaged gap width of 5 microns, (i.e. somewhat less than the Paschen minimum distance of 16 microns), Equation 3 yields a value for Z_{gap} of 3.22 x 10^5 (N/m^2)/(m/sec), which is approximately 800 times larger than the mechanical impedance per unit area of air. This very large mismatch is what makes the transducer described in U.S. Patent No. 4,885,783 intrinsically unsuitable for producing sound in air. (It is interesting to note that the mechanical impedance of water is much closer to the transducer's mechanical impedance, which explains why the transducer of U.S. Patent No. 4,885,783 works well for producing sound in water).

In practice it is neither necessary nor desirable to strive to obtain a mechanical impedance per unit area quite as low as that for air, because in many applications this would necessitate a transducer which would be so physically weak that it could too easily be damaged by routine use.

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In other words, a practical requirement is that the surface
of a transducer used to impart vibrations to air should be
reasonably robust.   For example, the surface could be
composed of 50 micron thick titanium alloy sheet, with
titanium being selected to provide a high ratio of strength
to mass, as well as resistance to chemical attack.   Such a
sheet has a mass per unit area of 0.225 kg/m^2. The mechan-
ical impedance per unit area associated with the mass of a
sheet is given by:

$$z_{mass} = 2\pi f m_{sheet} \qquad (4)$$

where z_{mass} is the mechanical impedance per unit area
associated with deflecting the mass, f is the frequency of
the mechanical oscillation, and m_{sheet} is the mass per unit
area of the sheet.   At a typical frequency of 10 kHz,
Equation 4 yields a mechanical impedance per unit area for
a 50 micron thick titanium sheet of about 14,100
$(N/m^2)/(m/sec)$, which is about 35 times greater than that
for air.

If it is desired to have an air gap whose impedance is
comparable to the foregoing value, Equation 3 can be solved
to show that at 10 kHz, the gap would have to be roughly
0.1 mm (i.e. 100 microns) thick.   But, this thickness is
very substantially beyond the thickness corresponding to
the Paschen minimum distance of Figure 2.

One solution which might be considered, but which does
not work, is to allow the gas to flow from the gap to the
region outside the transducer; or, to flow into the gap
from such region as the sheet transducer oscillates.   This
is impractical because such gas flow would have to occur
very rapidly; namely, at a flow rate which could not be
achieved, due to the viscous damping of the gas.   More-
over, even if the requisite gas flow rate could be achiev-
ed, in many applications such gas flow into and out of the
transducer would negate the desired operation of the device
by producing a secondary sound wave which would cancel the
intended wave.   For both of these reasons it is essential

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to maintain the effective gap size as described; that is, roughly 0.1 mm (i.e. 100 microns) thick.

We thus face two apparently conflicting transducer design criteria. On one hand, the gap between the transducer plates is preferably made as small as possible (about 5 microns on a time-averaged basis) in order to achieve large breakdown fields and hence large electrostatic pressures. On the other hand, the gap between the transducer plates is preferably made as large as possible (i.e. 0.1 mm) in order to avoid the problem of compressing a gas within a small gap, and thus allow the transducer's mechanical impedance per unit area to be closer to that of air.

Figure 3 shows schematically how one may simultaneously achieve the desirable features of both small and large gaps. Specifically, Figure 3 shows in cross-section opposed first and second sheets 30, 32 which together define a gas filled gap 34. First sheet 30 is flat, but second sheet 32 is textured such that gap 34 consists of a plurality of thick regions 36 and thin regions 38. In a typical example, the total "projected area" of thin regions 38 (i.e. the sum of the areas in which a notional cross-sectional plane parallel to sheets 30, 32 intersects the thin regions) may be about the same as the total projected area of thick regions 36 (i.e. the sum of the areas in which the aforesaid notional plane intersects the thick regions), such that the mechanical impedance of the overall gap 34 is approximately that of the average thickness; that is, the mean of the thickness of thick and thin regions 36, 38. The reason for this is that as sheet 30 oscillates as depicted by double-headed arrow 31, the gas which would otherwise have to be rarefied and compressed in thin regions 38 can instead flow alternately into and out of thin regions 38; and, out of and into thick regions 36, as depicted by double-headed arrows 39. In other words, the width of each of the thin regions is less than the width at which gas flow into and out of the thin regions can substantially increase the transducer's net mechanical impe-

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dance per unit area at frequencies within the transducer's intended operating frequency range. The maximum electrostatic force associated with thin regions 38 can easily be 100 to 1,000 times greater than that attainable with thick
5   regions 36 alone. The fact that only about 50% of the area of the transducer can be made up of such thin regions is a small price to pay for such a significant increase in maximum electrostatic pressure.

In order to take advantage of the principles described
10 above with reference to Figure 3, the invention provides several additional features. First, it is important that the electrostatic field energy be concentrated in thin regions 38; both to optimize the efficiency of the transducer, and to reduce the possibility of electrical break-
15 down in thick regions 36, which are incapable of support-ing large electric fields. Figure 4 shows how this can be achieved by providing conductive surfaces on the inner faces of the transducer sheets. Specifically, in Figure 4A, upper sheet 40 is entirely conductive; and, a conduc-
20 tive surface 46 is applied to lower sheet 42 in discrete strips located only on the flat tops of ridges 44 on sheet 42, such that conductive strips 46 are entirely located within thin regions 48, and not within thick regions 47.

Although the Figure 4A technique effectively con-
25 strains the electrostatic field energy to thin regions 48 as desired, it may in certain circumstances be easier to use the technique shown in Figure 4B, in which the entire surface of sheet 42 is covered with conductive material in the form of conductive sheet 49. Despite the fact that
30 sheet 49 borders both thin regions 48 and thick regions 47, most of the electrostatic energy is still concentrated in thin regions 48 because the field energy density is propor-tional to the square of the field, and the field itself is inversely proportional to the thickness of the gap. For
35 example, if thin regions 48 are 1/10th the thickness of thick regions 47, they would have 10 times the field, and 100 times the electrostatic energy density; so, although

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thin regions 48 are only 1/10th as thick as thick regions
47, 90% of the field energy would still be concentrated
within thin regions 48. Providing the fields are not too
high, the lower fields in thick regions 47 may be suffi-
5   ciently low that breakdown will not occur, so that this
technique would work.

Figure 4C shows another technique for maximizing the
electrostatic field energy in thin regions 48. Here, the
ridges atop elastomeric sheet 42 are structured such that
10 every fifth ridge 43 is 5 microns higher than the remaining
ridges 44. Accordingly, the upper conductive sheet 40
(which may be titanium) is supported atop the slightly
higher ridges 43. The tops of the shorter, remaining
ridges 44 are capped by gold contacts 45 which are electri-
15. cally connected to one terminal of a power supply (not
shown). Upper conductive sheet 40 is connected to the
other terminal of the power supply. When an appropriate
signal voltage is applied, the electrostatic forces between
sheet 40 and gold-capped ridges 44 set sheet 40 into
20 oscillation, thereby generating sound waves in the air
above sheet 40. An adhesive backing 41 can be provided on
elastomeric sheet 42 to create a "tape" which can easily be
applied to a surface.

