OPIC
Office de la propriété intellectuelle du Canada

CIPO
Canadian Intellectual Property Office

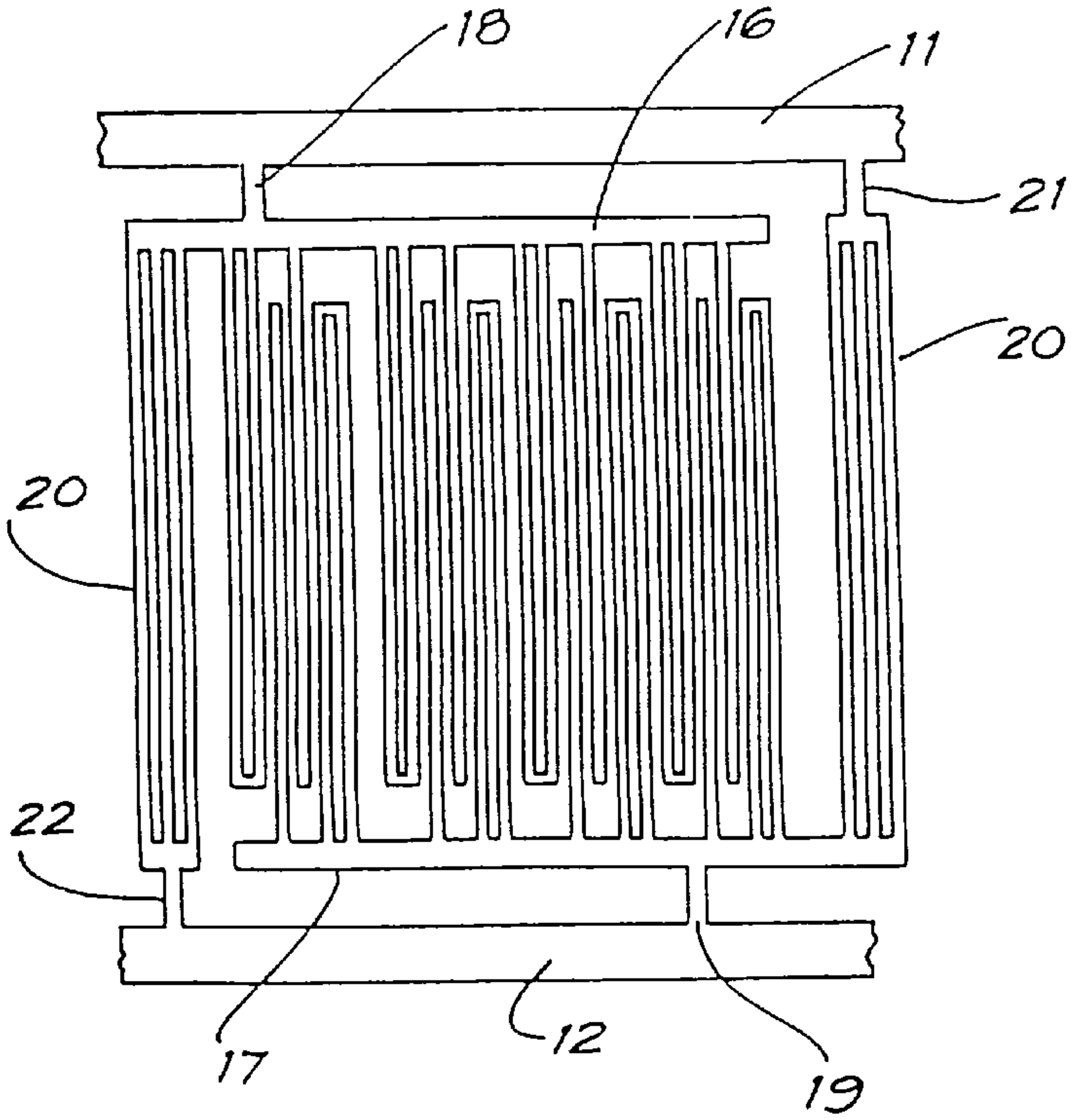
(12) (19) (CA) **Brevet-Patent**

(11) (21) (C) **2,002,179**
(22) 1989/11/03
(43) 1990/05/04
(45) 2000/05/23

(72) Vaughan, Richard, AU
(73) Vaughan, Richard, AU

(51) Int.Cl.^{5} H01P 9/04
(30) 1988/11/04 (PJ1305) AU

(54) **DISPOSITIFS A ONDES ACOUSTIQUES DE SURFACE**
(54) **SURFACE ACOUSTIC WAVE DEVICES**



(57) A surface acoustic wave transponder in which transducers (14) on the surface of a piezoelectric substrate (10) modify an interrogating signal. The transducers are phase encoded by selectively connecting their finger sets to respective busbars (11, 12) and by displacement relative to their nominal positions. Transducer fingers and track-crossing connections (20) are located so as to cause cancellation of reflected surface acoustic waves. A marker transducer (15) assists decoding. In the encapsulation of the transponders a cover plate (35) or individual cover plates (24) are attached to the substrate prior to the cutting of individual transponders from the substrate.

ABSTRACT

A surface acoustic wave transponder in which transducers (14) on the surface of a piezoelectric substrate (10) modify an interrogating signal. The transducers are phase encoded by selectively connecting their finger sets to respective busbars (11, 12) and by displacement relative to their nominal positions. Transducer fingers and track-crossing connections (20) are located so as to cause cancellation of reflected surface acoustic waves. A marker transducer (15) assists decoding. In the encapsulation of the transponders a cover plate (35) or individual cover plates (24) are attached to the substrate prior to the cutting of individual transponders from the substrate.

SURFACE ACOUSTIC WAVE DEVICES

FIELD OF THE INVENTION

The present invention relates to passive surface acoustic wave (SAW) transponders or tags for use in remote identification systems.

Known transponders of this kind comprise a substrate of piezoelectric material having coded information inscribed thereon, serving to receive electromagnetic energy, convert it to acoustic energy, store the converted energy for a period of time, re-convert the stored energy to electromagnetic form and re-transmit the electromagnetic energy. These tags thus produce a reply signal in response to the interrogation signal from the remote interrogator. The reply signal is processed to recover the code unique to the interrogated tag.

BACKGROUND ART.

Passive label interrogation systems employing SAW transponders are disclosed in Cole and Vaughan US patents 3,706,094, 3,755,803, 4,058,217 4,399,441. These systems incorporate a radio frequency transmitter capable of transmitting pulsed CW electromagnetic energy. Interrogation pulses are received at the remote antenna of a passive label and applied to a "launch" interdigitated transducer (IDT) on the surface of a piezoelectric substrate. This transducer converts the electrical energy received from the antenna into acoustic energy in the form of a surface acoustic wave or SAW that propagates on the substrate along a defined acoustic path. Groups of "coding" or "tap" IDT's are arranged at intervals along this path to convert the SAW back to electrical energy and in so doing to impart either an amplitude or phase coding to the signal that is then retransmitted via the antenna to the interrogator receiver. The antenna is a common antenna in the sense of acting both to receive and to re-transmit to the interrogator receiver. Of course, surface acoustic waves will simultaneously be launched from the tap IDT's, but as the linear SAW delay line behaves in a reciprocal fashion, these waves will sum constructively at the launch transducer effectively to double the overall delay line response.

Another form of interrogator uses a FMCW (frequency modulated continuous wave) signal. This technique is described in Australian patent specification 444,838 and in US patents 4,604,623, 4,605,929, 4,620,191, 4,623,890, 4,625,207 and 4,625,208 assigned to X-Cyte Corporation. This form of receiver utilises a simple homodyne process whereby the return signal is mixed with the originally transmitted "chirp" signal in a four quadrant multiplier to generate a low audio frequency baseband signal. A range of beat frequencies are generated because of the different delays of the transducers on the SAW delay line label. A different audio frequency is recovered for each of the elements of the encoding pattern and the relative amplitude and/or phase of these frequency elements represents the code pattern of that particular label. The encoded information is recovered by performing a spectral analysis of the baseband received signal.

In performing the spectral analysis of the beat frequencies generated by the FMCW system it is important that the comb line spectra fall on, or are coincident with, the centre of the discrete Fourier transform channels used to analyse them. Satisfying this condition minimises the intersymbol interference caused by physical limitations on the spacing between tap transducers.

The SAW delay line "chips" proposed in the prior art are produced on piezoelectric wafers of lithium niobate or quartz. The wafers are made from thin slices sawn from a synthetic crystal grown in an autoclave under rigidly controlled conditions of pressure, temperature and purity. Angles of cutting relative to the axes of the crystal determine the combination of properties in the wafer. Because of constraints on growing the synthetic crystals, wafer slices are limited to approximately 5" in diameter or circumscribed area.

The wafers are mirror polished and then covered with a layer of aluminium by vapour deposition. This thin metal layer is coated with a photosensitive resist which is then selectively exposed to form the desired transducer electrode pattern by means of high precision photolithography. The exposed resist and the underlying metal are then removed.

The critical step of exposing the resist is carried out by a well-known semiconductor mask-making process using step-and-repeat cameras. This involves using a pattern generator to produce reticles, each of which is a photographic copy (much like a photographic negative) of the layout of one chip, usually at a scale 10X the final chip size. For every chip with a different code a different and very accurate reticle must be produced.

Once the 10x reticles have been generated, there are two principal techniques which can be used to expose the resist.

Method 1.

In the first of these techniques, a 1x master mask is generated using a step-and-repeat camera held on a movable stage. Each plate exposure is a ten times photoreduction of one 10x reticle. Between exposures the stage is moved by a precise amount to the next chip position, the reticle is changed to provide the pattern for the next and differently coded chip, and the plate is exposed to transfer the chip pattern to the master mask. This process is repeated until the complete master mask area has been covered with differently coded SAW chips.

The master mask is used to contact print one or more working masks, which are used to contact print or expose resist on a metallised wafer. It will be clear that a different master mask is required for each wafer in order to make differently coded chips.

Method 2.

In the second approach, a 10x reduction direct-step-on-wafer camera is used directly to expose the resist on the metallised wafer. This eliminates the intermediate step of preparing a master mask, but still requires the 10x reticle to be changed to provide the pattern for the next and differently coded chip. It will be appreciated that a different 10x reticle is still required for each and every differently coded chip. The cost of these reticles is still a prohibitive factor in the cost of the chips themselves.

It is to be understood that references above to 10x reductions are by way of example only, and that it makes no difference in principle whether 5 times, 20 times or some other ratio is used. The possibility of such and other minor variations will be clear to those experienced in the art.

After exposing the photoresist on the metallised wafer the unwanted metallisation is selectively etched away.

The number of high precision 10x reticles may be reduced by using a second process uniquely to code a number of chips produced from the same reticle. This process may comprise a second photographic exposure, at a much lower resolution than that of the 10x reticle, before etching, or the use of some cutting means such as a laser trimmer after the chip has been manufactured. The number of 10x reticles required is reduced by the number of unique codes that can be produced by such a secondary process for each original reticle.

X-Cyte Corporation Australian patent 564,844 describes one method of reducing the number of reticles and master masks. In this method delay pads insert a selectable coding delay between the transducer elements. This allows a single reticle to be used to make the master mask, which is then used to generate all wafers. A subsequent cutting operation of lower precision is then used to trim the delay pads for each chip, thus generating unique codes.

This technique has the disadvantage that it is applicable only to piezoelectric materials with a high piezoelectric coupling constant, such as lithium niobate, as only such materials allow sufficiently small delay pads. With piezoelectric materials with a low coupling coefficient, such as quartz or zinc oxide, the length required for the delay pads would exceed the distance between the coding transducers.

In the method of the present invention, many wafers can be made from a single master mask, and the master mask is made from a single reticle. By thus spreading the cost of the reticle and master mask over many chips a great reduction in tag cost is achieved. To achieve this, while at the same time allowing the use of piezoelectric materials of either high or low coupling coefficients, the tags of the present invention incorporate novel features of transducer layout.

It is fundamental to the proper operation of coded delay lines of the type to which the present invention relates, that the transducer structures produce minimum reflection of the propagating surface acoustic wave, to avoid confusion of the returned code. Such reflections are caused by SAW impedance discontinuities due to finger mass loading and surface conductivity effects. This problem is addressed in US patent No. 4,620,191, where a solution is proposed involving the location of groups of tap transducers in multiple parallel acoustic paths. The present invention provides an alternative approach, by means of a transducer structure which uses wave cancellation to reduce these effects.

In prior art processes the finished wafers are divided into chips which are hermetically sealed, antennas are connected, and the assembly packaged to produce the final tag. These can be costly operations, and the need exists for an improved approach to the packaging process. The present invention provides methods for hermetic sealing and antenna connection which reduce the cost of these operations.

OBJECTS OF THE INVENTION:

A principle object of the present invention is to provide an approach to the design and manufacture of such transponders which will enable reductions in manufacturing and production costs.

It is also an object of the present invention to provide a novel design of phase reversible tap transducer which allows phase encoding easily to be accomplished from a standard wafer mask.

It is a further object of the invention to provide a design of tap transducer which minimises SAW reflections.

It is a further object of the present invention to provide amplitude encoding of selected transducers in such a way that the transducer capacitance remains constant enabling the SAW delay line to be tuned for maximum return signal strength and hence signal-to-noise ratio.

It is a further object of the present invention to provide packaging techniques which reduces the cost of production of a complete, hermetically sealed chip.

It is a further object of the present invention to provide a SAW coded delay line transponder in which may be employed a form of piezoelectric substrate that is significantly lower in cost than presently used materials such as quartz and lithium niobate, and which enables a significantly larger wafer size, so as to maximise the number of chips or die per wafer.

Further objects of the present invention include the provision of means to enhance the readability of a tag by the use of an optional "marker" tap transducer.

These objects, as well as further objects which will become apparent from the discussion that follows, are achieved, according to the present invention, by the location of the tap transducers, by the physical design of the tap transducers, by the choice of wafer material and by the techniques employed to package the chip.

It is to be appreciated that different forms of the invention will embody some but not necessarily all of the above objects.

SUMMARY OF THE INVENTION.

In one form, the present invention resides in a surface acoustic wave transponder comprising a plurality of tap transducers in contact with a piezoelectric material, means for the reception of an interrogating signal, means transmitting said interrogating signal as a surface acoustic wave in said material and means for retransmitting said interrogating signal modified by said tap transducers, said retransmitting means including first and second signal transmission means connected to each tap transducer, each tap transducer comprising a first set of electrically interconnected parallel fingers and a second set of electrically interconnected parallel fingers interdigitated with the fingers of the first set, characterised in that each said set of fingers is selectively connectable to one or the other of said first and second transmission means.

Preferably, the fingers of each set are respectively connected to first and second conductive path means, and these path means are connected by interruptable connection means to each of the first and second transmission means.

In a further form, the invention resides in a method of encoding such a transponder, comprising the steps of selectively interrupting said connection means such that the first set of fingers of a given tap transducer are connected to a selected one of the first and second signal transmission means and the second set of fingers is connected to the other of said signal transmission means, thereby determining the phase of the connection of that tap transducer with said transmission means.

In another form the invention resides in a SAW transponder comprising a plurality of tap transducers in contact with a piezoelectric material, means for the reception of an interrogating signal, means transmitting said interrogating signal as a surface acoustic wave along said surface and means for retransmitting said interrogating signal modified by said tap transducers, said retransmitting means including first and second signal transmission means connected to each tap transducer, each tap transducer comprising a first set of electrically interconnected parallel fingers and a second set of electrically interconnected parallel fingers interdigitated with the fingers of the first set, characterised in that the location of the edges of the fingers of each transducer is chosen in relation to the wave length of the surface acoustic wave such that surface acoustic wave reflections from said edges cancel.

From another aspect, such a transponder is characterised in that the fingers are located at such intervals along the path of the surface acoustic wave that reflections from their edges cancel.

In yet another form, the invention resides in a SAW transponder comprising a plurality of tap transducers in contact with a piezoelectric material, means for the reception of an interrogating signal, means transmitting said interrogating signal as a surface acoustic wave along said surface and means for retransmitting said interrogating signal modified by said tap transducers, said retransmitting means including first and second signal transmission means connected to each tap transducer, each tap transducer comprising a first set of electrically interconnected parallel fingers and a second set of electrically interconnected parallel fingers interdigitated with the fingers of the first set, characterised in that a group of fingers of at least one of said tap transducers is displaced in the path of the surface acoustic wave so as to be in phase opposition to another group of fingers of the same transducer.

In a further form, the invention provides a SAW transponder comprising a plurality of tap transducers in contact with a piezoelectric material at regular nominal spacings of surface acoustic wave path lengths, means for the reception of an interrogating signal, means transmitting said interrogating signal as a surface acoustic wave along said surface and means for retransmitting said interrogating signal modified by said tap transducers, characterised in that a further transducer is provided, spaced by a known surface acoustic wave path length from said tap transducers.

In a further form, the invention resides in a method of manufacturing surface acoustic wave transponders, each consisting of a layer of metallisation on a piezoelectric substrate, the method comprising the steps of applying said metallisation over an area as a repetitive pattern of individual transponder patterns, attaching a cover plate over said area, and subsequently cutting through said cover plate and said substrate in orthogonal directions to separate individual transponders.

In a further form, the invention resides in a method of manufacturing a plurality of surface acoustic wave transponders each consisting of a layer of metallisation in contact with a piezoelectric substrate, the method comprising the steps of producing said metallisation over an area as a repetitive pattern of individual transponder patterns, attaching a transponder cover plate over each transponder pattern, and subsequently cutting through said substrate in orthogonal directions to separate individual transponders.

In another form, the invention resides in a surface acoustic wave transponder consisting of a layer of metallisation in contact with a piezoelectric substrate and having a contact region at at least one end, a cover plate being attached over said metallisation, characterised in that each cover plate is provided with contact regions opposed to the contact regions of the transponders and extending beyond them.

To facilitate an understanding of the invention in its various forms, practical embodiments will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic plan view showing the layout of a transponder chip incorporating the present invention;

Figure 2 is a detailed view of the metallisation pattern of a single transducer;

Figure 3 illustrates a relatively phase shifted transducer;

Figure 4 illustrates a transducer modulated in amplitude relative to that of Figure 2;

Figure 5 is a schematic isometric view of portion of the chip;

Figure 6 is a schematic cross section of the chip illustrated in Figure 6;

Figure 7 illustrates an alternative transducer structure;

Figure 8 is a fragmentary plan view of a metallised substrate.

Figure 9 is a fragmentary bottom plan view of a cover plate.

Figures 10 (a) to (d) illustrate an economical tag construction according to a preferred form of the invention:

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS.

The general layout of a tag incorporating the present invention is shown in Fig. 1. A substrate 10 of piezoelectric material has printed thereon busbars 11 and 12, which are connected respectively to a centre fed dipole antenna (not shown). From the busbars 11 and 12 interdigitated fingers of conductive material project to provide a launch transducer 13 and a series of encoding tap transducers 14.

In the preferred FMCW interrogator implementation, the returned phase information from each tap transducer on the tag is presented to the signal analysis unit as a unique frequency. The signal returned by a complete tag is thus the vector sum of the signals returned by each individual tap transducer, and is equivalent to a comb line spectrum, with the number of frequency peaks corresponding to the number of tap transducers on the label and with the amplitude and relative phase of these peaks corresponding to the amplitude and phase encoded information of the delay line label.

The homodyne demodulated received signal is sampled at baseband by an analogue-to-digital converter. This sampled signal is then analysed by a discrete Fourier transform which separates the returned frequencies into discrete frequency bins or channels. The phase differences or amplitude ratios between these bins then becomes the tag code. If the comb line spectrum derived from the tag return does not align with the DFT analysis channels then energy from one comb line will incorrectly be assigned to an adjacent channel. This misalignment will cause inter-symbol interference between analysis channels and will degrade the readability of the tag. Misalignment can be caused by a tag being at an unexpected range, or by a Doppler shift due to a tag's velocity relative to the interrogator.

It is well known that complex frequency shifts can be used to align comb line spectra with DFT channels. It is difficult, however, to determine the shift required to correct for the misalignment. With good signal to noise ratios it is possible to examine the ripple and edge steepness of the DFT result and use this as a guide to alignment, but in a noisy signal this technique is prone to error.

In one form of the present invention, accurate alignment is facilitated by the addition to the tag of a separate "marker" tap transducer 15. This transducer is located as close as possible to the encoding transducers 14 but far enough away to allow discrimination of the alignment and encoding responses under conditions of severe inter-symbol interference. In the preferred embodiment this marker transducer is located three channel spacings before the encoding transducers. The launch transducer is not used for this purpose because its response is swamped by low frequency environmental clutter, and it is too far from the encoding transducers to allow accurate alignment.

As mentioned above, it is desirable to minimise reflection of the propagating SAW wave by the tap transducers. In accordance with a preferred form of the present invention, physical reflections from the fingers are eliminated by cancellation. In the embodiment of the invention illustrated in Fig. 2, the fingers are located along the acoustic wave path at such intervals that successive leading and trailing edges of the interdigitated fingers are respectively separated by a distance which is equal to one third of the wave length of the SAW. With equal mark space ratio, the finger width will thus be $\lambda/6$.