The Figure 4C design substantially increases the
25 volume of air trapped inside the transducer between conduc-
tive sheet 40 and elastomeric sheet 42 without increasing
the distance between the electrodes, which would otherwise
reduce the electrical breakdown strength of the air between
the electrodes and thus also reduce the maximum power
30 output of the transducer. Increasing the volume of trapped
air reduces the resistance (i.e. impedance) to the motion
of sheet 40, and thus allows the generation of louder (i.e.
higher pressure) sound waves by the transducer. Second,
because there is nothing but air in the electric field
35 between the transducer's electrodes, other modes of elec-
trical breakdown (e.g. breakdown of the elastomer) are
avoided. Third, any breakdown current must flow between

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the two electrodes (i.e. between one or more of the gold
contacts 45 and conductive sheet 40), thus requiring
current flow along the full extent of at least one of the
"U" shaped paths formed between an adjacent pair of ridges

5   43, 44. A breakdown voltage of about 10^8 volts per meter
would be required to produce such a current, which is
within the desired range.

    The specific technique used to concentrate the elec-
trostatic field energy in the thin regions is not import-

10 ant. All that matters is that some such technique be
employed to ensure the efficiency of the transducer. Those
skilled in the art will be able to devise techniques alter-
native to those described above in relation to Figures 4A,
4B and 4C.

15   In general, the average thickness of the gap in the
thick regions must greatly exceed the thickness of the gap
in the thin regions. The optimum ratio of these two
thicknesses can be determined in any given case by examin-
ing the trade off between two factors. On the one hand,

20 increasing this ratio will decrease the mechanical impe-
dance of the device, which in general will improve the
performance and hence the value of the device. However, as
this ratio becomes larger, the rate of improvement on
further increases drops rapidly, as the performance rises

25 toward a limiting value which will not be exceeded no
matter how large the ratio is made. On the other hand, the
difficulty of fabrication, and hence the cost of the
device, will rise rapidly as the ratio of the thicknesses
is increased. Therefore, the ratio of the value to the

30 cost will in general have a maximum value, which will
generally occur at a thickness ratio which is large enough
to achieve most of the desired performance gain, without
incurring too much extra cost. Typically, this ratio will
be in the range of 3 to 15, but in rare circumstances the

35 optimum as described above may lie outside that range.

    It will be appreciated that the typical desired
dimension of 5 microns for the thickness of the thin

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regions is very small relative to the typical accuracies with which ordinary surfaces are made, and is exceedingly small compared to the typical accuracies with which ordinary surfaces are positioned. The invention provides a

5   means of overcoming this practical difficulty. For the transducer to perform as has been described, it is not in fact necessary for the flatness inaccuracy or position inaccuracy of the surface to be substantially less than the typical desired thin gap thickness of 5 microns. All that

10   matters is that within any given thin region the separation between the transducer sheets be maintained reasonably consistently at the desired dimension. Figure 5 shows schematically how this can be achieved. Lower, textured sheet 52 is relatively inflexible and is shown to have

15   exaggerated dimensional errors (represented by the different heights of the upwardly protruding flat-topped ridges on sheet 52). Flat upper sheet 50 is comparatively flexible on the size scale of the errors in sheet 52. Numerous "localized positioning means" 54 are provided to maintain

20   the correct dimension for the thin gap regions 56 (i.e. the distance between the inner face of sheet 50 and the adjacent faces of the flat-topped upwardly protruding ridges on sheet 52). Localized positioning means 54 must not interfere with the electrical operation of the transducer. They

25   must also be flexible so that oscillations of the transducer can still occur. Those skilled in mechanical and micro-mechanical design will be able to devise numerous arrangements for achieving such localized flexible positioning means, one of which is described below, but all of

30   which fall within the scope of this invention.

        If the transducer is to achieve the desired mechanical impedance per unit area, gas must be able to flow from the thin regions into the thick regions and back as the transducer oscillates. The necessity of such gas flow gives

35   rise to additional mechanical impedance. This impedance arises both from the mass of the moving air (which contributes to a greater relative extent than the mass of the

sheets, because the air moves a greater distance); and,
from the viscous drag of the air moving against stationary
surfaces. Both of these aerodynamic sources of mechanical
impedance per unit area will increase with increased width
5   of the thin regions. Therefore, to ensure that this
impedance does not substantially degrade operation of the
transducer, it will typically be necessary to appropriately
restrict the width of the thin regions. For the exemplary
cases described below, the most practical designs shown
10   have typical values for the width of the thin regions which
are smaller than this limiting value. In other cases, it
may be necessary to carry out detailed aerodynamic calcula-
tions involving viscous drag and inertial effects to
establish that this is in fact the case.

15   Those skilled in the art will appreciate that the
optimum design of a transducer embodying the invention
depends upon the transducer's intended usage and upon
associated trade offs between physical strength, desired
coupling efficiency to the selected medium (which will have
20   a characteristic mechanical impedance), frequency, desired
amplitude of oscillation, etc. There are no specific
guidelines which will adequately cover every case, but
several design criteria are desirably incorporated in
practical embodiments of the invention. For example, as
25   mentioned above, it is highly desirable for the thickness
of the thin regions to be substantially less than the
Paschen minimum distance for the gas and gas pressure in
the gap of the transducer in question, in order to allow
enhanced electrostatic fields to be present.

30   Once the mass per unit area of the transducer's
vibrating sheet is determined, it will be desirable to
select a thickness for the thick regions of the gas filled
gap which is large enough that the net mechanical impedance
per unit area associated with compressing the gas in the
35   gap is of the same order as or smaller than the mechanical
impedance per unit area associated with vibrating the mass
per unit area.

Once a target is established for the thickness of the
thin and thick gas filled gap regions, practical design
considerations will strongly suggest the typical width
dimensions for the thin and thick regions. Typically, the
5   thin and thick regions will have approximately the same
total area and their typical widths will be on the order of
the thickness of the gas filled gap in the thick regions.
In addition to such practical dimensional considerations,
however, it is also highly advantageous to ensure that the
10   typical width of the thin regions is small enough that the
viscosity and inertia of gas flowing into and out of these
regions does not substantially increase the net mechanical
impedance per area of the transducer in its intended
operating conditions.

15   Similarly, although a variety of flexible positioning
means can be envisioned (one example being described
below), it is highly desirable that whatever means is used
is sufficiently flexible to ensure that the stiffness of
the positioning means does not substantially reduce the
20   output of the transducer. In other words, the net mechan-
ical impedance per unit area associated with forces arising
from the positioning means should be of the same order or
less than the net mechanical impedance per unit area
associated with the mass per unit area of the transducer
25   sheets under their intended operating conditions.

Figures 6A, 6B and 6C depict a preferred embodiment of
the invention. Figure 6A is a side view showing only two
of the numerous upwardly protruding flat-topped linear
ridges 64 on lower sheet 62 which define the transducer's
30   thin and thick regions relative to flat upper sheet 60, as
described above. Figure 6B is an end view of the same
structure. Figure 6C is an enlarged view of the encircled
portion of Figure 6B. Sheet 62 is made of silicone rubber.
The thin and thick regions are each typically 400 microns
35   wide (dimension "W" in Figure 6A). The thick regions are
also typically 400 microns thick (dimension "H_{thick}" in
Figure 6A). The thin regions are typically 5 microns thick

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(dimension "H_{thin}" in Figure 6A). A plurality of conductive strips 65 (Figure 6C) are deposited atop ridges 64 as described above in relation to Figure 4A. Strips 65 may comprise a vacuum deposited layer, typically gold, which is
5   sufficiently thin that it remains adhered to and does not change the flexibility of the silicone rubber comprising sheet 62. Strips 65 are electrically connected together to form a single conductive "surface" on lower sheet 62.

Upper sheet 60 is a 50 micron thick sheet of electri-
10   cally conductive titanium alloy which constitutes a fairly low mass, relatively robust external surface for providing vibrations in air. The inward face of upper sheet 60 bears a thin insulating coating 67 which reduces the possibility of catastrophic failure of the transducer, should a manu-
15   facturing flaw result in a localized error in the dimensions and hence allow electrical breakdown to occur. Sheet 60 is provided with a plurality of breathing holes 68 which are large enough to allow the pressure of the gas trapped between sheets 60, 62 to equilibrate with the gas pressure
20   external to the transducer at frequencies substantially below the transducer's intended operating frequency range; but small enough that, at the transducer's operating frequency, very little gas flows into or out of these holes. Typically, the diameter of holes 68 may be 1 to 10
25   microns. Alternatively, holes 68 may be of a larger diameter, if they are filled with a porous plug or covered with a porous membrane, to achieve the same net effect.

The use of rubber to form the bulk of sheet 62 is beneficial for two reasons. First, it helps to ensure that
30   there is sufficient flexibility for the localized positioning means to appropriately fix the desired thickness of the thin regions, without the positioning means having to be extraordinarily strong, which therefore means that it need not be very stiff. Second, by taking advantage of the
35   flexibility of the rubber itself, one may design a simple but effective flexible localized positioning means. This can be understood with respect to the end view in Figure

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6B, in which the localized positioning means takes the form
of a series of adhesive spacing strips 66 having a thick-
ness H_{thin} equal to the desired thickness of the thin region;
and, a width great enough that a reasonable bond strength

5   can be achieved between strips 66 and the top surface of
ridges 64, yet small enough that the strips 66 do not cover
a substantial portion of the area of the thin region.
Strips 66 need not be elastomeric, since the compressibil-
ity of such material on the size scale of strips 66 would

10   be negligible anyway. Rather, the flexibility associated
with strips 66 results from the deformability of the rubber
substrate underneath. With the dimensions as shown, using
typical elastomeric materials, the net stiffness associated
with the deformation of the rubber in this case will be

15   comparable to the stiffness associated with the air com-
pression, and is thus acceptable. Many variations of this
design concept are possible and will have different advan-
tages in different situations. For example, it may be
desirable not to require strips 66 themselves to be good

20   electrical insulators, and it may therefore be desirable to
configure the conductive surfaces to avoid intense electric
fields in the vicinity of strips 66. In some cases strips
66 may not need to be adhesive per se, since there may be
available an external positioning force, such that strips

25   66 need only apply compressive resistance rather than
adhesion.

       Sheet 62 need not be formed with parallel, flat-
topped ridges like those shown in Figure 6A. Alternative
structures capable of achieving the principles described

30   above will doubtless occur to those skilled in the art.

       One important application of the invention, depicted
in Figure 7, is as a means for modifying aerodynamic flow
over a rigid surface such as wing 70. This is achieved by
applying transducer 71 (constructed as described above in

35   relation to Figures 6A and 6B) to a portion of the wing's
surface, and then applying a controlled electrical signal
to the transducer, thereby causing a controlled acoustical

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excitation 72 in the air flow. The specific design de-
scribed above in relation to Figures 6A and 6B comprises
many of the characteristics which are desirable in such an
application; namely, low overall thickness, relatively high
5   efficiency, relatively low weight, an external surface
which is relatively robust, and a capability of producing
sound levels at a frequency and intensity suitable for
modifying aerodynamic flow. Specifically, the design shown
is capable of producing acoustic excitations of approxi-
10   mately 120 db at 10^4 hertz, which under certain circum-
stances has been shown to change the characteristics of the
transitions to turbulence of air flow over a wing, and of
the separation of flow over the wing, in manners which can
be advantageous for a variety of reasons. Again, depending
15   on the flow characteristics in question and the desired
effects, a variety of different configurations may be
employed, and can be easily devised using the methods and
structures described herein.

     As will be apparent to those skilled in the art in the
20   light of the foregoing disclosure, many alterations and
modifications are possible in the practice of this inven-
tion without departing from the spirit or scope thereof.
Accordingly, the scope of the invention is to be construed
in accordance with the substance defined by the following
25   claims.

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WHAT IS CLAIMED IS:

1. An electrostatic transducer having first and second
    sheets (40, 42) separated by a gas-filled gap, each of
    said sheets having a conductive surface for imposing
    electric fields within said gap, said transducer
    characterized by flexible positioning means (44) for
    maintaining a desired time-averaged thickness of said
    gap, said gap comprising a plurality of thick regions
    (47) and a plurality of thin regions (48), wherein:
    (a) said thin regions have a total projected area
        comprising a substantial portion of either one of
        said sheets' total area;
    (b) said thick regions have a total projected area
        also comprising a substantial portion of either
        one of said sheets' total area;
    (c) said gap has an average thickness in said thick
        regions which greatly exceeds said gap's average
        thickness in said thin regions; and,
    (d) means for concentrating said electric fields'
        electrostatic field energy in said thin regions.

2. An electrostatic transducer as defined in Claim 1,
    wherein any path length extending directly through
    said gas between said conductive surfaces is greatly
    exceeded by any path length extending along said
    flexible positioning means between said conductive
    surfaces.

3. An electrostatic transducer as defined in Claim 1 or
    2, wherein said positioning means comprises an
    elastomeric material.