To examine the effect of this spacing, consider firstly the leading edge discontinuities. Assuming that each leading edge discontinuity has an identical effect, then each set of three successive fingers reflects a proportion of the energy summing to zero, viz.,

$$E + E\angle 2\times120^\circ + E\angle 2\times240^\circ = 0$$

The effect of the leading edge discontinuities has thus been nulled.

Consider secondly the trailing edge discontinuities. Again assuming only that each trailing edge discontinuity has an identical effect, then each set of three successive fingers reflects a proportion of energy summing to zero, viz.,

$$E\angle 2\theta + E\angle 2\theta + 2\times120^\circ + E\angle 2\theta + 2\times240^\circ = 0$$

where θ is a phase angle dependent on the finger width and being nominally equal to 60° for $\lambda/6$ wide fingers having a nominally equal mark-space ratio.

As a consequence of the independent summing to zero of the leading and trailing edge discontinuities, the finger mark-space ratio and therefore manufacturing etch control is not critical.

The example given here of "self cancellation" of three successive $\lambda/6$ fingers at a spacing periodicity of $\lambda/3$ is not exhaustive. A spacing of $\lambda/3$ gives the widest possible fingers for a given fundamental frequency. At 915 mHz this spacing gives dimensions which can be achieved in production with current photolithographic technology. With a system employing a lower centre frequency, or with higher resolution photolithography, cancellation from four successive $\lambda/8$ fingers of spacing periodicity $\lambda/4$ is workable, viz.,

$$E + E\angle 2 \times 90^\circ + E\angle 2 \times 180^\circ + E\angle 2 \times 270^\circ = 0,$$

and likewise for even smaller periodicities, e.g.

$\lambda/5$, $\lambda/6$, etc., provided the spacing also allows satisfactory coupling between the transducers and the SAW at the fundamental frequency of the signal.

Given a selected a finger spacing, the pattern of polarity of successive transducer fingers must also be chosen. Thus, in the case of $\lambda/3$ spacing described here, the fingers should be connected to the busbars 11 and 12 in the pattern illustrated in Figs. 2 to 4, if the most efficient coupling is to be achieved.

In general the polarity pattern of the fingers can be examined by plotting the stepwise approximation of the electric potential due to the fingers, and, with a knowledge of the relationship between piezoelectric displacement and electric field for the substrate material, using a Fourier transform to derive the fundamental sine wave. The most efficient pattern is that which maximizes the amplitude of this fundamental sine wave.

As will be observed in the drawings, the polarity pattern of the fingers for $\lambda/3$ spacing (++-+--) repeats in sections 2 in length, and consists of phase-reversed left and right half-sections each one wavelength long. This structure maximizes the amplitude of the fundamental frequency sine wave. Other patterns, such as repeating left half-sections, will produce a fundamental frequency sine wave of less amplitude.

It will be appreciated that the number of fingers used in the transducer will preferably be chosen to be an integral multiple of the number of fingers in a section. In the case of $\lambda/3$ spacing, the preferred number of fingers will therefore be an integral multiple of 6.

While in this way SAW reflections generated at transducer discontinuities can be reduced or cancelled, it will be realised that surface acoustic waves arising from electrical regeneration at the transducers must also be controlled in a practical label by, for example and depending on the strength of the piezoelectric coefficient of the substrate, the number of fingers used for transducers and/or by the electrical impedance loading shunted across the busbars 11 and 12 of the delay line. Electrical regeneration can never be entirely eliminated but since it depends on a voltage being induced across one or more tap transducers and this voltage then causing the generation and propagation of a "secondary" SAW, this effect can usually be reduced to negligible proportions by arranging for a sufficient loss in this 2-step generation and regeneration process.

In the practice of the present invention as illustrated in Fig. 2, the interdigitated fingers of the coding transducers 14 are provided with individual busbars 16 and 17, separated from the adjacent busbar 11 or 12 but connected thereto by respective metallisation bridges 18 and 19. Furthermore, each "coding bus" 16 and 17 is connected to the opposite main busbar 11 or 12 by tracks 20 and respective bridges 21 and 22. In this way a structure is created whereby each coding bus can be connected to either busbar 11 or busbar 12 by cutting the appropriate cutting bridges. By appropriate choice of cutting it is thus possible to produce an IDT whose phase is "flipped" by 180 degrees. Cutting the bridges 21 and 22 produces an IDT at relative 0 degrees, while cutting the bridges 18 and 19 produces an IDT at relative 180 degrees.

It can be seen that the flip connecting tracks 20 pass across the active SAW region. It is of course desirable to minimise the disturbing effect of the flip connections crossing the active SAW region. The two major sources of such disturbance are reflections of the acoustic wave at the boundary discontinuities between the metallisation and the piezoelectric material, and the mass loading effect of the metallisation upon the piezoelectric material.

The boundary discontinuities can be minimised by correct choice of the dimension X (Fig. 2), representing the interval by which the elements are spaced along the acoustic path. In accordance with this aspect of the invention, the dimension X is a function of the number of discontinuities across the active region. In Fig. 3 there are 3 leading edge discontinuities and 3 trailing edge discontinuities due to the three elements which cross the SAW active region.

By choosing the spacing of the leading edge discontinuities correctly it is possible to vector sum the contributions from the leading edges so that their effect is nulled. The approach here is similar to that discussed above in relation to the spacing of the fingers of the transducer, but without limitations brought about by the need for signal coupling with the substrate. In this example, if we assign a distance of $(3n+1)\lambda/3$ (equal to 120 degrees phase shift) for X we find that, assuming each discontinuity has similar effect and re-radiates a proportion of the energy E, that

$$E + E \underline{/2x120^\circ} + E \underline{/2x240^\circ} = 0$$

The effect of the leading edge discontinuity has been nulled. Similarly, by spacing the trailing edges at multiples of $(3n+1)\lambda/3$ we can null the trailing edge discontinuities. The leading and trailing edges have again been treated separately as this removes the need to consider whether a trailing edge discontinuity has the same properties as a leading edge discontinuity or not.

It will be understood that the connecting track may consist of more than or less than three elements, and the above approach can be generalised correspondingly. For a "flip" connection of k elements the leading edges (and independently the trailing edges) should be spaced at multiples of $(kn + 1)\lambda/k$ such that the reflections from k successive edges sum identically to zero, viz., for the simplest case of n = 0,

$$E + E\underline{/2(1 \times 360^\circ/k)} + E\underline{/2(2 \times (360^\circ/k))} + \ldots$$

$$\ldots + E\underline{/2((k-1) \times 360^\circ/k))} = 0$$

With the above condition holding for any group of k elements, then it is permissible for a "flip" connection to consist of more than one k element group if this is desirable, for example to reduce the resistance of such "flip" connections. The approach can thus be generalised to the statement that for k elements in a flip connection, and treating them as groups of j leading and trailing edges where k/j is an integer, then the leading edges and trailing edges must be separated by $(jn+1)\lambda/j$. That is to say, the elements are located along the path of the surface acoustic wave at intervals of $(jn + 1)\lambda/j$.

Where the reflecting properties of the leading and trailing edge are similar, a single connecting track will be a special case of the above approach. Where these properties differ, however, the track width will be chosen to achieve cancellation in accordance with those properties.

It will have been observed that in the illustrated embodiment, the connecting tracks 20 consist of three elements of equal mark-space ratio. In order to reduce resistance it may be desirable to provide elements which are of substantially greater width than the space between them. For example, three elements may be provided, each of λ width, spaced apart by $\lambda/3$, so that successive elements are located at $4\lambda/3$ intervals.

As will be appreciated by those familiar with printed circuit and integrated circuit technology, the techniques which can be used selectively to remove the cuttable bridges include chemical etching or the use of a photoplotter to define the bridges to be etched. Alternative approaches include laser scribing or electrical fusion, whereby contacts are provided on both the coding buses and the chip busbars to allow sufficient current to pass through the coding bridges to cause them to become open circuit.

It should be noted that the representation of the IDT's in Figs. 2, 3 and 4 has been simplified, and that the number of elements in a practical IDT will depend on the piezoelectric material chosen for the substrate.

To enable quad phase coding to be achieved two types of flip coded IDT's are employed. The transducer shown in Fig. 2, Type A (0/180), is placed at a nominal reference position, while the Type B (90/270) transducer shown in Fig. 3 is displaced a quarter of a wavelength either towards or away from the launch transducer. Further extensions can be made to this principle to provide other types of transducers, at more phase angles and/or with different amplitude responses, to allow extension from quad phase coding to some higher level of coding.

The launch transducer 13 is of well known IDT design for generating a surface acoustic wave. The placement of subsequent transducers is in units of a given separation. In the preferred embodiment this separation is in units of delay as realised as distance on the SAW chip. Depending on the bandwidth which is allowed for the interrogating and response signals, this may represent the distance a SAW wave travels on the surface in a period of the order of 80 to 160 nsecs. The alignment transducer 15 is placed many units of separation away from the launch transducer 13 (for example approximately 960 nsecs). The alignment transducer 15 is of well known IDT design.

The first tap or encoding transducer is reference transducer 14a, which as described above is preferably placed three separation units past the alignment transducer 15. The reference transducer 14a is of the flip code design described above in relation to Fig. 2 and is preferably a type A transducer due to the manufacturing errors possible in placement over a 3 unit distance. Following the reference transducer 14a are a flip coding transducers 14 spaced at consecutive one separation unit distances from each other. The coding transducers 14 are a combination of type A and type B transducers, and in the illustrated embodiment fifteen of these transducers are used.

This method of chip manufacture allows a code space in this case of $4^{15} \times 2 = 2,147,483,648$. This is due to the fifteen coding transducers each having 4 available positions (choice of A or B type flip transducer set to either 0 or 180 degrees and 90 or 270 degrees respectively). The factor of 2 is the extra code due to the phasing of the reference transducer 14a with respect to the alignment transducer 15.

The fifteen flip transducers, chosen to be either A or B type transducers, are available for programming into one of 2 states by severing the cuttable bridges, and there is also the type A reference transducer which can be in 1 of 2 states. This allows $2^{16} = 65,536$ chips to be made from the one reticle before a new reticle must be made.

There has thus been a reduction in the reticles needed by a factor of 65,536, a significant saving in reticles.

There are also savings in the number of master masks needed, since the number of master masks required is reduced by a factor equal to the number of chips on each wafer, which may for example be 1024.

The number of flip coding transducers 14 is chosen to suit the particular application, within several restraints. The length and therefore the cost of the SAW chips will increase with the number of tap transducers and will be inversely dependent upon the bandwidth of interrogating signal allowed by the regulatory authorities in the country concerned. The code capacity will depend upon the number of bits encoded per transducer (for example, 2 bits per transducer for simple quad phase encoding). Some applications may place limits on the length of the tag, for example in the case of implantable tags for the livestock industry. While some applications may require only a small code capacity, for example twelve bits or less, others may require as many as 64 bits including error correction bits.