4. An electrostatic transducer as defined in Claim 3,
    wherein:
    (a) said gas has a gas pressure in said gap; and,
    (b) said transducer further comprises means for
        equalizing said gas pressure in said gap with a
        gas pressure external to said transducer, at fre-
        quencies substantially below said transducer's
        intended operating frequency range.

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5.   An electrostatic transducer as defined in Claim 4,
      wherein said positioning means comprises an elasto-
      meric material forming an integral part of one of said
      sheets and bearing a conductive coating, said coating
      having a thickness less than that which would signifi-
      cantly impede flexibility of said coated sheet.

6.   An electrostatic transducer as defined in Claim 5,
      wherein said conductive surface on at least one of
      said sheets is coated with a thin ceramic for electri-
      cally isolating said surface from said gap.

7.   An electrostatic transducer as defined in Claim 1 or
      2, wherein:
      (a)   said gas has a gas pressure in said gap; and,
      (b)   said gap thickness in said thin regions is less
            than or equal to the Paschen minimum distance for
            said gas and said gas pressure.

8.   An electrostatic transducer as defined in Claim 7,
      wherein:
      (a)   said sheets have:
            (i)   a component z_{gap} of net mechanical impedance
                  per unit area due to pressure changes
                  required to compress and rarefy said gas
                  within said gap;
            (ii) a component z_{mass} of net mechanical impedance
                  per unit area due to said sheets' mass; and,
      (b)   said gap thickness in said thick regions is
            sufficiently large that said component z_{gap} has a
            magnitude of the same order as, or less than the
            magnitude of said component z_{mass} at frequencies
            within said transducer's intended operating fre-
            quency range.

9.   An electrostatic transducer as defined in Claim 8,
      wherein each of said thin regions have a width less
      than the width at which gas flow into and out of said
      thin regions can substantially increase said trans-
      ducer's net mechanical impedance per unit area at

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frequencies within said transducer's intended operating frequency range.

10. An electrostatic transducer as defined in Claim 9, wherein:

(a) said positioning means has a net mechanical impedance per unit area z_{pos};

(b) said sheets have a component z_{mass} of net mechanical impedance per unit area due to said sheets' mass; and,

(c) z_{pos} has a magnitude of the same order as, or less than the magnitude of said component z_{mass} for frequencies within said transducer's intended operating frequency range.

11. An electrostatic transducer as defined in Claim 10, wherein said positioning means comprises an elastomeric material.

12. An electrostatic transducer as defined in Claim 11, wherein:

(a) said gas has a gas pressure in said gap; and,

(b) said transducer further comprises means for equalizing said gas pressure in said gap with a gas pressure external to said transducer, at frequencies substantially below said transducer's intended operating frequency range.

13. An electrostatic transducer as defined in Claim 12, wherein said positioning means comprises an elastomeric material forming an integral part of one of said sheets and bearing a conductive coating, said coating having a thickness less than that which would significantly impede flexibility of said coated sheet.

14. An electrostatic transducer as defined in Claim 13, wherein said conductive surface on at least one of said sheets is coated with a thin ceramic for electrically isolating said surface from said gap.

15. An electrostatic transducer as defined in Claim 7, wherein each of said thin regions have a width less than the width at which gas flow into and out of said

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thin regions can substantially increase said trans-
ducer's net mechanical impedance per unit area at
frequencies within said transducer's intended operat-
ing frequency range.

16.   An electrostatic transducer as defined in Claim 7,
      wherein:

      (a)   said positioning means has a net mechanical impe-
            dance per unit area z_{pos};

      (b)   said sheets have a component z_{mass} of net mechan-
            ical impedance per unit area due to said sheets'
            mass; and,

      (c) z_{pos} has a magnitude of the same order as, or less
            than the magnitude of said component z_{mass} for fre-
            quencies within said transducer's intended oper-
            ating frequency range.

17.   An electrostatic transducer as defined in Claim 15,
      wherein:

      (a)   said positioning means has a net mechanical impe-
            dance per unit area z_{pos};

      (b)   said sheets have a component z_{mass} of net mechan-
            ical impedance per unit area due to said sheets'
            mass; and,

      (c) z_{pos} has a magnitude of the same order as, or less
            than the magnitude of said component z_{mass} for fre-
            quencies within said transducer's intended oper-
            ating frequency range.

18.   An electrostatic transducer as defined in Claim 1 or
      2, wherein:

      (a)   said sheets have:

            (i)   a component z_{gap} of net mechanical impedance
                  per unit area due to pressure changes
                  required to compress and rarefy said gas
                  within said gap;

            (ii) a component z_{mass} of net mechanical impedance
                  per unit area due to said sheets' mass; and,

      (b)   said gap thickness in said thick regions is
            sufficiently large that said component z_{gap} has a

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magnitude of the same order as, or less than the magnitude of said component z_{mass} at frequencies within said transducer's intended operating frequency range.

19. An electrostatic transducer as defined in Claim 18, wherein each of said thin regions have a width less than the width at which gas flow into and out of said thin regions can substantially increase said transducer's net mechanical impedance per unit area at frequencies within said transducer's intended operating frequency range.

20. An electrostatic transducer as defined in Claim 18, wherein:

(a) said positioning means has a net mechanical impedance per unit area z_{pos};

(b) said sheets have a component z_{mass} of net mechanical impedance per unit area due to said sheets' mass; and,

(c) z_{pos} has a magnitude of the same order as, or less than the magnitude of said component z_{mass} for frequencies within said transducer's intended operating frequency range.

21. An electrostatic transducer as defined in Claim 20, wherein each of said thin regions have a width less than the width at which gas flow into and out of said thin regions can substantially increase said transducer's net mechanical impedance per unit area at frequencies within said transducer's intended operating frequency range.

22. An electrostatic transducer as defined in Claim 1 or 2, wherein each of said thin regions have a width less than the width at which gas flow into and out of said thin regions can substantially increase said transducer's net mechanical impedance per unit area at frequencies within said transducer's intended operating frequency range.

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23. An electrostatic transducer as defined in Claim 22,
     wherein:
     (a) said positioning means has a net mechanical impe-
          dance per unit area z_{pos};
     (b) said sheets have a component z_{mass} of net mechan-
          ical impedance per unit area due to said sheets'
          mass; and,
     (c) z_{pos} has a magnitude of the same order as, or less
          than the magnitude of said component z_{mass} for fre-
          quencies within said transducer's intended oper-
          ating frequency range.

24. An electrostatic transducer as defined in Claim 1 or
     2, wherein:
     (a) said positioning means has a net mechanical impe-
          dance per unit area z_{pos};
     (b) said sheets have a component z_{mass} of net mechan-
          ical impedance per unit area due to said sheets'
          mass; and,
     (c) z_{pos} has a magnitude of the same order as, or less
          than the magnitude of said component z_{mass} for fre-
          quencies within said transducer's intended oper-
          ating frequency range.

25. An electrostatic transducer as defined in Claim 7,
     wherein:
     (a) said positioning means has a net mechanical impe-
          dance per unit area z_{pos};
     (b) said sheets have a component z_{mass} of net mechan-
          ical impedance per unit area due to said sheets'
          mass; and,
     (c) z_{pos} has a magnitude of the same order as, or less
          than the magnitude of said component z_{mass} for fre-
          quencies within said transducer's intended oper-
          ating frequency range.

26. A method of modifying aerodynamic flow characteristics
     over a rigid surface, said method comprising the steps
     of:

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     (a)   applying to said surface a transducer constructed in accordance with Claim 1 or 2; and,

     (b)   applying a time-varying voltage across said sheets, thereby imposing said electric fields within said gap and causing said sheets to oscillate in a desired frequency and amplitude range.

27.   A method of modifying aerodynamic flow characteristics over a rigid surface, said method comprising the steps of:

     (a)   applying to said surface a transducer constructed in accordance with Claim 10; and,

     (b)   applying a time-varying voltage across said sheets, thereby imposing said electric fields within said gap and causing said sheets to oscillate in a desired frequency and amplitude range.

28.   A method of modifying aerodynamic flow characteristics over a rigid surface, said method comprising the steps of:

     (a)   applying to said surface a transducer constructed in accordance with Claim 14; and,

     (b)   applying a time-varying voltage across said sheets, thereby imposing said electric fields within said gap and causing said sheets to oscillate in a desired frequency and amplitude range.

29.   A method of acoustically exciting a medium adjacent to a surface, said method comprising the steps of:

     (a)   applying to said surface a transducer constructed in accordance with Claim 1 or 2; and,

     (b)   applying a time-varying voltage across said sheets, thereby imposing said electric fields within said gap and causing said sheets to oscillate in a desired frequency and amplitude range.

30.   An electrostatic transducer having first and second sheets (40, 42) separated by a gas-filled gap, each of said sheets having a conductive surface for imposing electric fields within said gap, said transducer characterized by flexible positioning means (44) for

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maintaining a desired time-averaged thickness of said
gap, said gap comprising a plurality of thick regions
(47) and a plurality of thin regions (48) in gas
communication with one another, whereby gas may be
exchanged between said regions in response to oscilla-
tion of said transducer, thereby minimizing impedance
of said transducer.