During the exposure of the resist on the wafer the following steps are performed:

1. An accurate mask common to all chips with a given combination of A & B type transducers is used to create a pattern on the wafer resist. This mask creates many chips but all of the cuttable bridges are still intact.

2. Each chip is then individually coded by appropriately selecting which cuttable bridges to cut. This is preferably done by using a pattern generator (similar to and possibly even the same pattern generator as used for the 10X reticle manufacture) directly to expose the resist over the bridges to be cut. The bridges produced by the masking process are made large enough so that the photographic resolution is sufficient to cut them without needing the intermediate step of a reticle and 10X reduction.

3. The wafer is then processed to produce individually coded chips.

As mentioned above, in the preferred forms of the present invention, amplitude coding is added to the quad phase encoding described above. While such coding may be achieved by a simple measure such as the removal of a proportion of the fingers of a tap transducer to reduce its coupling with the substrate, this has the disadvantage of altering the capacitance of the transponder, and would therefore require individual tuning of transponders to achieve impedance matching with the antenna, depending on the amplitude coding.

This problem is avoided in preferred forms of the invention, according to which amplitude encoding is achieved by the longitudinal displacement of a group of the fingers of a given transducer, relative to the remaining fingers or to another group of the fingers of that transducer.

Fig. 4 shows a transducer layout in which the transducer fingers comprise 4 groups of fingers each group having an equal number of fingers (in this example, 6). The fingers of one group, the left hand group as seen in Fig. 4, are displaced from the remaining groups by one half a wave length. Consideration of this layout will reveal that the first three groups will contribute a tapped signal with the same phase and a nominal amplitude of three units, while the fourth group will contribute an antiphase signal with an amplitude of one unit. The net effect will be to supply to the busbars a tapped signal of 2 units, or one half the amplitude of a transducer in which none of the groups is displaced. Amplitude modulation is thus achieved which may be superimposed upon the quad phase modulation described above.

It will be appreciated that finger groups may be displaced in other ways to achieve similar results. For example, groups each comprising one eighth of the fingers of a transducer may be displaced by $\lambda/4$ in opposite directions, also providing a 50% amplitude modulation. Again, changes of amplitude of more or less than 50% can be achieved by appropriate choice of the proportion of interfering fingers.

In addition to the economies achieved by the new approaches to transponder design described so far, the present invention enables the use of inexpensive materials, rather than quartz or lithium niobate as in the prior art. In its preferred forms, the present invention employs cheap borosilicate glass as the substrate material, coated with a thin film of zinc oxide. The ZnO film is formed by planar RF magnetron sputtering, which allows optimal control of substrate temperature.

Zinc oxide is a well known piezoelectric material with a hexagonal crystalline structure, and polycrystalline ZnO films of suitable orientation, i.e. with the C axis normal to film surface, can be deposited on glass by the sputter technique.

It is the orientated crystal structure that yields a strong piezoelectric effect in the film. The thickness of the film is chosen to be less than one acoustic SAW wavelength, and to optimise the piezoelectric coupling coefficient. For transponder operation at 915MHz, this thickness would be of the order of 1.5 microns. Thus as shown schematically in Figs. 5 and 6 the thin film substrate is a layered structure in which a piezoelectric film 10 is suitably deposited on a non piezoelectric base 23 suitably of borosilicate glass. The aluminium metal for the IDT's 14 is then deposited on this film by vacuum evaporation or sputtering. The normal photolithographic processes are used to produce the chips.

An alternative to this method is to deposit the SAW transducers directly on the surface of the non-piezoelectric glass 23 rather than on the surface of the piezoelectric film 10. As shown in Fig. 7, the ZnO film is then formed over the top of the glass and the metal transducer fingers, the thin film serving to convert the electrical signals of the IDT into SAW waves and back again. The glass base material provides the mechanical strength and serves as the SAW transmission material. An important secondary function of this technique is that the ZnO film layer forms a protective barrier for the aluminium IDT's and thus increases the delay line reliability.

By these methods, the glass base material can be chosen to have large physical dimensions limited only by the X-Y travel of the step-and-repeat camera used for the photolithographic process. Typically, a large glass plate 8 inches square or more may be used as a processed wafer, capable of yielding a very large number of individual chips. Selective etches are available which allow etching of either the aluminium metallisation or the zinc oxide alone. The use of a larger wafer allows proportionately less wastage required for handling.

Figs. 8 and 9 illustrate the method of fabrication according to an aspect of the invention which enables the encapsulation of the transponders to be completed prior to the slicing of the individual transponders from the wafer or substrate. In this embodiment, rows 30 of transponder metallisation patterns are applied to a wafer, with the connection pads of longitudinally adjoining patterns being applied in a continuous area 31. (No attempt is made to show the transducers in this figure).

A sealant such as an epoxy resin of low gas permeability or a glass frit is applied by silk screening to the surface of a cover plate 35 (Fig.9) of the same dimensions as the wafer. The sealant is applied in the form of "moats" 36 located to surround each transponder, leaving the pads 26 outside, when the cover plate is located over the wafer. The cover plate is placed over the wafer and the sealant cured or allowed to set, preferably under pneumatic pressure.

The moats 36 are of a height which provides a small gap between the cover plate and the wafer.

The cover plate is then sliced along the lines 32 in Fig. 8, to a depth which is just above the contact pads 31, and the strips of cover plate material between these pairs of cuts are removed (for example by air suction) to expose the pads 31. Individual transponders are then created by slicing right through the assembly on the lines 33 and 34. An antenna (not shown) is then attached to each transponder in any suitable manner.

Alternatively, a spacing sealant can be applied in the manner described to the surface of the wafer and the individual cover plates positioned over each transponder by a pick-and-place machine. After curing, the wafer is sliced in the normal way.

In the practice of the present invention therefore, handling cost is reduced by performing the sealing process while the chips are still in wafer form. While in this technique as described above the sealant is described as being applied to the cover plate, it may alternatively be applied to the wafer or substrate.

It should also be observed that this method is equally applicable to devices comprising zinc oxide on glass, as well as to wafers of lithium niobate or quartz.

Traditionally SAW devices have been constructed with the wire bonding pads fabricated along with the SAW metallisation on the surface of the active piezoelectric material. The bonding pads consume valuable active material (such as lithium niobate) but do not rely upon any of the active characteristics of that material to function. In another aspect of the present invention the cover plate provides mechanical support for the bonding pads and thus allows the area of active piezoelectric material to be reduced.

To minimise the area of active SAW material, the SAW chip may be redesigned with much reduced metal contact pads. The size of these pads now only need be sufficient to support the epoxy which provides the hermetic sealing for the chip. Fig. 10 illustrates a SAW chip with bonding pads reduced to the minimum size necessary for hermetic sealing. The glass cover plate 24 is extended in size to allow room for the metal bonding pads 25 produced by a simple process onto the cheap glass cover plate material.

Connection of the large bonding pads 25 on the cover plate 24 with the small bonding pads 26 on the SAW chip may be achieved by using conductive epoxy 27 only in the vicinity of the pads 26. The hermetic seal is then completed by placing normal epoxy 28 around the perimeter of the SAW chip, as shown in the cross-sectional view of Fig. 10(d).

It will be appreciated that each transponder must be equipped with an appropriately tuned antenna. Such antennae may be mounted on the cover plate and connected by means of the bonding pads 25, but since the dimensions of these pads are not constrained by considerations of substrate material cost, the pads 25 themselves may in suitable cases be dimensioned to act as antennae, providing an elegant solution to the problem of antenna attachment.

CLAIMS

1. A surface acoustic wave transponder comprising a plurality of tap transducers in contact with a piezoelectric material, means for the reception of an interrogating signal, means transmitting said interrogating signal as a surface acoustic wave in said material and means for retransmitting said interrogating signal modified by said tap transducers, said retransmitting means including first and second signal transmission means connected to each tap transducer, each tap transducer comprising a first set of electrically interconnected parallel fingers and a second set of electrically interconnected parallel fingers interdigitated with the fingers of the first set, characterised in that the fingers of each transducer are located at such intervals along the path of the surface acoustic wave such that surface acoustic wave reflections from their edges cancel, and further characterised in that each said set of fingers is selectively connectable to one or the other of said first and second transmission means.

2. A transponder as claimed in claim 1, wherein each tap transducer includes first and second conductive path means, the fingers of the first and second set being connected respectively to said first and second path means.

3. A transponder as claimed in claim 2, wherein said conductive path means are each connected by interruptible connection means to said first and second transmission means.

A

4. A transponder as claimed in claim 3, wherein each interruptible connection means which crosses the path of said acoustic wave include a plurality of parallel conductive tracks, said conductive tracks being located along the path of said wave at such intervals that reflections of the surface acoustic wave from their edges cancel.

5. A transponder as claimed in claim 4, wherein each said connection means include j conductive tracks located along the path of said wave at intervals of

$$(jn + 1) \lambda /j$$

where λ is the wavelength of the surface acoustic wave and n is 0 or an integer.

6. A transponder as claimed in claim 5, further characterised in that each interruptible connection means which crosses the path of the surface acoustic wave includes a plurality of groups of j parallel conductive tracks.

7. A transponder as claimed in claim 5, in which j = 3 and n = 0.

8. A transponder as claimed in claim 5, in which j + 3 and n = 1.

9. A transponder as claimed in claim 3, further characterised in that said signal transmission means include a pair of parallel conductive tracks, said conductive path means of each tap transducer comprise parallel conductive tracks, and said interruptible

connection means comprise conductive tracks extending between a given conductive path means and each of the signal transmission means.

10. A method of encoding a transponder of the kind defined in claim 3, comprising the steps of selectively interrupting said connection means such that the first set of fingers of a given tap transducer is connected to a selected one of the first and second signal transmission means and the second set of fingers is connected to the other of said signal transmission means, thereby determining a phase of the connection of that tap transducer with said transmission means.

11. A transponder as claimed in claim 1, wherein the tap transducers are placed at nominal positions regularly spaced along the path of the surface acoustic wave.

12. A transponder as claimed in claim 11, wherein at least one of the tap transducers is displaced along the path of the surface acoustic wave, relative to its nominal position.

13. A transponder as claimed in claim 11, in which at least one of the tap transducers is displaced along the path of the surface acoustic wave by one quarter of the wavelength of the surface acoustic wave, relative to its nominal position.

14. A method of manufacturing transponders of the kind claimed in claim 12 or 13, including the steps of preparing on a substrate a pattern of transponders in each of which

A

the same first selected tap transducer, or the same first selection of tap transducers, is so displaced, providing each transponder with a unique phase encoding by the method claimed in claim 10, preparing on a substrate a second pattern of transponders in each of which the same selected tap transducer, or the same second selection of tap transducers, is so displaced, and providing each transponder of the second pattern with a unique phase encoding by the method claimed in claim 10.