31. An electrostatic transducer having first and second
sheets (40, 42) separated by a gas-filled gap, each of
said sheets having a conductive surface for imposing
electric fields within said gap, said transducer
characterized by flexible positioning means (44) for
maintaining a desired time-averaged thickness of said
gap, said gap comprising a plurality of thick regions
(47) and a plurality of thin regions (48) wherein:
(a) said gas has a gas pressure in said gap;
(b) said gap thickness in said thin regions is less
than or equal to the Paschen minimum distance for
said gas and said gas pressure; and,
(c) each of said thin regions have a width less than
the width at which gas flow into and out of said
thin regions can substantially increase said
transducer's net mechanical impedance per unit
area at frequencies within said transducer's
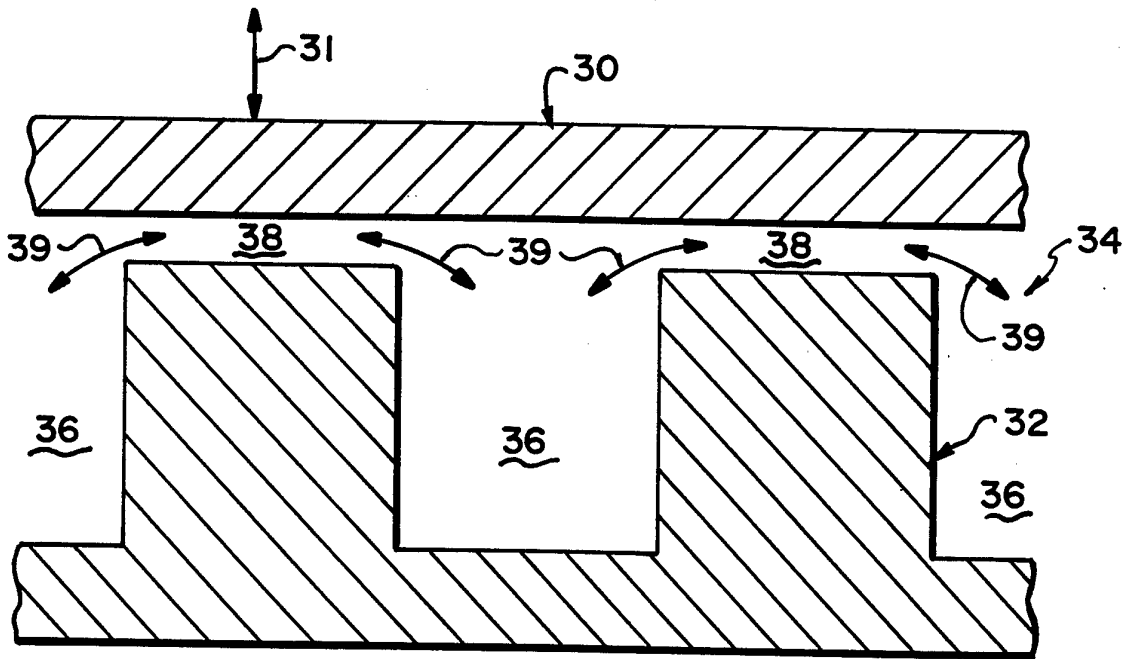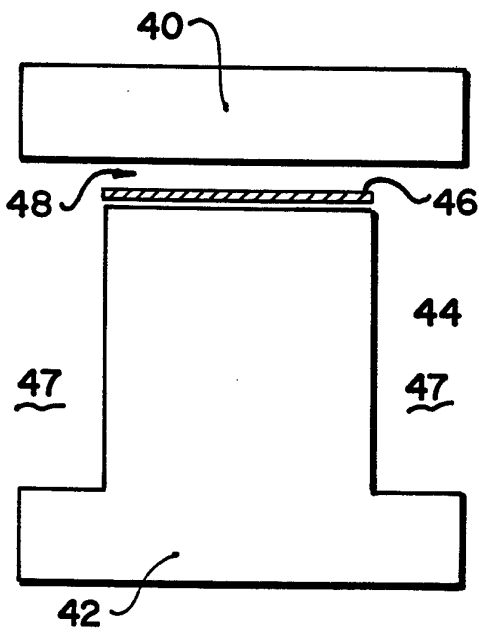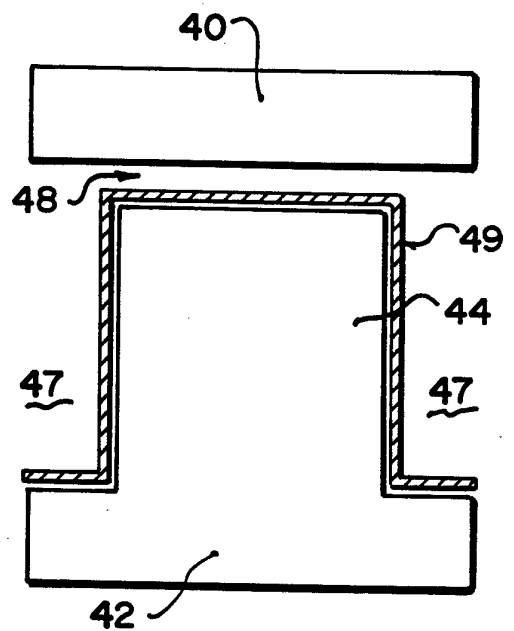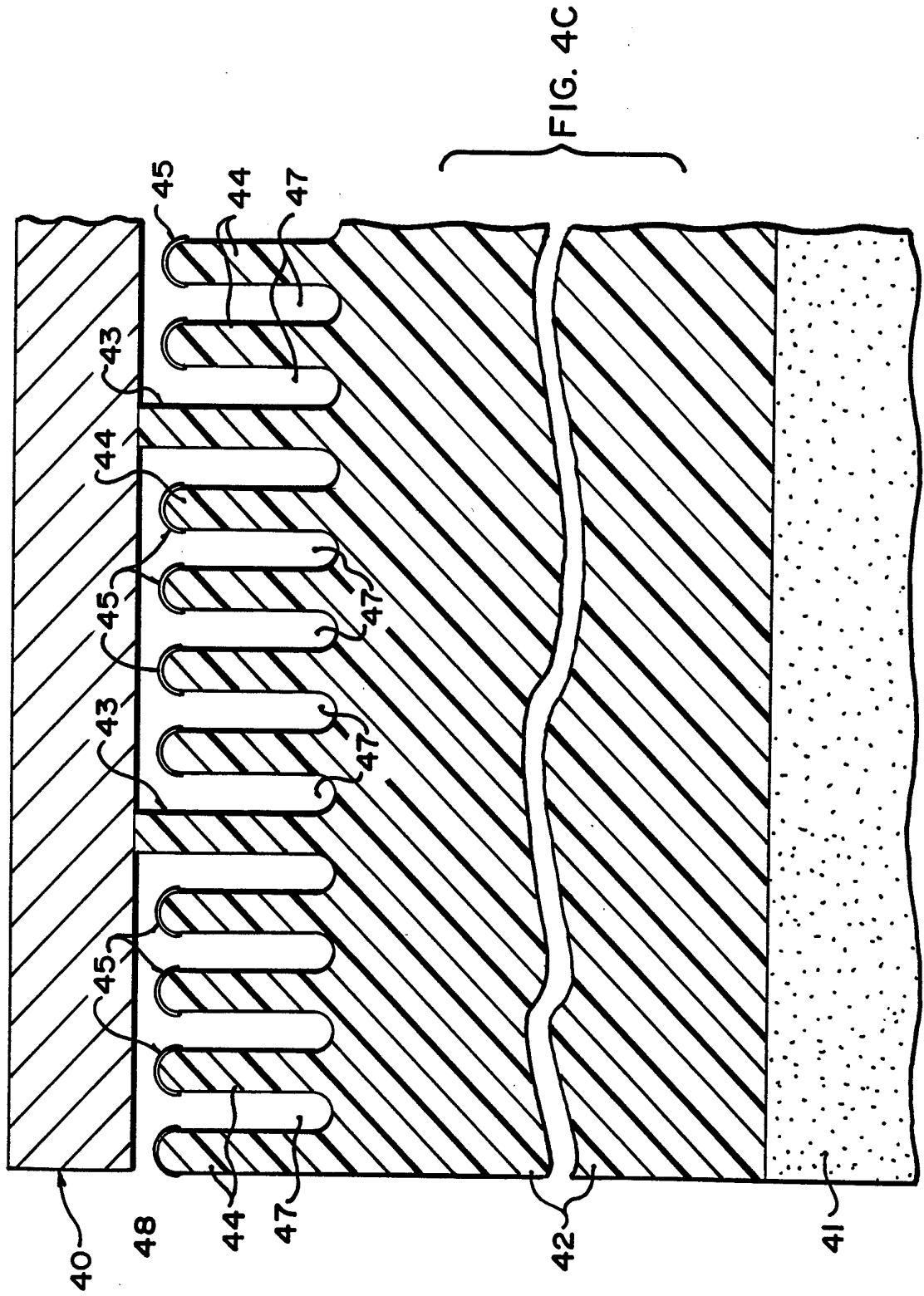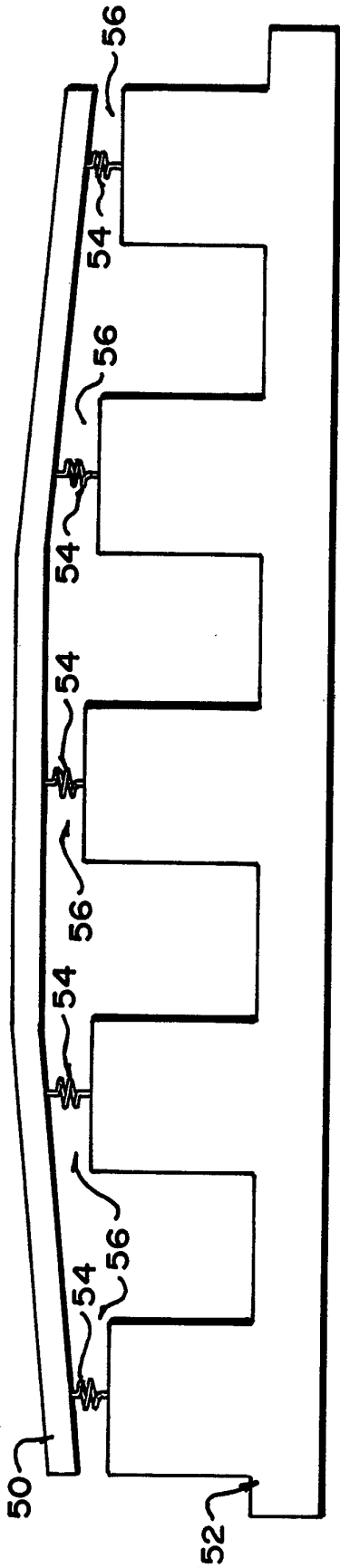intended operating frequency range.

1/5
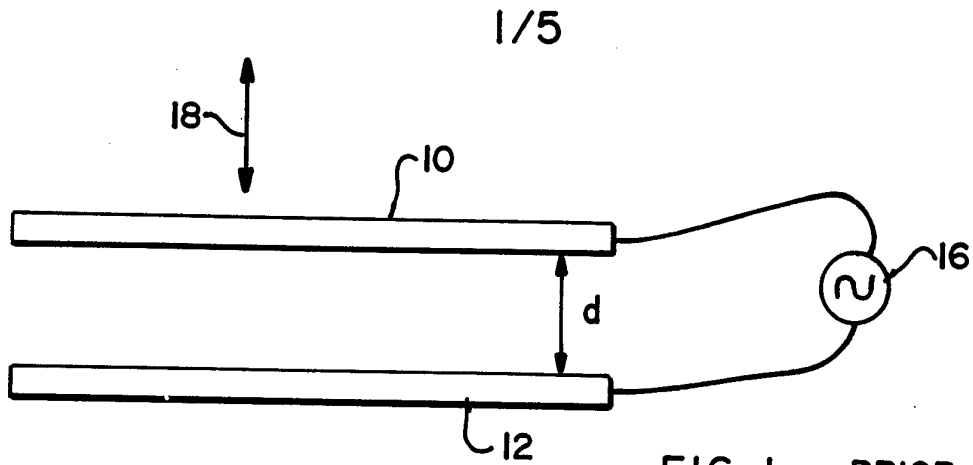
FIG. 1   PRIOR ART
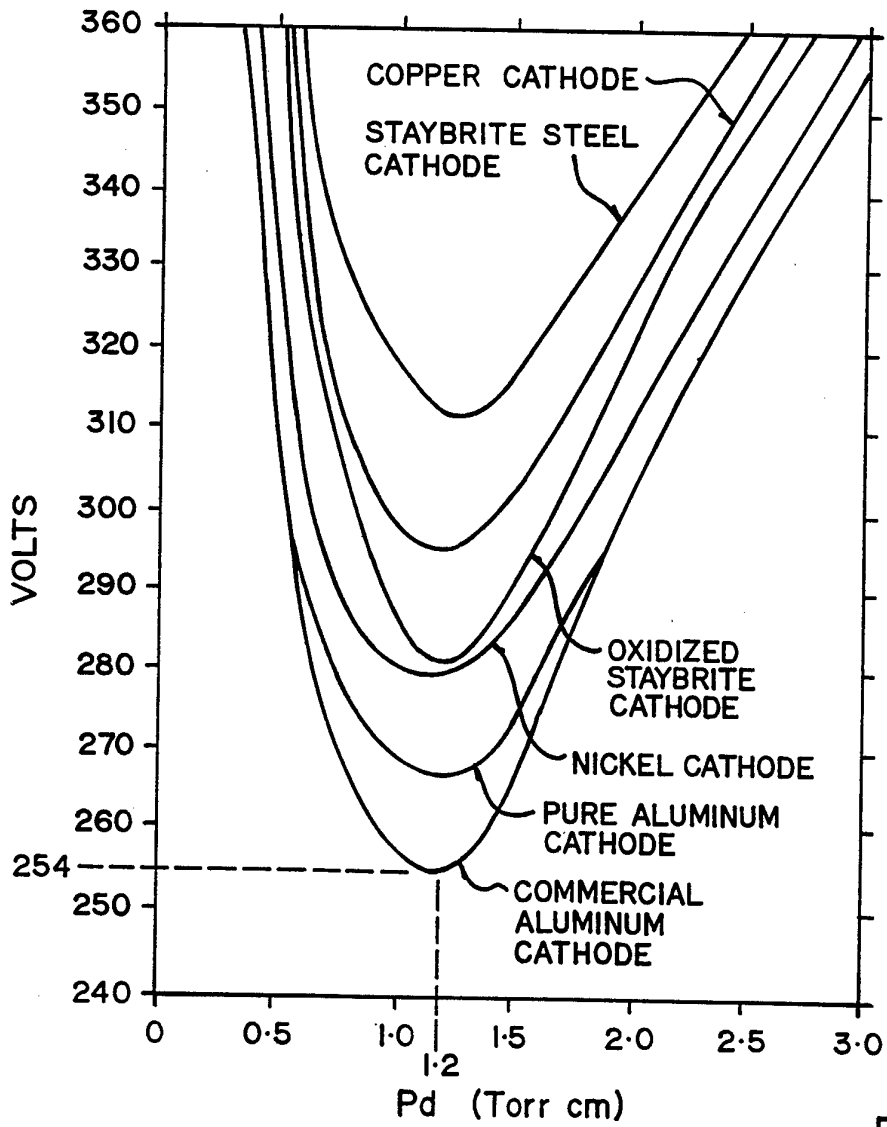
FIG. 2