15. A surface acoustic wave transponder as claimed in claim 1, wherein the fingers of each transducer are located at intervals of one third of the wavelength of said acoustic wave.

16. A transponder as claimed in claim 15, wherein said first set of fingers is connected with said first signal transmission means and said second set of fingers is connected with said second signal transmission means, further characterised in that the fingers are arranged in successive groups along the path of the acoustic wave, the fingers in each group being in the following order, namely, two fingers of the first set, one finger of the second set , one finger of the first set, two fingers of the second set.

17. A surface acoustic wave transponder as claimed in claim 16, characterised in that a group of fingers of at least one of said tap transducers is displaced in the path of the surface acoustic wave so as to be in phase opposition to another group of fingers of the same transducer.

A

18. A transponder as claimed in claim 17, in which the first group of fingers is displaced in the path of the surface acoustic wave by (2n + 1) λ /2 relatively to the remaining fingers of said transducer, where λ is the wavelength of the surface acoustic wave and n is 0 or an integer.

19. A surface acoustic wave transponder as claimed in claim 18, further characterised in that said group of fingers contains one quarter of the total number of fingers in the transducer.

20. A surface acoustic wave transponder as claimed in claim 19, wherein said displacement is λ /2.

21. A method of manufacturing surface acoustic wave transponders of the kind defined in any one of claims 17 to 20, including the steps of preparing on a substrate a first pattern of transponders in each of which a said group of fingers of the same first selected tap transducer, or of the same first selection of tap transducers, is so displaced, and preparing on a substrate a second pattern of transponders in each of which a said group of fingers of a second selected tap transducer, or of the same second selection of tap transducers, is so displaced.

22. A method of manufacturing a transponder of the kind defined in any one of claims 17 to 20, including the steps of preparing on an substrate a pattern of transponders in each of which the same first selected transducer, or the same first selection of a plurality of transducers, is so displaced, providing each transducer with a unique phase

A

encoding by the method defined in claim 10, preparing on a substrate a second pattern of transponders in each of which the same second selected transducer, or the same second selection of a plurality of transducers, is so displaced, and providing each transponder of the second pattern with a unique phase encoding by the method defined in claim 10.

23. A surface acoustic wave transponder as claimed in claim 1, wherein a further transducer is provided, spaced by a known surface acoustic wave path length from said tap transducers.

24. A surface acoustic wave transponder as claimed in claim 23, wherein the spacing of said further transducer is a multiple of the nominal spacing between the tap transducers.

25. A surface acoustic wave transponder as claimed in claim 24, wherein said multiple is 3.

26. A method of manufacturing a plurality of surface acoustic wave transponders, each of the kind defined in any one of claims 1 to 9, 11 to 13, 15 to 20 or 23 to 25, each consisting of a layer of metallisation in contact with a piezoelectric substrate, the method comprising the steps of producing said metalisation over an area as a repetitive pattern of individual transponder patterns, attaching a cover plate over said area, and subsequently cutting through said cover plate and said substrate in orthogonal directions to separate individual transponders.

A

27. A method of manufacturing a plurality of surface

acoustic wave transponders, each of the kind defined in any one of claims 1 to 9, 11 to 13, 15 to 20 or 23 to 25, each consisting of a layer of metallisation in contact with a piezoelectric substrate, the method comprising the steps of producing said metallisation over an area as a repetitive pattern of individual transponder patterns, attaching a cover plate over each transponder pattern, and subsequently cutting through said substrate in orthogonal directions to separate individual transponders.

28. A method of manufacturing a plurality of surface acoustic wave transponders, each of the kind defined in claim 1, each consisting of a layer of metallisation in contact with a piezoelectric substrate, the method comprising the steps of producing said metalisation over an area as a repetitive pattern of individual transponder patterns, applying spacing means to the metalised substrate, attaching a cover plate over said spacing means, and subsequently cutting through said cover plate and said substrate in orthogonal directions to separate individual transponders.

29. A method as claimed in claim 28, wherein said spacing means is applied around boundaries of each transponder.

30. A method as claimed in claim 28, wherein said spacing means comprises a sealant.

31. A method as claimed in claim 30, wherein said sealant is an adhesive sealant.

A

32. A method as claimed in claim 31, wherein said sealant is an epoxy resin.

33. A method as claimed in claim 31, wherein said sealant is a glass frit.

34. A method as claimed in claim 28, wherein each individual transponder pattern includes a contact region at at least one end thereof, and, after attachment of the cover plate and prior to said orthogonal cutting, strips of said cover plate are removed to expose said contact regions.

35. A method of manufacturing a plurality of surface acoustic wave transponders, each of the kind defined in claim 1, each consisting of a layer of metallisation in contact with a piezoelectric substrate, the method comprising the steps of producing said metallisation over an area as a repetitive pattern of individual transponder patterns, applying spacing means to the metalised substrate, attaching a cover plate over the spacing means, and subsequently cutting through said substrate in orthogonal directions to separate individual transponders.

36. A method as claimed in claim 35, wherein said spacing means is applied around the boundaries of each transponder.

37. A method as claimed in claim 35, wherein said spacing means comprises a sealant.

38. A method as claimed in claim 37, wherein said sealant is an adhesive sealant.

A

39. A method as claimed in claim 38, wherein said sealant is an epoxy resin.

40. A method as claimed in claim 38, wherein said sealant is a glass frit.

41. A method as claimed in claim 35, wherein each individual transponder pattern includes a contact region at at least one end thereof, and, after attachment of the cover plate and prior to said orthogonal cutting, strips of said cover plate are removed to expose said contact regions.

42. A surface acoustic wave transponder as claimed in claim 1, wherein the transponder consists of a layer of metallisation in contact with a piezoelectric substrate and has a contact region at at least one end with a cover plate being attached over said metallisation, the cover plate being provided with contact regions opposed to the contact regions of the transponder and extending beyond them.

43. A transponder as claimed in claim 42, wherein a conductive sealant is provided between each contact region of the transponder and the opposed contact region of the cover plate.

44. A transponder as claimed in claim 43, wherein the contact regions on said cover plate are dimensioned to act as an antenna for said transponder.

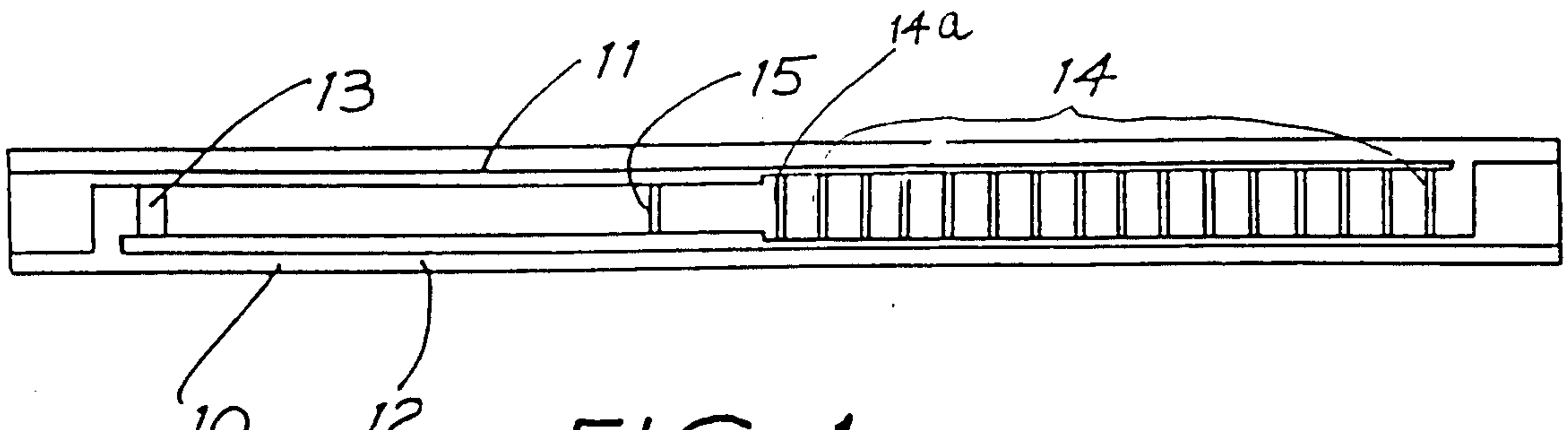


FIG. 1

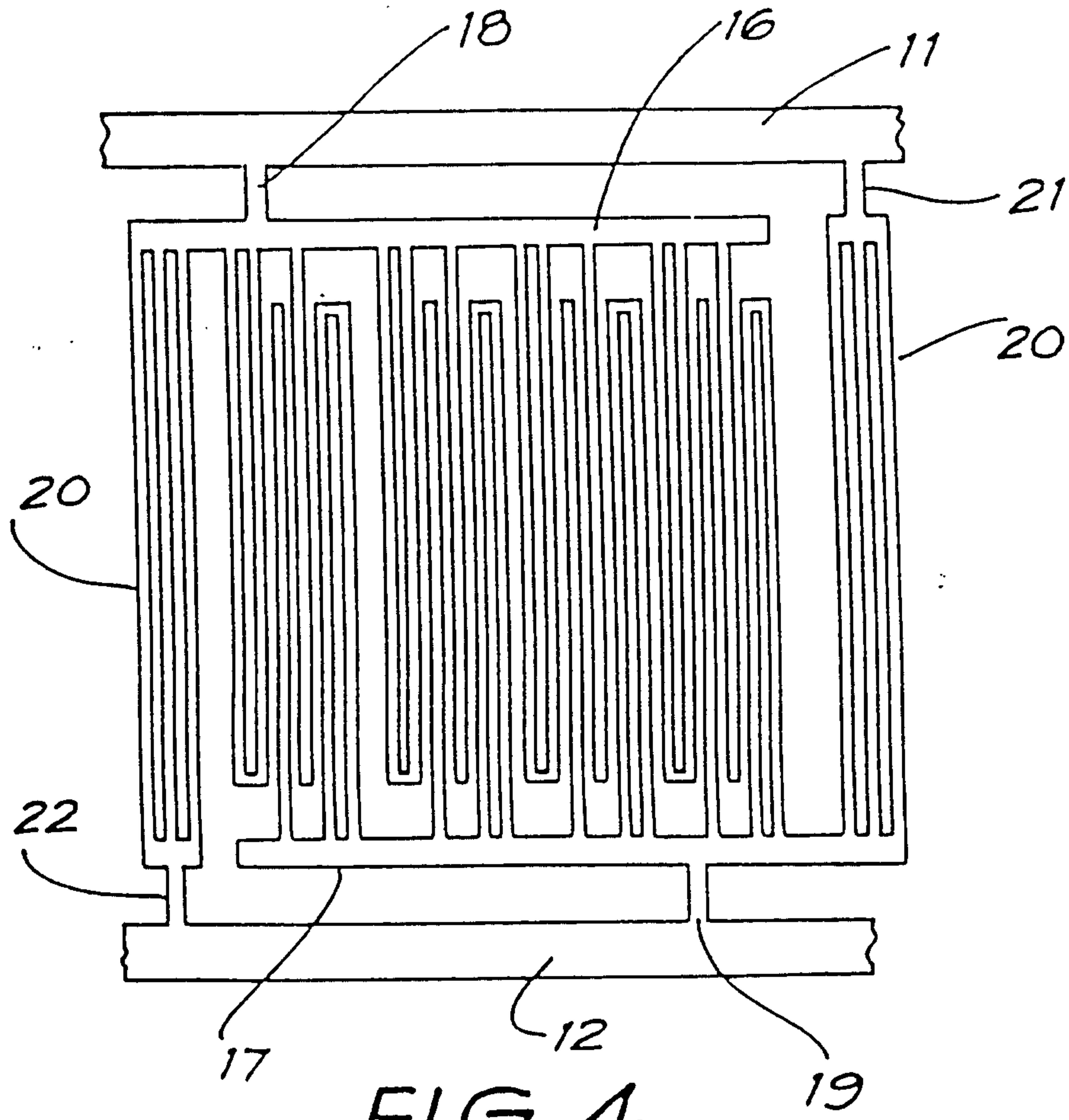


FIG. 4

A

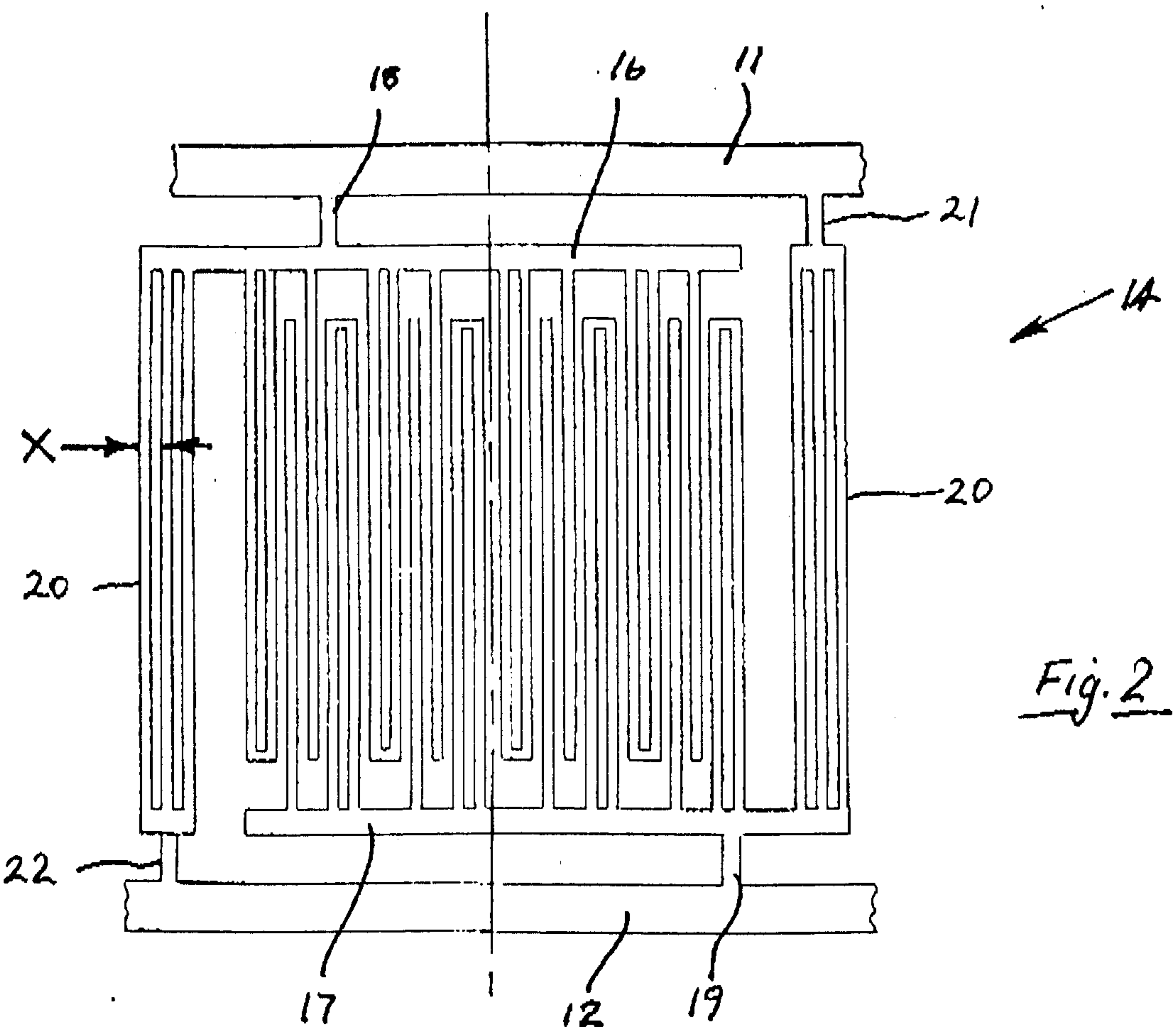


Fig. 2

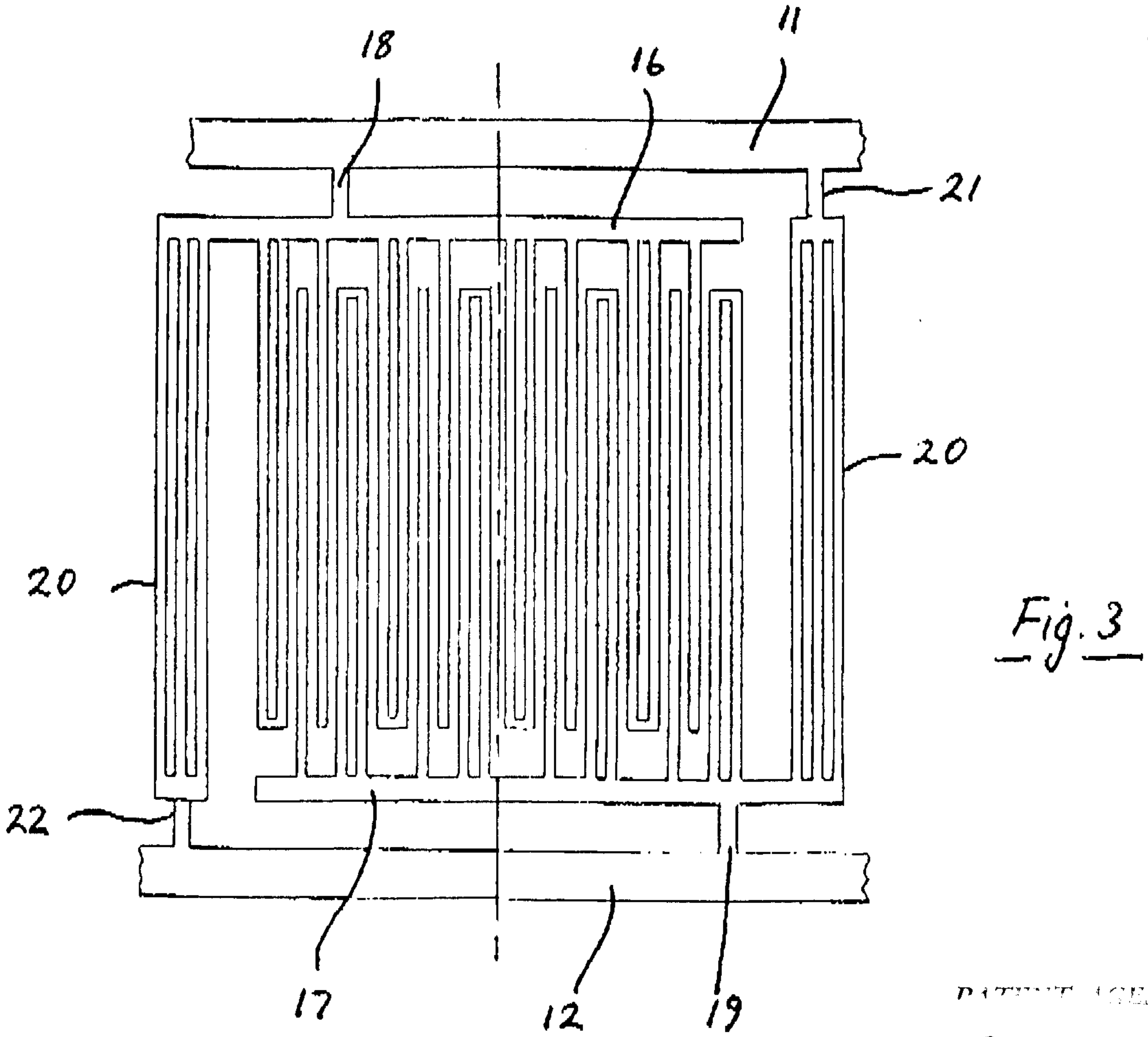


Fig. 3

PATENT AGENTS

Swabey Ogilvy Renault