FIG. 3

FIG. 4A

FIG. 4B

FIG. 4C

FIG. 5
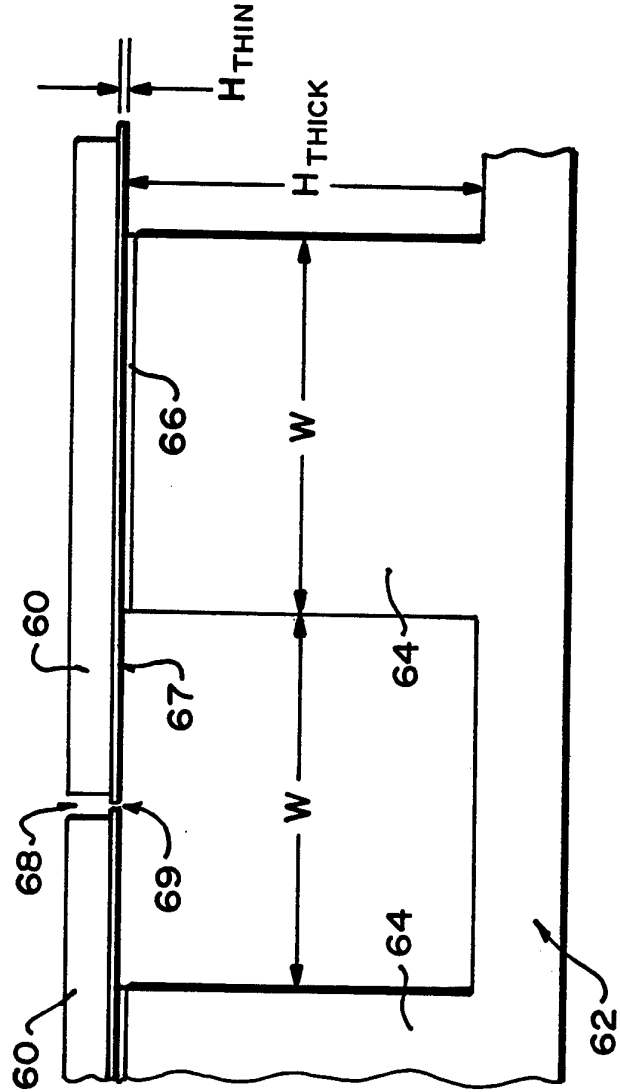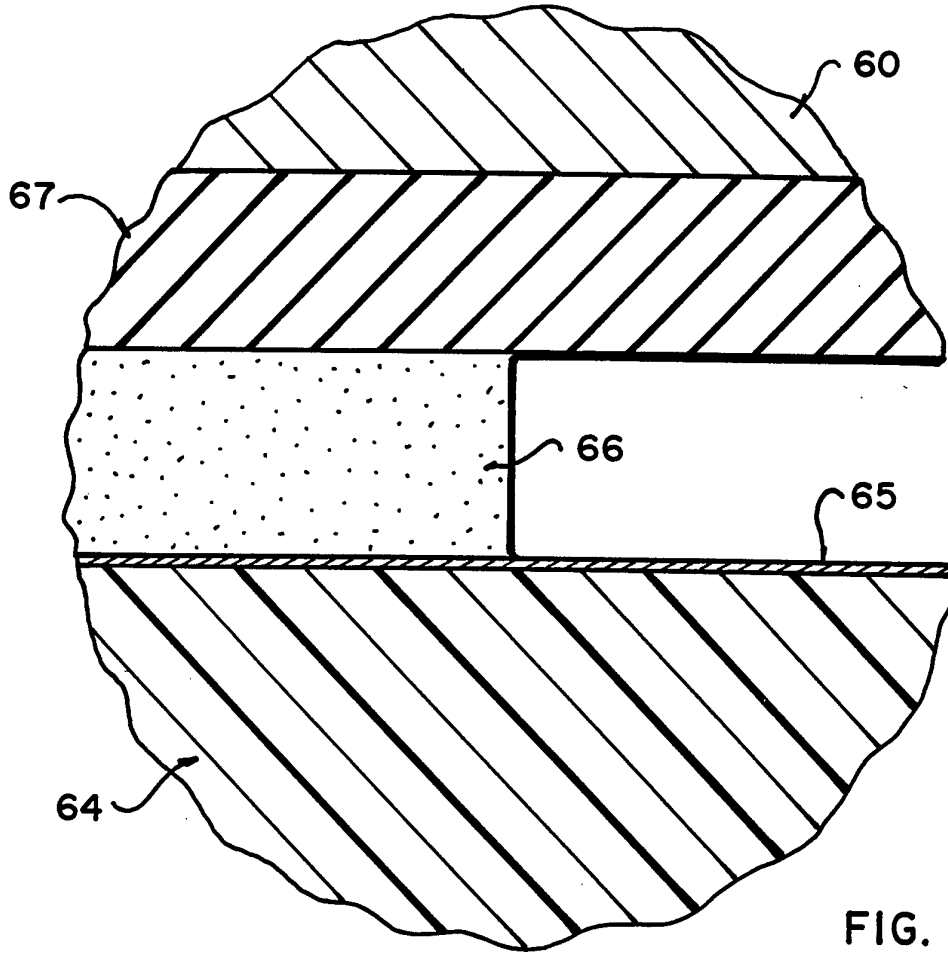
FIG. 6A
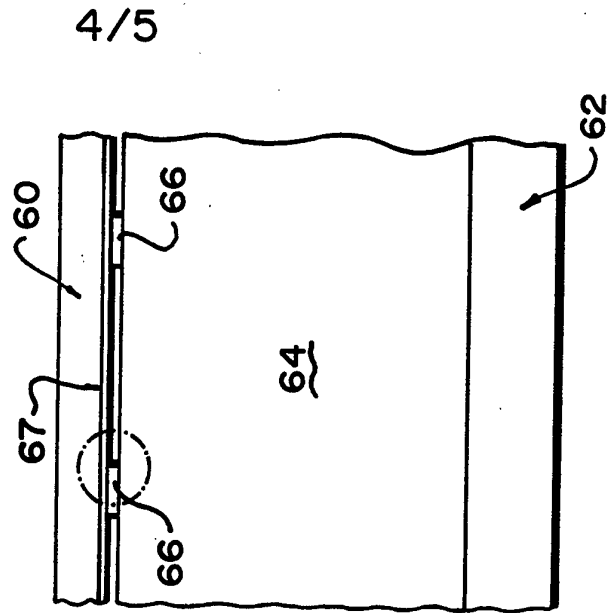
FIG. 6B

FIG. 6C

FIG. 7

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   B06B1/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   B06B G01H G10K H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category°	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DE,C,892 773 (SIEMENS & HALSKE AG.) 17 April 1941 see page 2, line 1 - line 25 see page 2, line 71 - line 120; figures 2,3 ---	1,3-7, 30,31
Y	US,A,4 885 783 (L.A.WHITEHEAD EA.) 5 December 1989 cited in the application see abstract; claims 1-4 see column 4, line 10 - column 66 ---	1,3-7, 30,31
	-/--	

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

° Special categories of cited documents :

'A' document defining the general state of the art which is not considered to be of particular relevance

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'L' document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

'O' document referring to an oral disclosure, use, exhibition or other means

'P' document published prior to the international filing date but later than the priority date claimed

'T' later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

'X' document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

'Y' document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

'&' document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 1994	'-7. 12. 94

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Haasbroek, J

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INTERNATIONAL SEARCH REPORT

Inter   nal Application No

PCT/CA 94/00379

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ACUSTICA, vol.19, 1968 pages 295 - 299 Z.SKVOR 'On the acoustical resistance due to vicous losses in the air gap of electrostatic transducers' see the whole document	8,9
A	GB,A,1 532 008 (HUNTEC LIMITED) 15 November 1978 see page 2, line 90 - line 122	4,12
Y	US,A,4 887 248 (E.L.GRIEBELER) 12 December 1989	1,2,30, 31
A	see abstract; figure 16 see column 13, line 26 - line 52	5,6,13, 14
Y	EP,A,0 144 234 (L.KAY) 12 June 1985	1,2,30, 31
A	see abstract; figures 1,2 see page 6, line 18 - page 7, line 23	5,6,13, 14
A	DATABASE WPI Derwent Publications Ltd., London, GB; AN 83-827989 & DE,A,32 28 939 (MESSERSCHNITT-BOLKOW-BLO) 24 November 1983 see abstract	26-28

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
DE-C-892773		NONE		
US-A-4885783	05-12-89	CA-A-	1277415	04-12-90
GB-A-1532008	15-11-78	CA-A-	1029846	18-04-78
US-A-4887248	12-12-89	NONE		
EP-A-0144234	12-06-85	AU-B-	573655	16-06-88
		AU-A-	3609084	13-06-85
		US-A-	4704556	03-11-87
		GB-A,B	2151025	10-07-85
		JP-A-	60157060	17-08-85