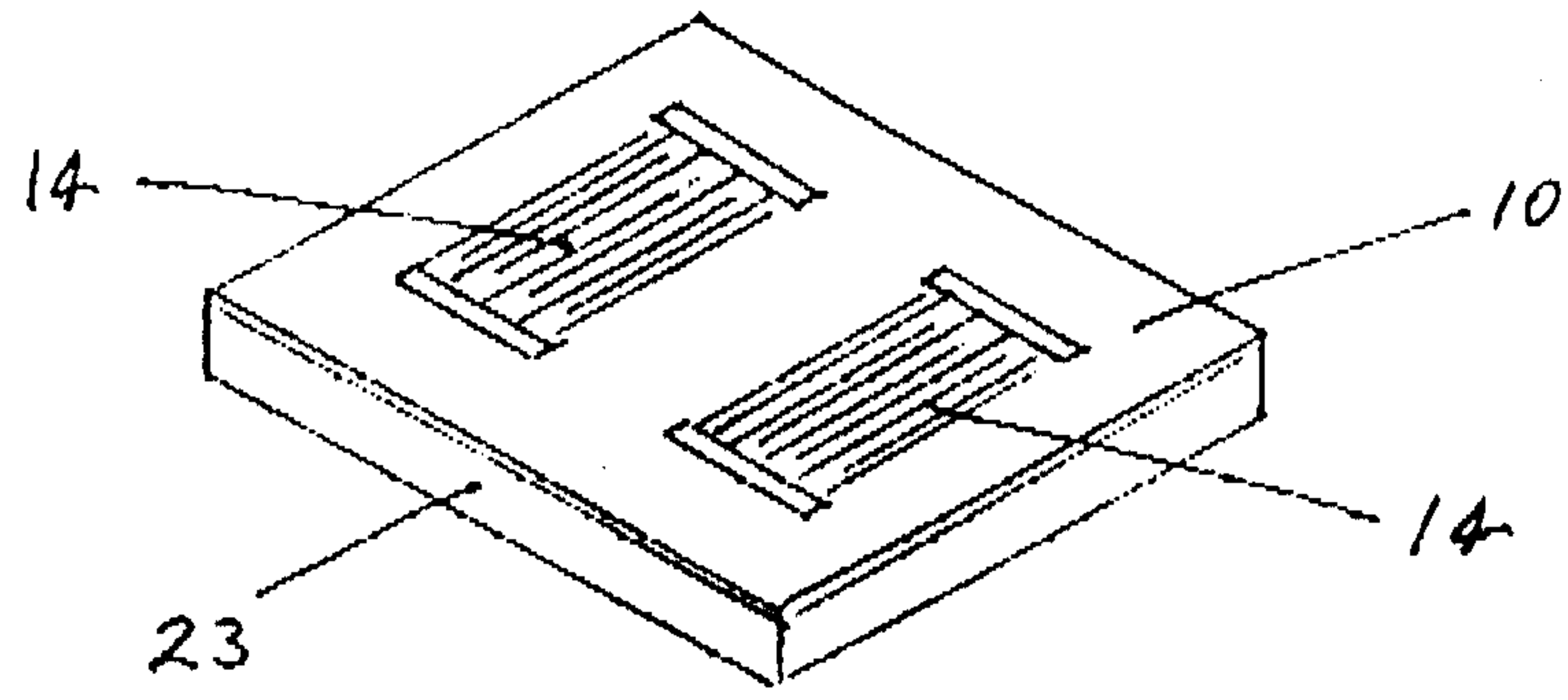


Fig. 5

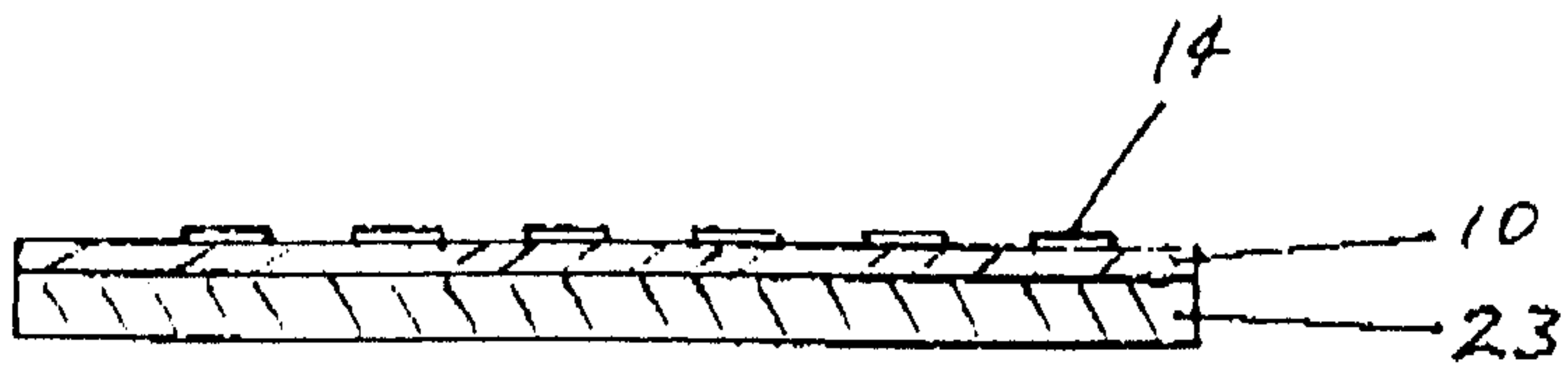


Fig. 6

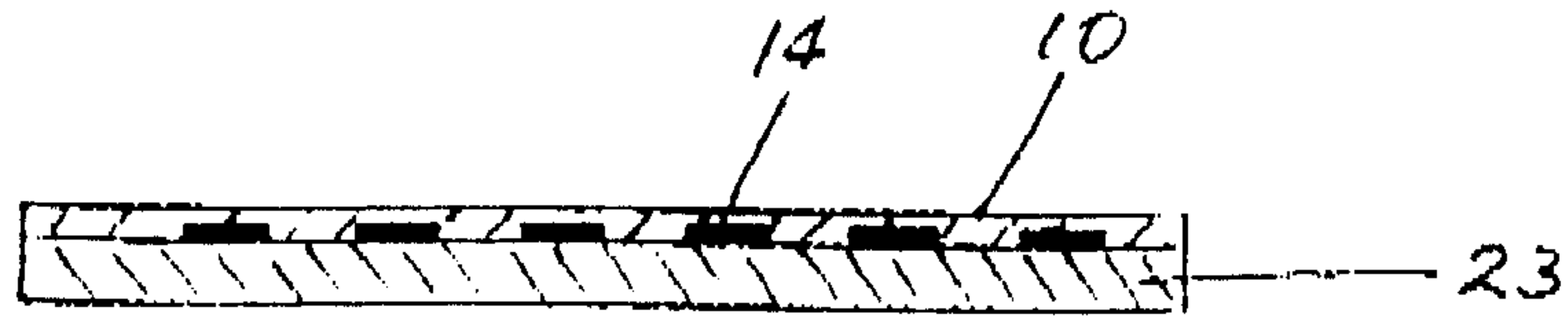


Fig. 7

PATENT AGENTS

Swabey Ogilvy Renault

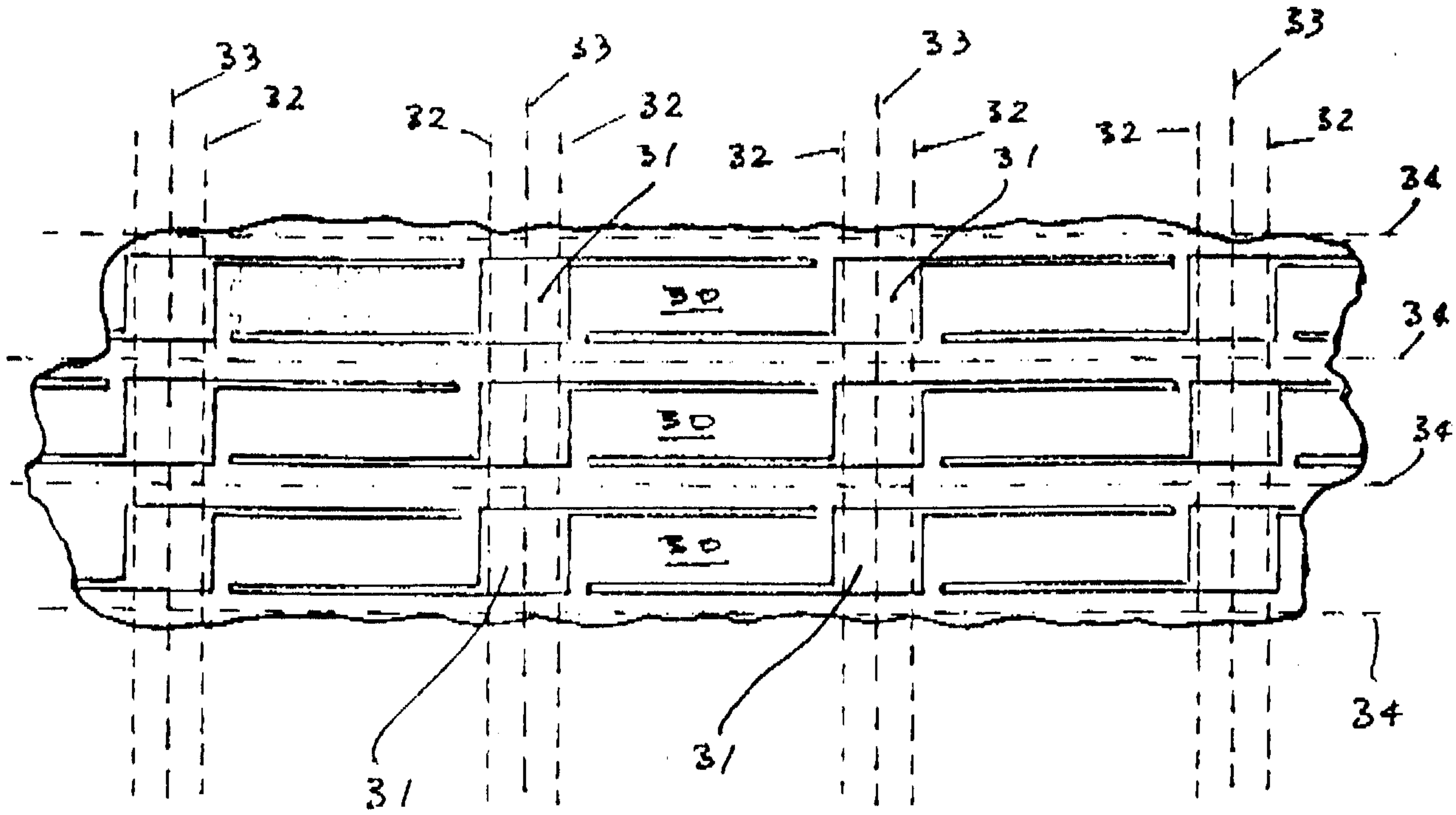


Fig. 8

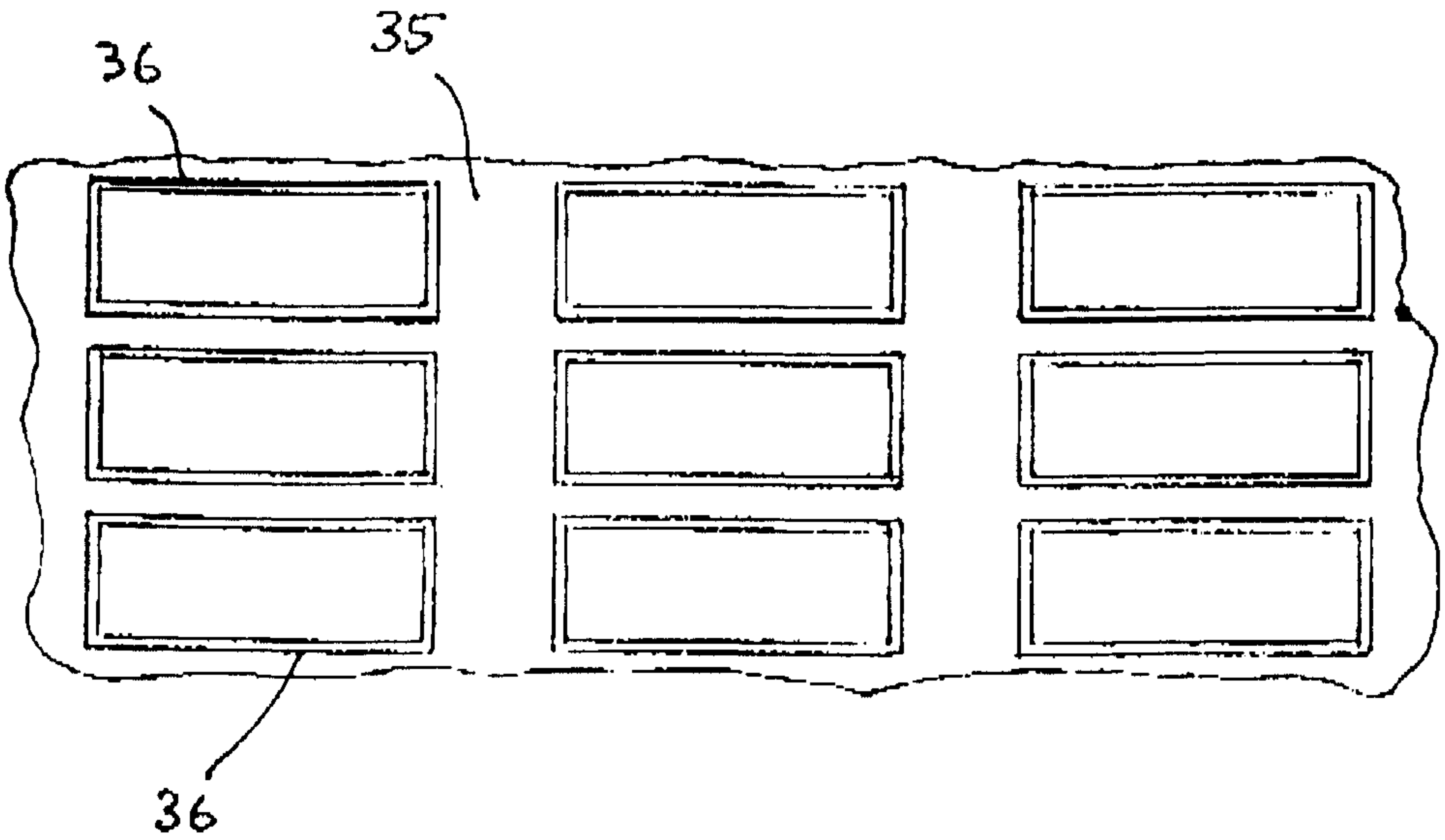


Fig. 9

PATENT AGENTS

Swabey Ogilvy Renault

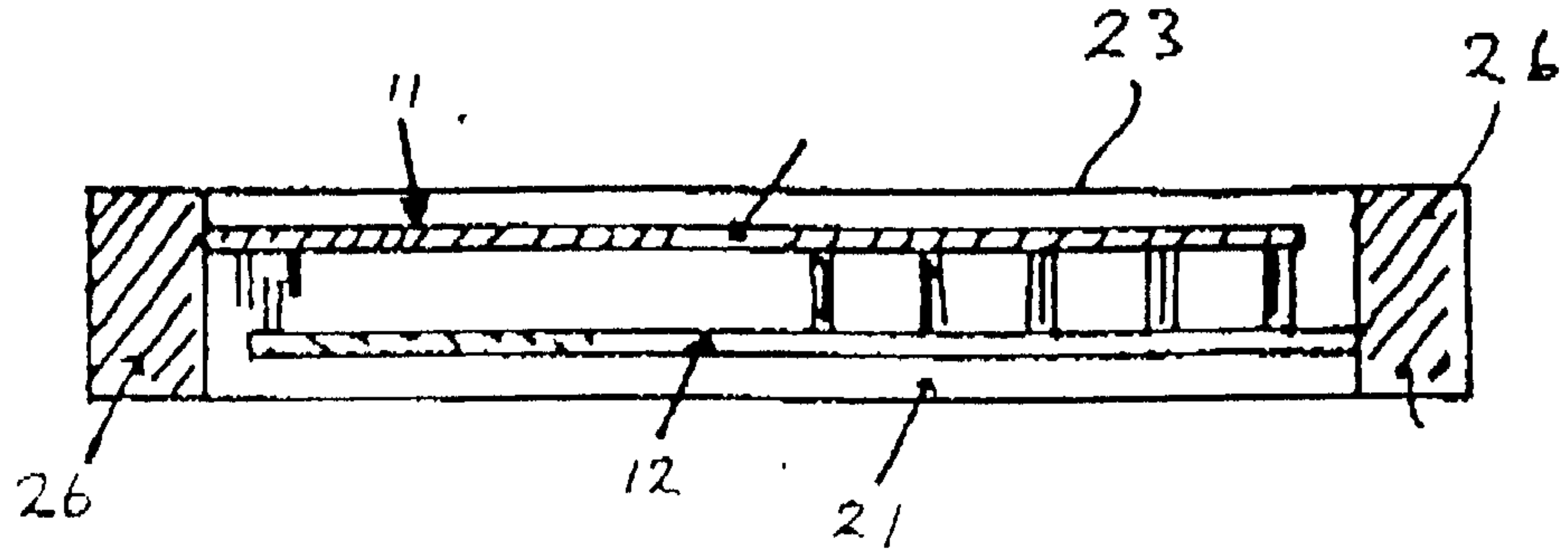
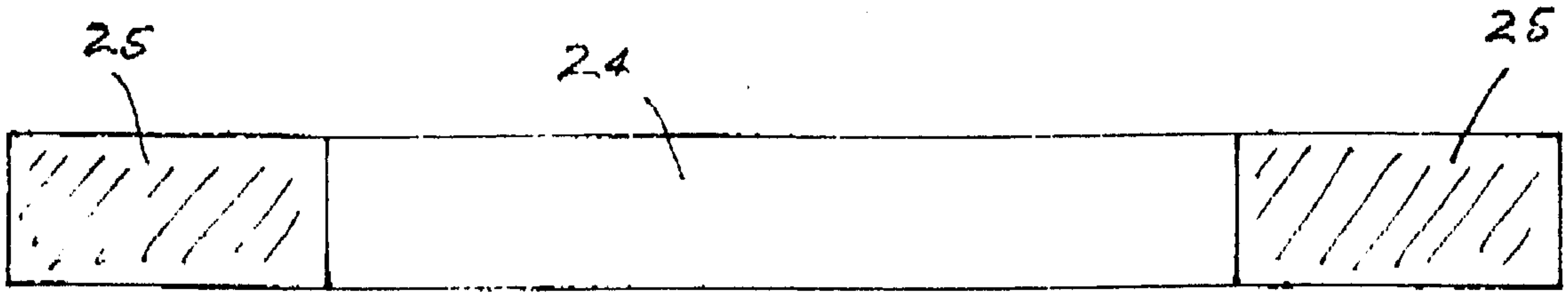
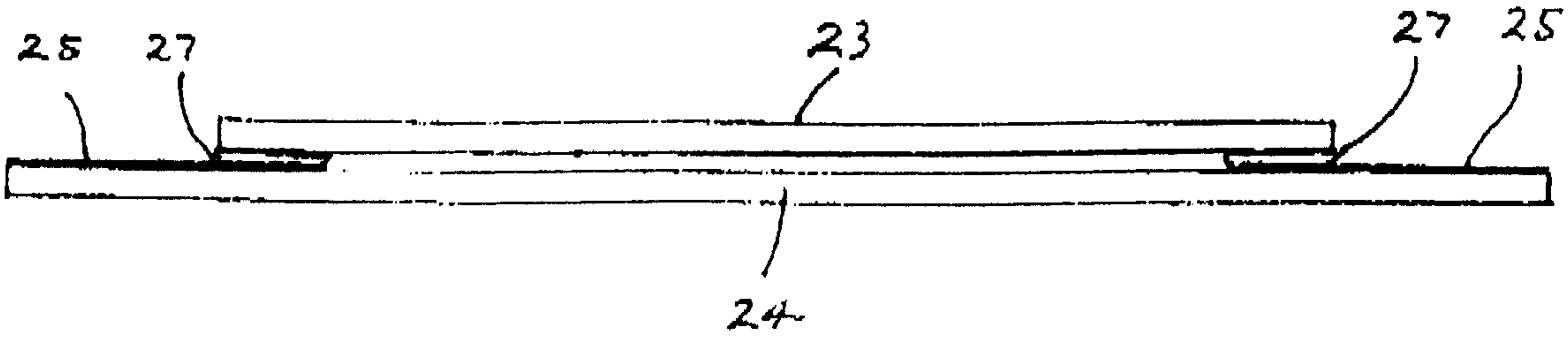


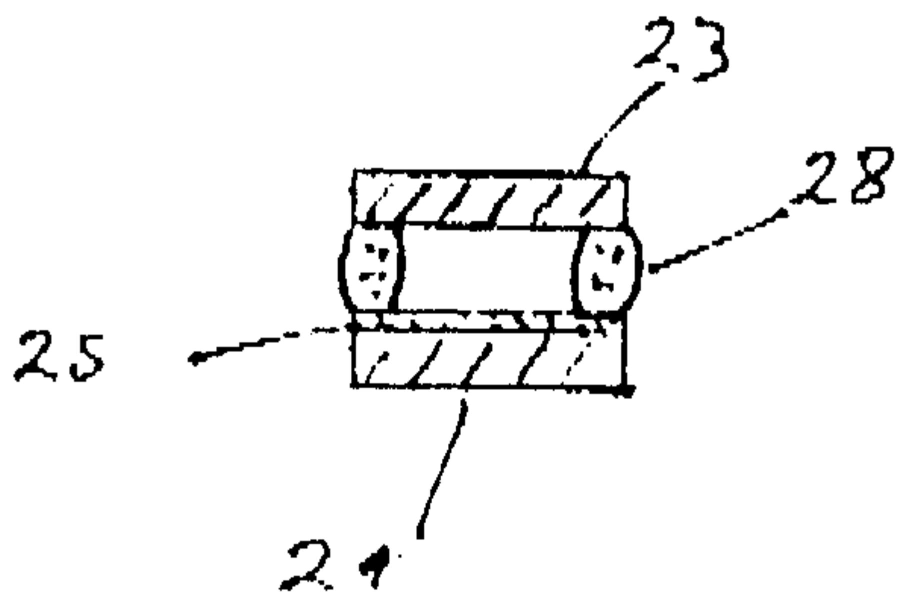
Fig. 10(a)



(b)



(c)



(d)

Swabey Ogilvy Renault